

CHEM103

General Chemistry

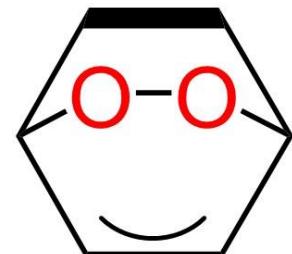
Chapter 13: Properties of Solutions



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Department of Chemistry
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Education



Assignment 11

Homework 11

Due date: 23rd Nov. (Wed)



Review on Chapter 11

van der Waals Interactions, London Dispersion forces,
Dipole-Dipole Interactions, Ion-Dipole Interactions &
Hydrogen Bond

Polarizability, Boiling Point, Melting Point, Vapor Pressure, Viscosity, Surface Tension, Cohesion and Adhesion, Capillary Action

Phase Diagram, Heat of Fusion/Vaporization/Sublimation, Heating Curves, Critical Temperature and Pressure, Supercritical Fluids

Liquid Crystals



Outline of Chapter 13

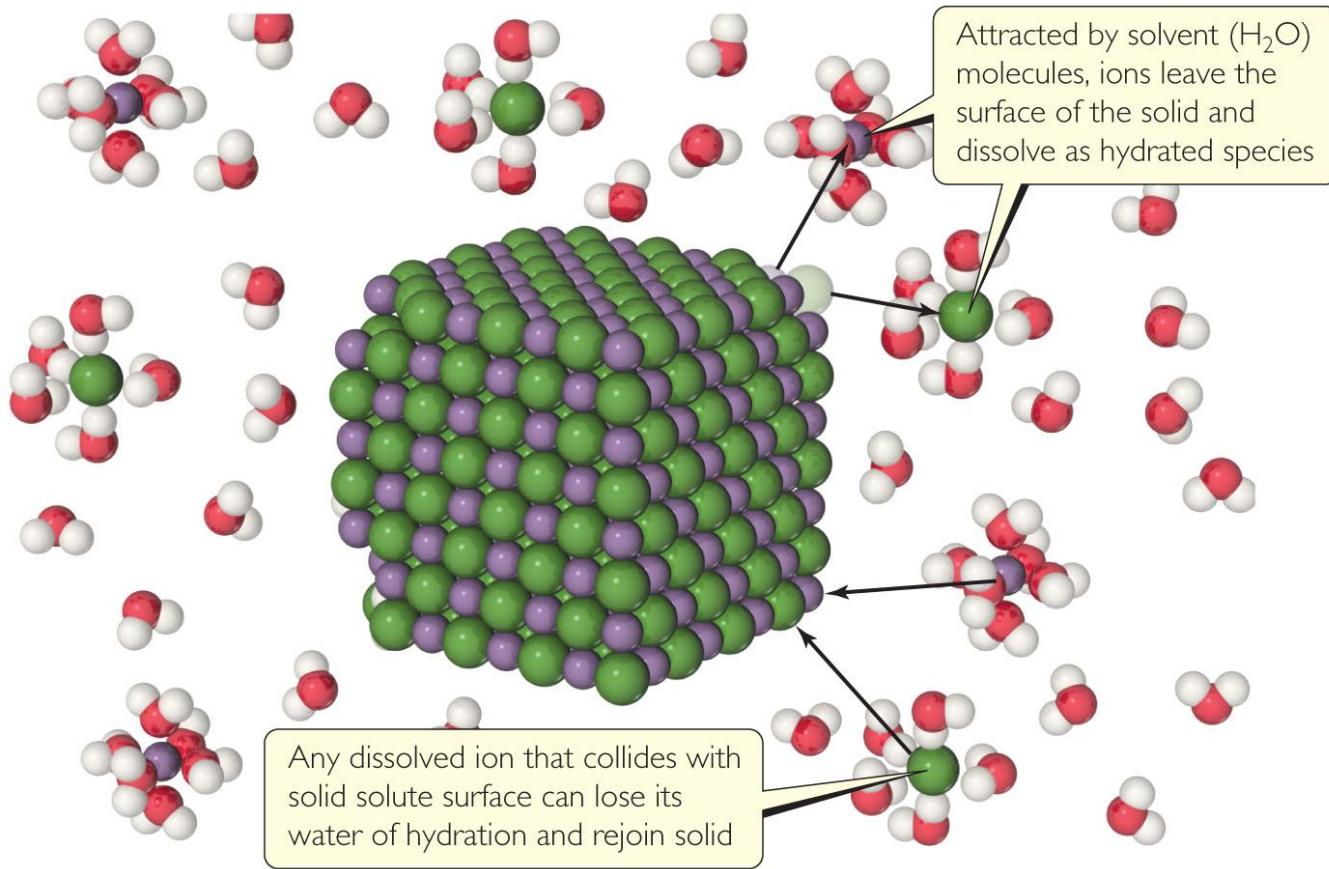
Dissolution: Entropy/Randomness, Intermolecular Interactions

Saturated/Supersaturated/Unsaturated Solution ;
Crystallization, Solubility, Miscible/Immiscible; Henry's Law

Mass Percentage (ppm & ppb), Mole Fraction, Molarity,
Molality

Colligative Properties: Raoult's Law, Van't Hoff Factor,
Osmosis (Osmotic Pressure)

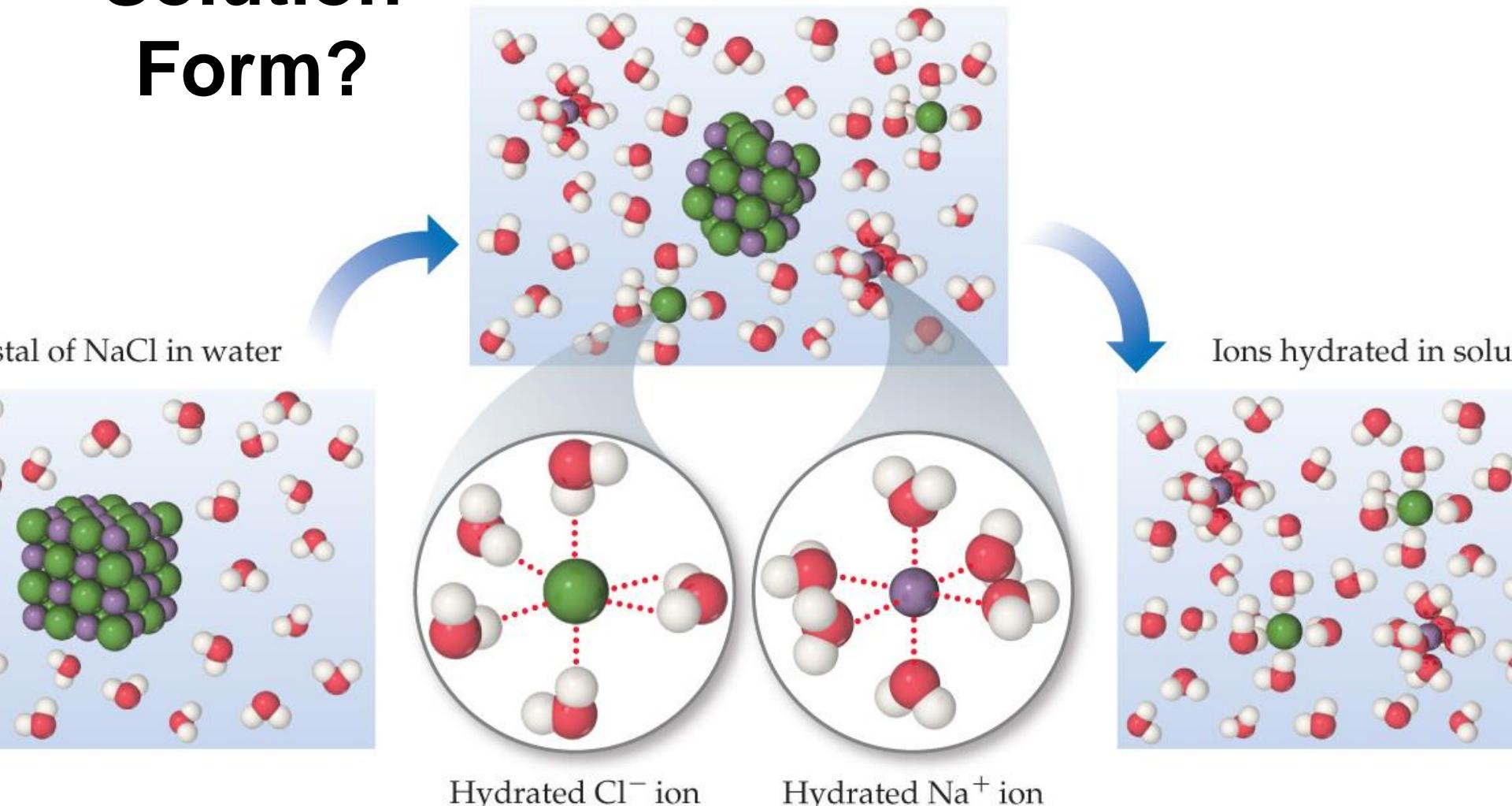
Solutions



- **Solutions (Chapter 4): homogeneous mixtures** of two or more pure substances (one as **liquid** generally).
- In a solution, the **solute** is **dispersed (分散)** **uniformly** throughout the **solvent**.

How Does a Solution Form?

Solvent–solute interactions between water molecules and NaCl allow solid to dissolve

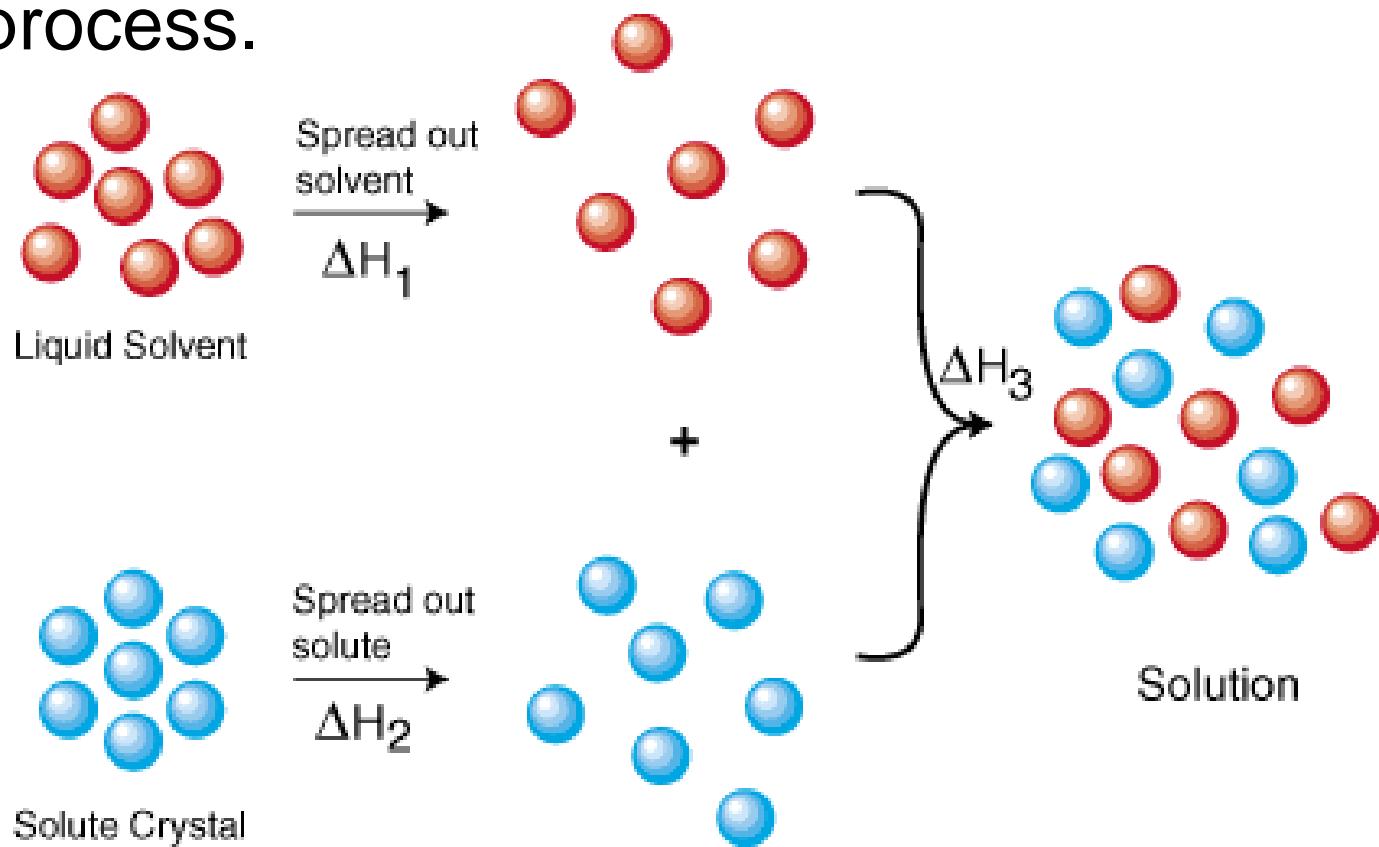


As a solution forms, the **solvent pulls solute particles apart and surrounds, or called **solvates**, them.**

The solution process

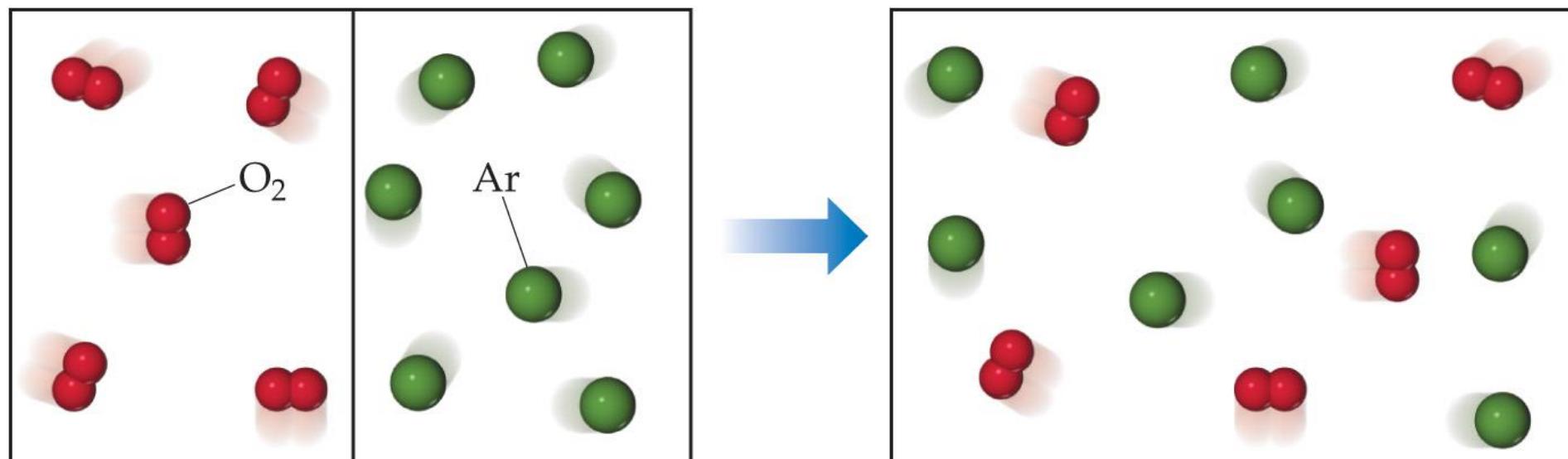
The ability of substances to form solutions depends on two factors:

- (1) the **natural tendency** of substances to **mix & spread** into **larger volumes**.
- (2) the **types of intermolecular interactions** involved in the solution process.



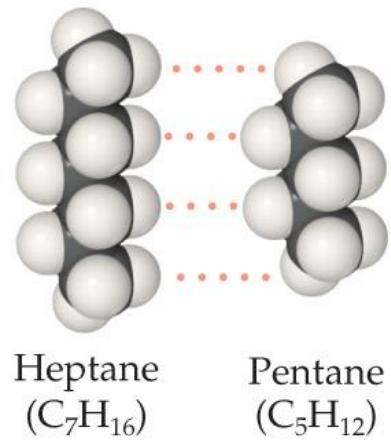
Natural Tendency toward Mixing

- Mixing of gases is a **spontaneous** (自发) process.
- Each gas acts as if it is alone to fill the container.
- **Mixing** causes **more randomness** in the position of the molecules, **increasing** a thermodynamic quantity called **entropy** (熵 will learn more in Chapter 19).
- The **formation of solutions** is **favored** by the **increase in entropy** that accompanies mixing.

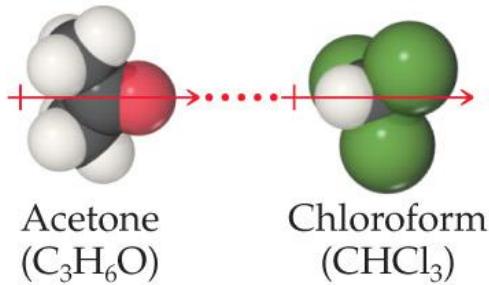


Intermolecular Interactions

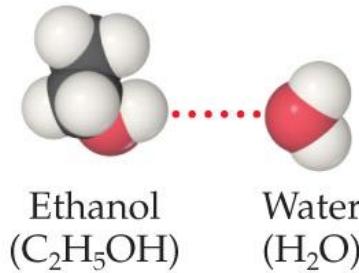
Dispersion



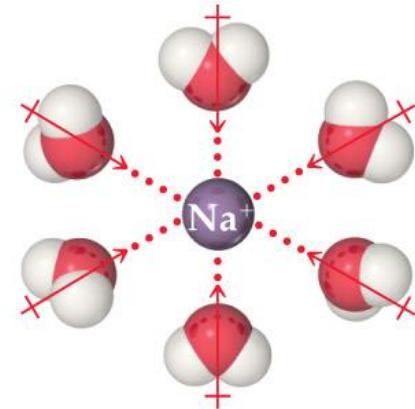
Dipole-dipole



Hydrogen bond



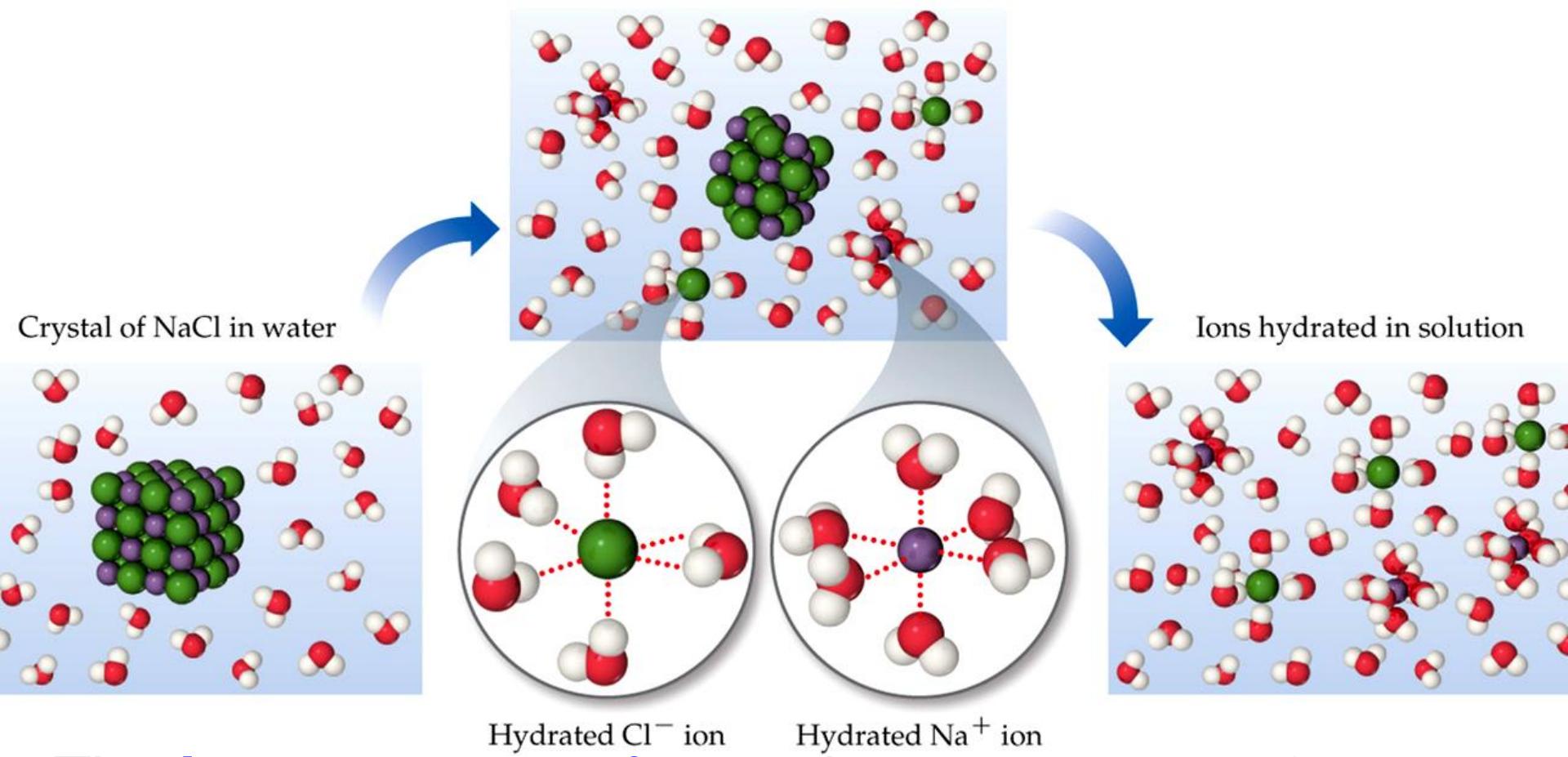
Ion-dipole



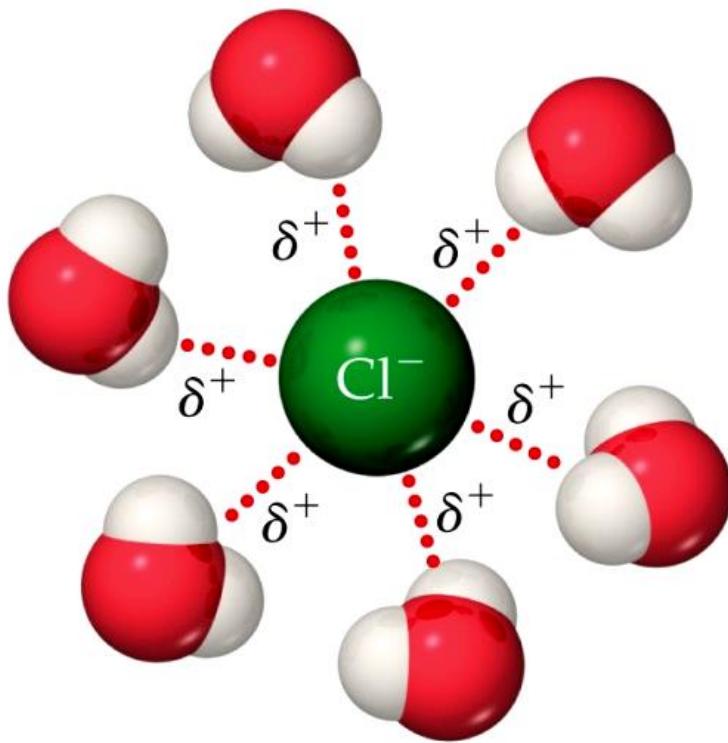
Any **intermolecular force of attraction** can be the attraction between solute and solvent molecules.

Solutions

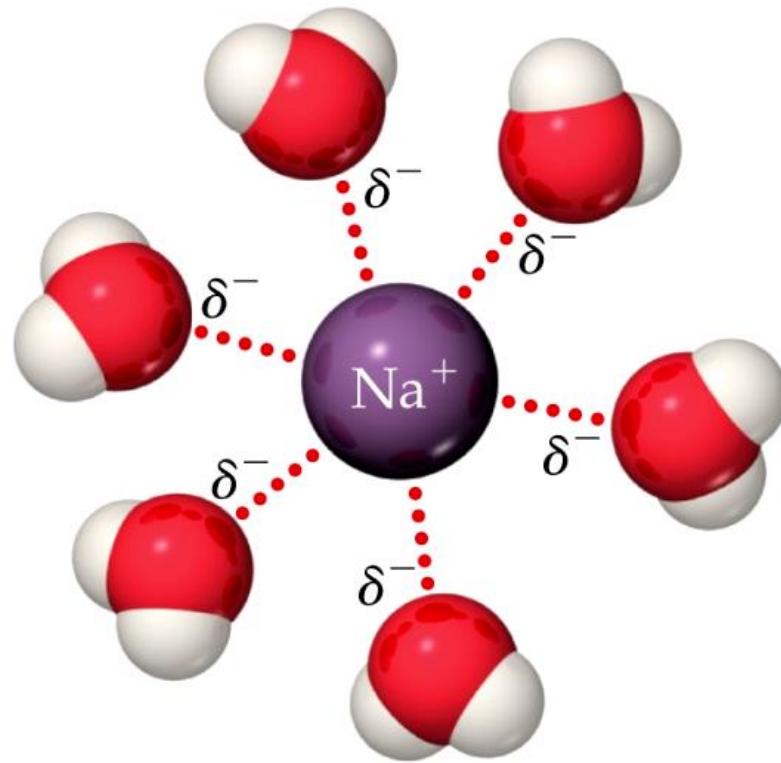
Solvent-solute interactions
between water molecules and
NaCl allow solid to dissolve



- The **intermolecular forces** between **solute & solvent particles** must be **strong enough** to compete with those between **solute particles** & those between **solvent particles**.



Positive ends of polar molecules are oriented toward negatively charged anion



Negative ends of polar molecules are oriented toward positively charged cation

- If an ionic salt is soluble in water, it is because the **ion–dipole interactions** are **strong enough** to overcome the **lattice energy** of the salt crystal.

Energy Changes in Solution

Three kinds of intermolecular interactions are involved in solution formation:

- **Solute–solute interactions** must be overcome (broken) to disperse the solute particles.
- **Solvent–solvent interactions** must be overcome (broken) to make room for the solute particles.
- **Solvent–solute interactions** occur as the particles mix.

$$\Delta H_{\text{soln}} = \Delta H_{\text{solute}} + \Delta H_{\text{solvent}} + \Delta H_{\text{mix}}$$

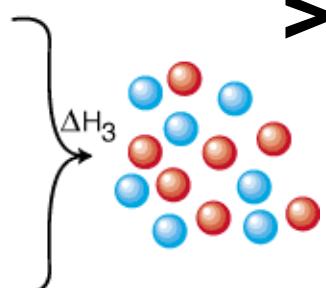
↓ ↓ ↓
 >0 >0 <0



Spread out solvent
 $\xrightarrow{\Delta H_1}$



Spread out solute
 $\xrightarrow{\Delta H_2}$

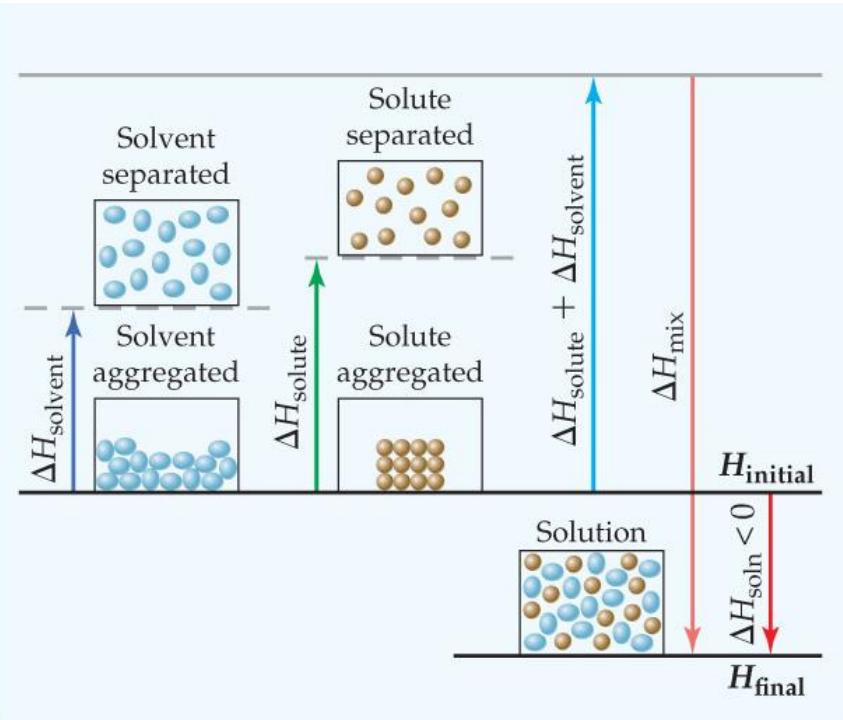


Solution

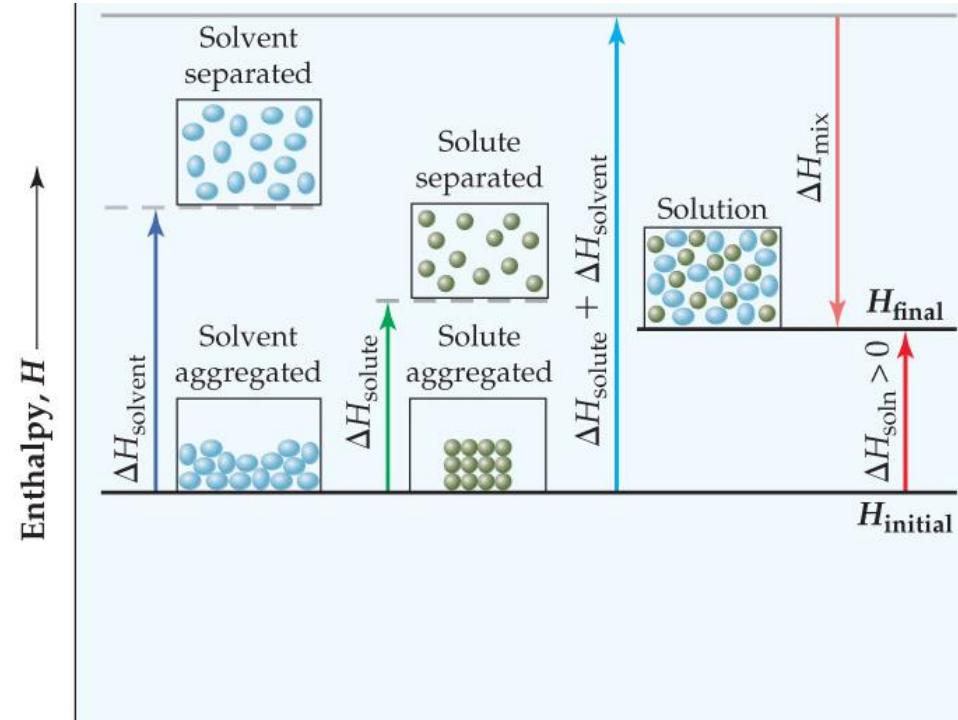


Exothermic or Endothermic

Enthalpy, H



Exothermic solution process

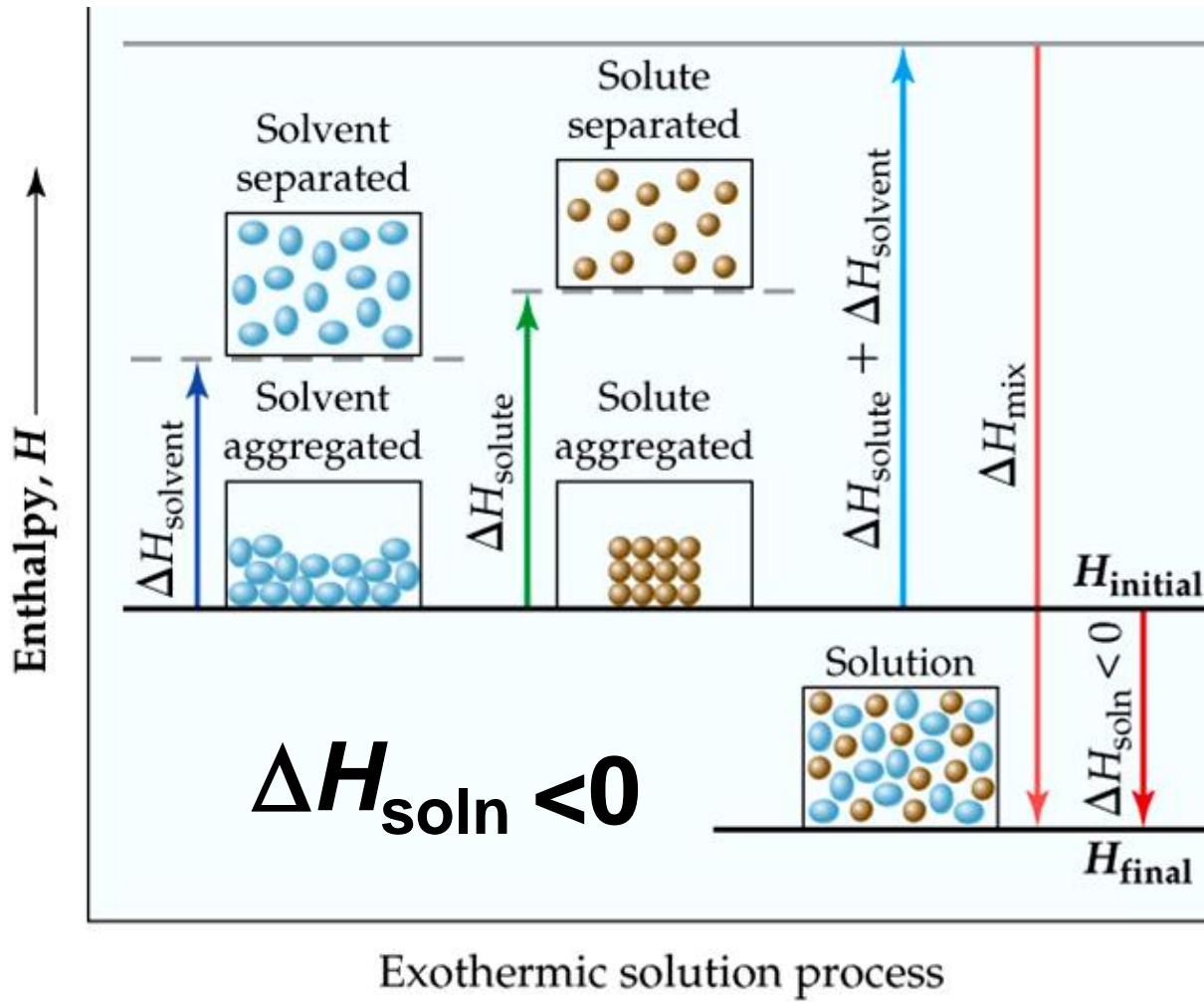


Endothermic solution process

$$\Delta H_{soln} = \Delta H_{solute} + \Delta H_{solvent} + \Delta H_{mix}$$

- For a reaction to occur, ΔH_{mix} must be close to or larger than the sum of ΔH_{solute} & $\Delta H_{solvent}$.
- The **randomness from entropy** will affect the process too.

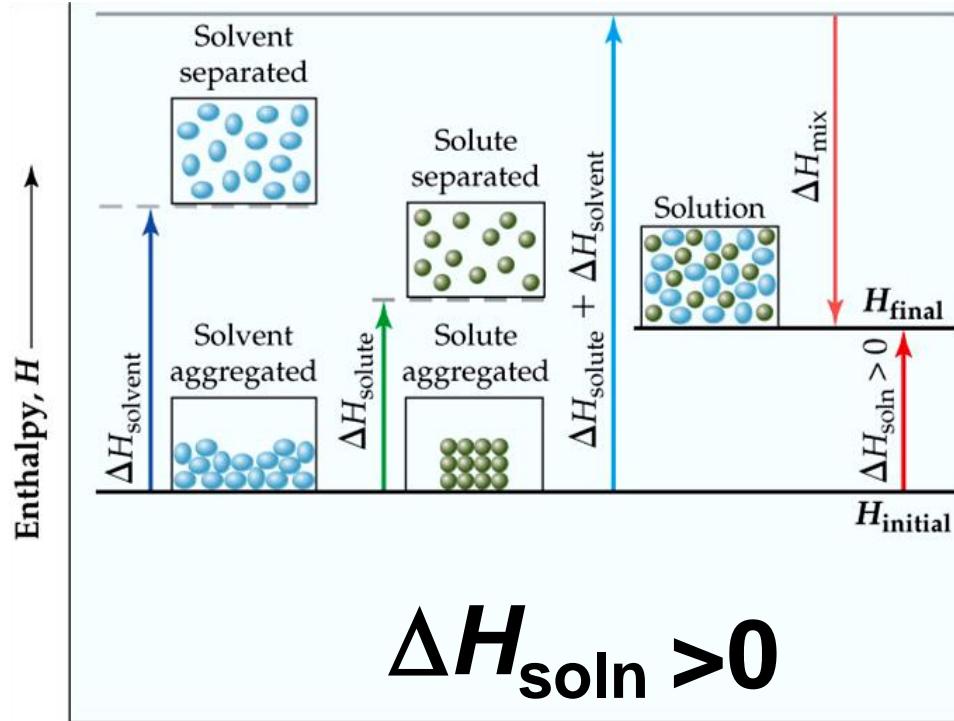
- The solution process tends to occur **spontaneously** for the exothermic solution process.



$$\Delta H_{\text{soln}} = \Delta H_{\text{solute}} + \Delta H_{\text{solvent}} + \Delta H_{\text{mix}}$$

Why Do Endothermic Processes Occur?

- Things do **not** tend to occur **spontaneously** (i.e., without outside intervention) **unless the energy of the system is lowered.**



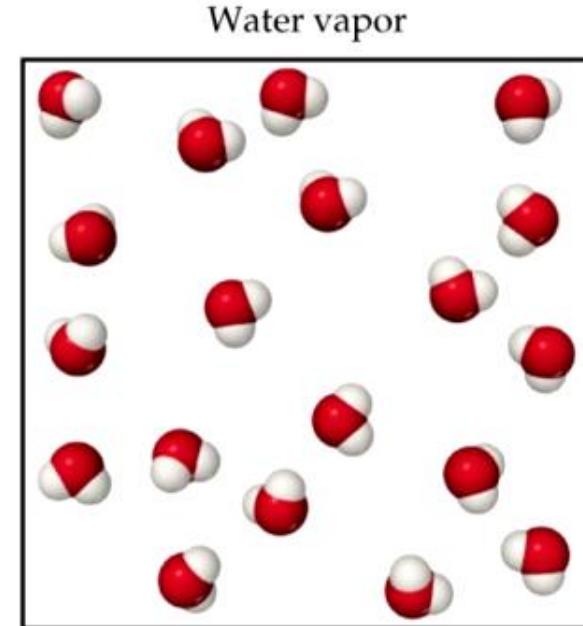
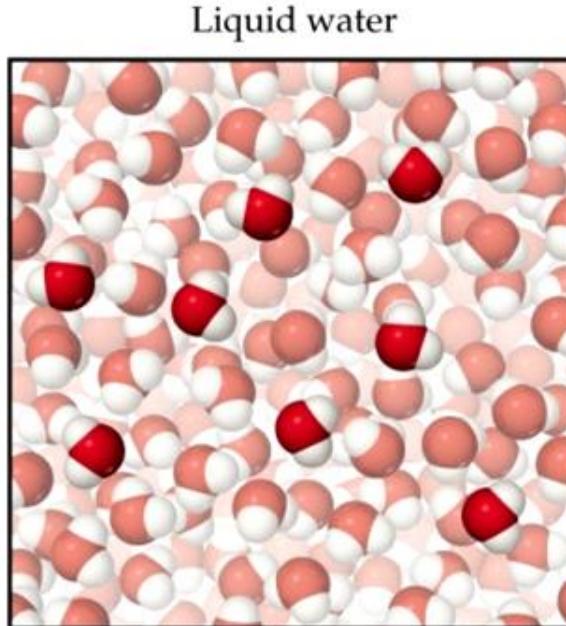
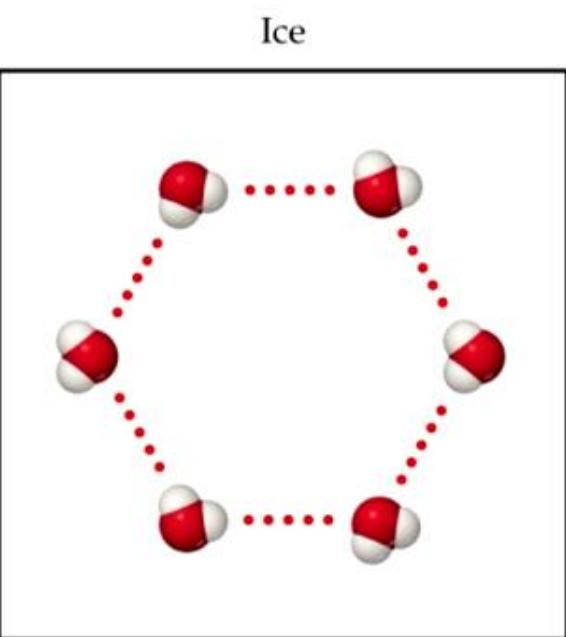
$$\Delta H_{\text{soln}} > 0$$

Endothermic solution process

- Increasing** randomness (**entropy**) of a system tends to **lower free energy (G)** of the system (Chapter 19).
- So even though **enthalpy may increase**, the **overall free energy** of the system can **still decrease** if the system becomes **more disordered**.

Entropy (Chapter 19): $S(g) > S(l) > S(s)$

Increasing entropy



$$\Delta G = \Delta H - T\Delta S$$

$\Delta G < 0$, the **forward** reaction is **spontaneous**

- For example, the dissolution of ammonium nitrate (NH_4NO_3) in water, **heat is absorbed**, not released.

Ammonium nitrate in instant ice pack



Magnesium sulfate in instant hot pack



Aqueous Solution vs. Chemical Reaction



Nickel metal and hydrochloric acid



Nickel reacts with hydrochloric acid, forming $\text{NiCl}_2(aq)$ and $\text{H}_2(g)$. The solution is of NiCl_2 , not Ni metal



$\text{NiCl}_2 \cdot 6 \text{ H}_2\text{O}(s)$ remains when solvent evaporated

- A substance disappears when it comes in contact with a solvent, it does not mean the substance dissolved. It may have reacted, like nickel with hydrochloric acid.



Aqueous Solution vs. Chemical Reaction



Nickel metal and hydrochloric acid



Nickel reacts with hydrochloric acid, forming $\text{NiCl}_2(aq)$ and $\text{H}_2(g)$. The solution is of NiCl_2 , not Ni metal

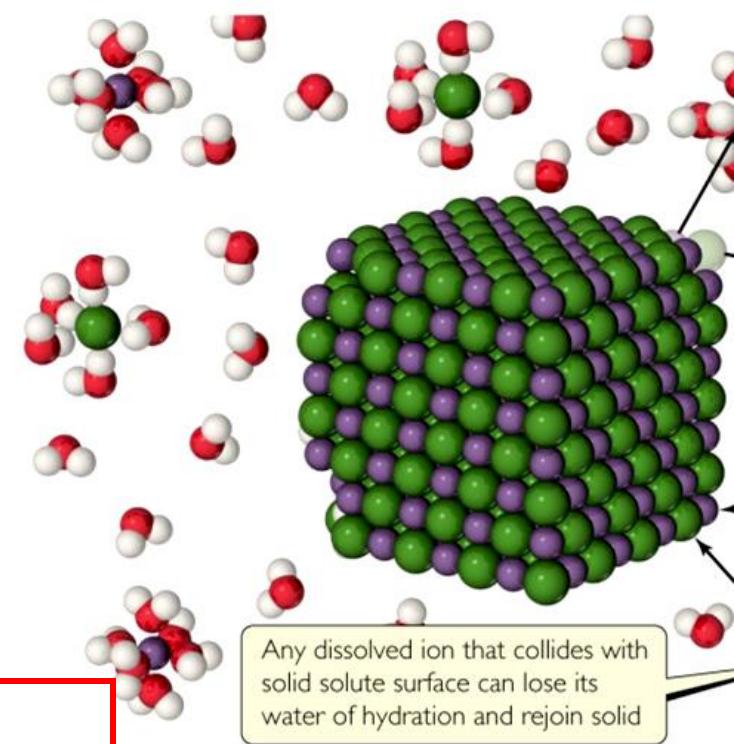
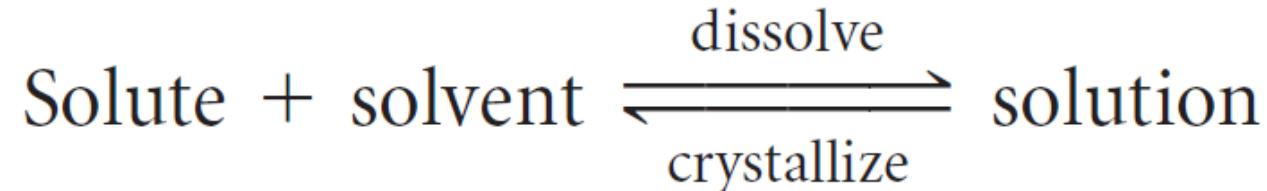


$\text{NiCl}_2 \cdot 6 \text{H}_2\text{O}(s)$ remains when solvent evaporated

- **Dissolution** is a **physical change**: you can **get back the original solute by evaporating the solvent**.
- If you **can't get it back**, the substance **didn't dissolve only, it reacted**.

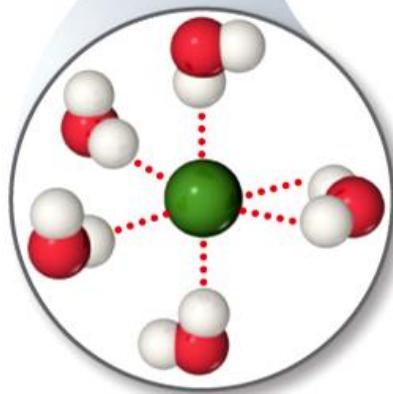
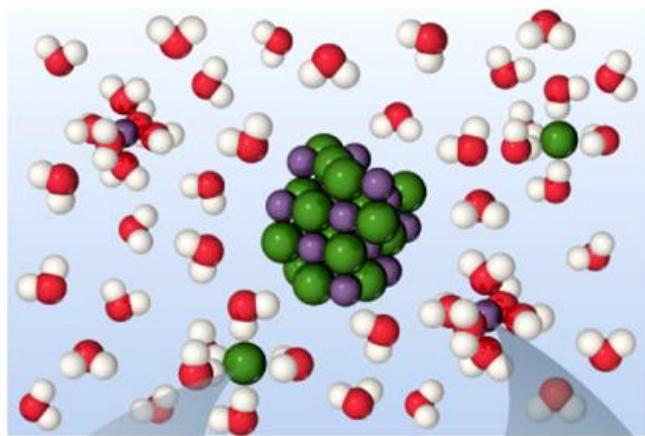
Types of Solutions

- In the process of **dissolution**, solid solute dissolved in a **solvent** → **concentration of solute** particles in solution **increase** → **Increasing the chances** that **solute** particles **collide with solid surface & reattach**.
- Dissolved solute is in **dynamic equilibrium** with solid solute particles.
- Opposite of **dissolution** (solution-making) process: so-called **crystallization**.

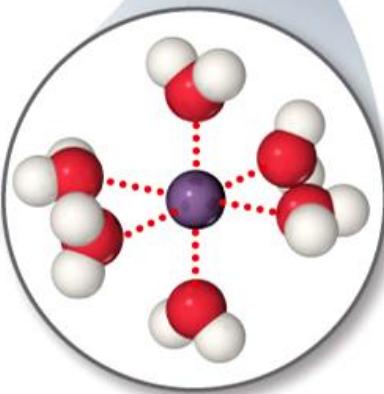


Solutions

Solvent–solute interactions between water molecules and NaCl allow solid to dissolve

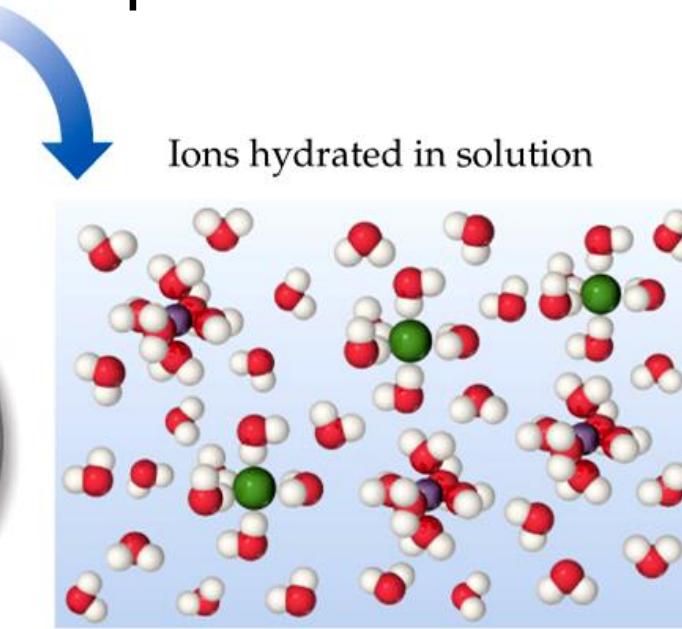


Hydrated Cl^- ion



Hydrated Na^+ ion

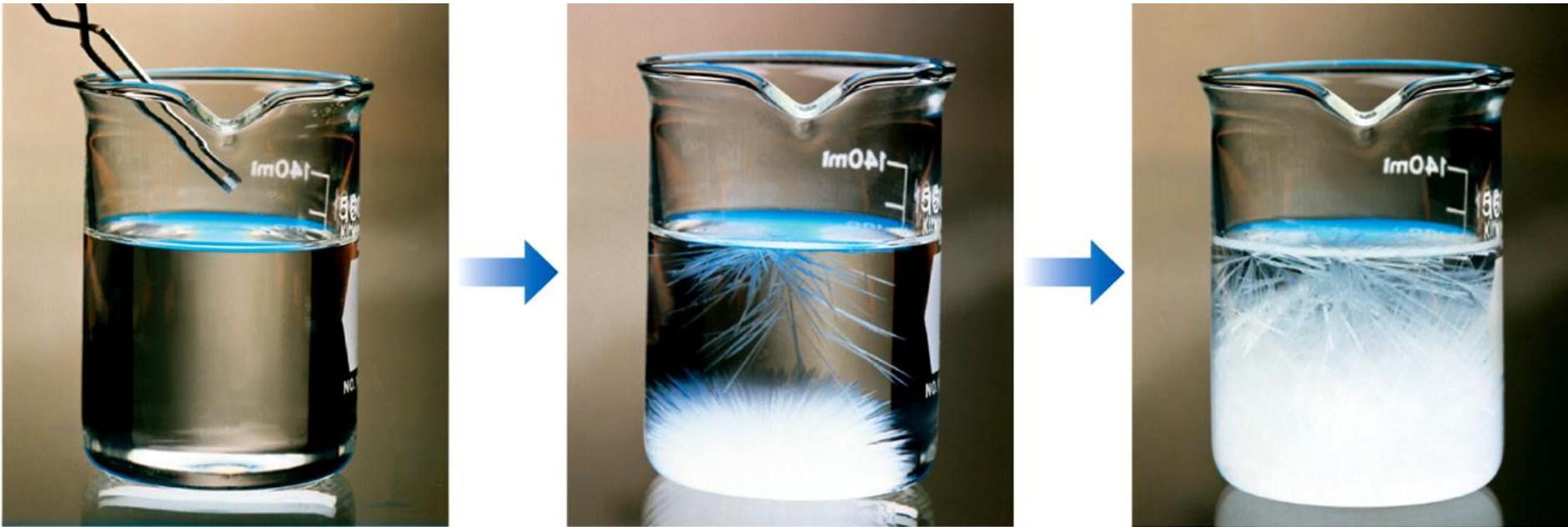
- In a **saturated** (饱和) solution, the solvent holds **as much solute as** is possible at that temperature.



Ions hydrated in solution



- If we dissolve **less solute** than the amount needed to form a saturated solution, the solution is **unsaturated** (不饱和).



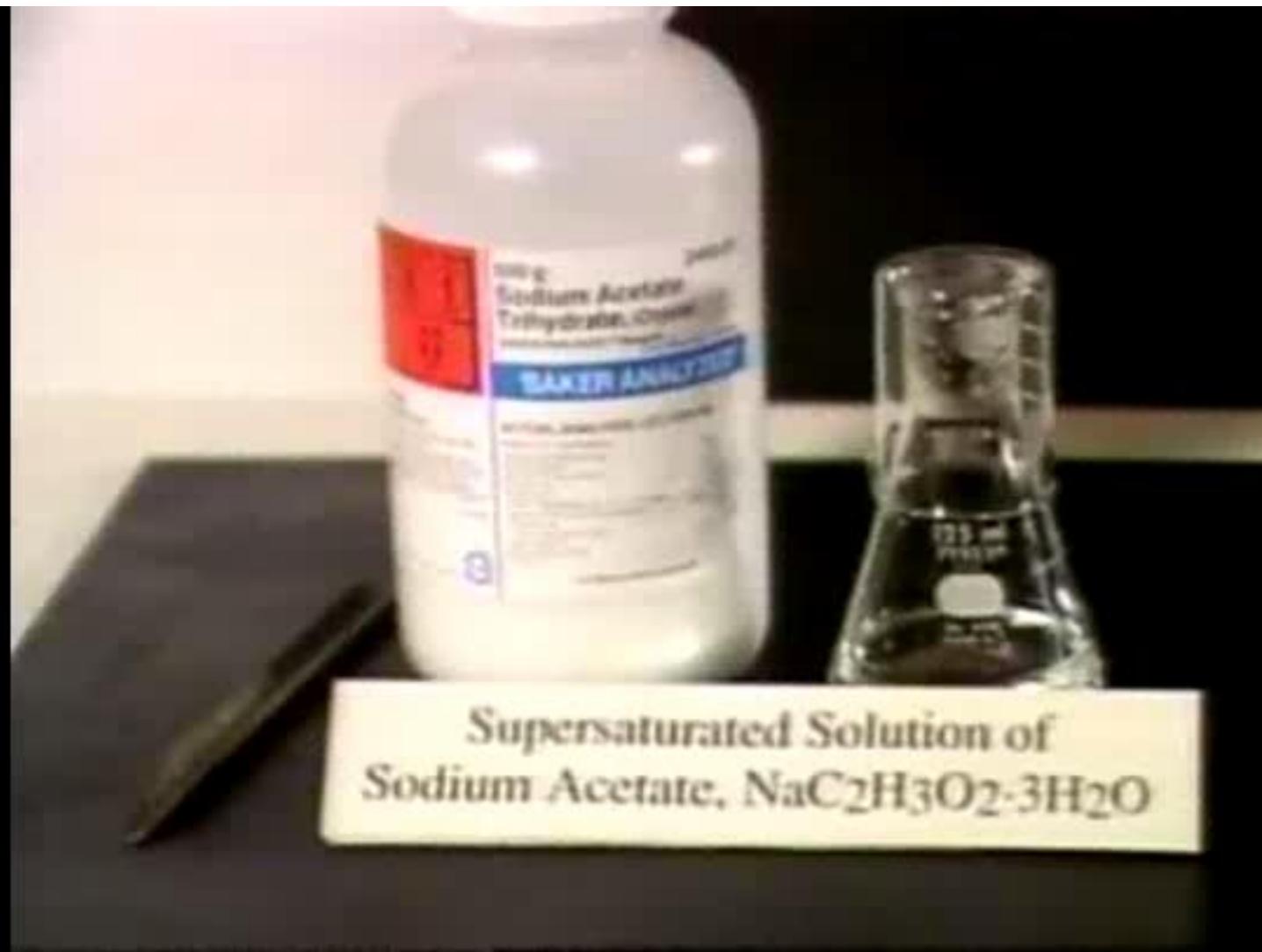
Seed crystal of sodium acetate
added to
supersaturated solution

Excess sodium acetate
crystallizes from solution

Solution arrives at saturation

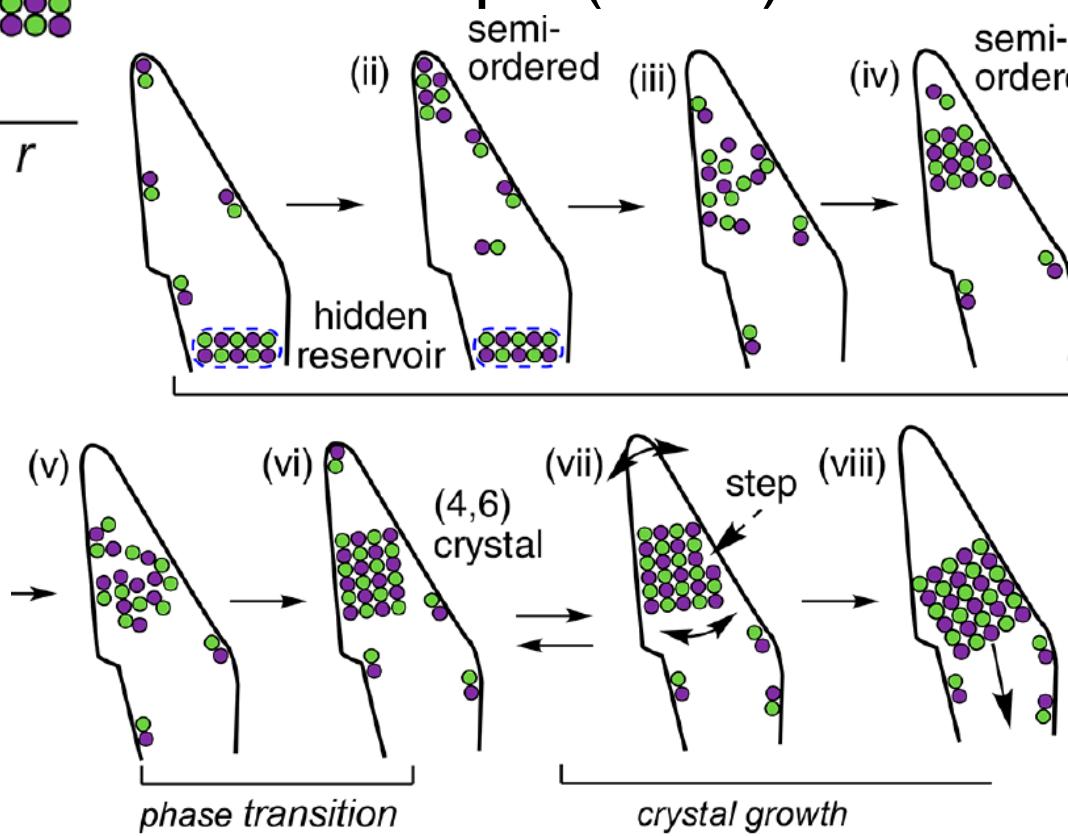
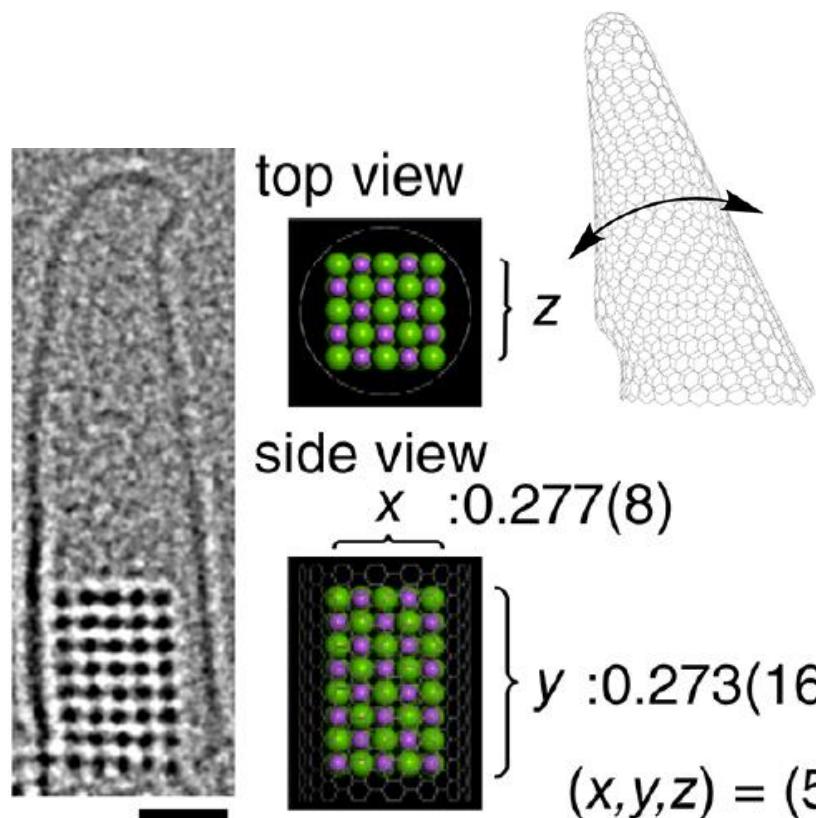
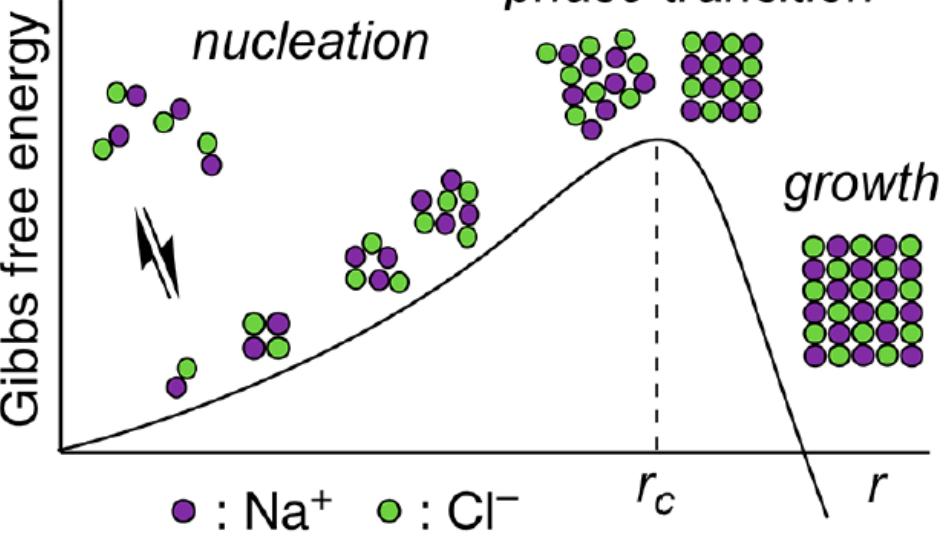
- In **supersaturated** (过饱和的) solutions, the solvent **holds more solute** than is normally possible at that temperature.
- These solutions are **unstable**; **crystallization** can usually be stimulated by **adding a “seed crystal”** or **scratching** the side of the flask.

Crystallization of Supersaturated NaOAc



(Extra Info.)

Nucleation of NaCl transmission electron microscope (TEM)



Solubility

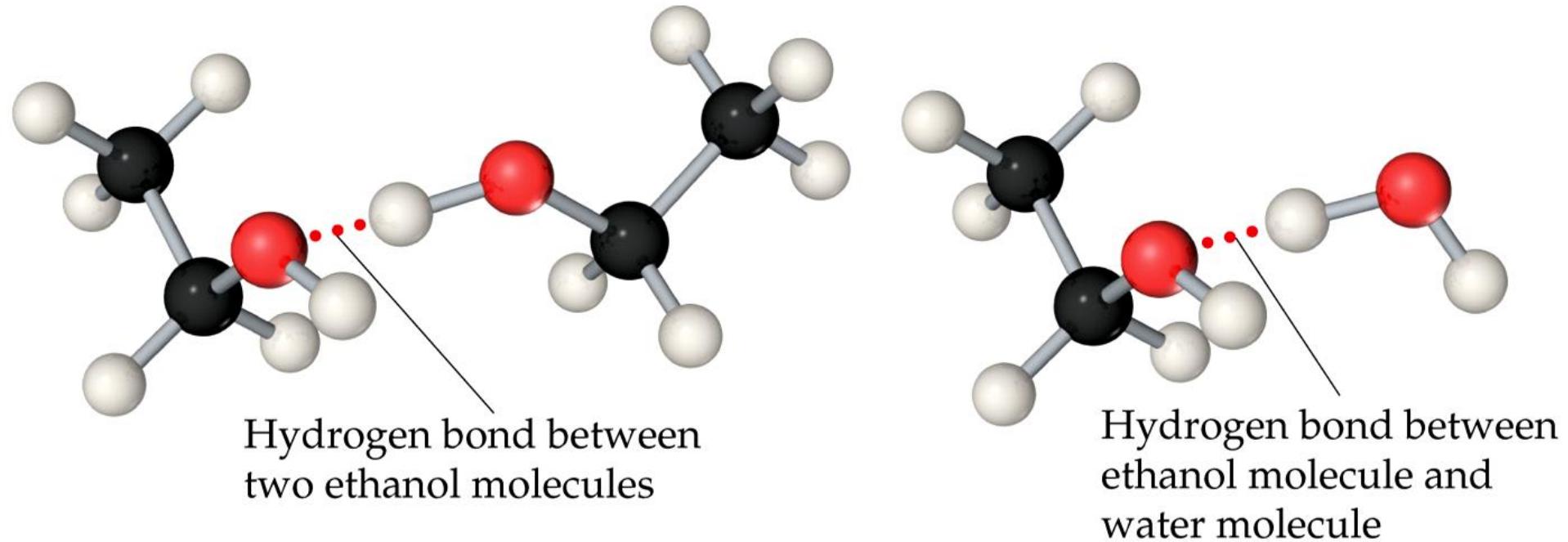
- Solubility: maximum amount of solute can dissolve in a given amount of solvent at a given temperature.
- Chemists use the concept “**like dissolves like**”:
- **Polar substances** tend to **dissolve** in **polar solvents**.
- **Nonpolar substances** tend to **dissolve** in **nonpolar solvents**.

Alcohol	Solubility in H ₂ O	Solubility in C ₆ H ₁₄
CH ₃ OH (methanol)	∞	0.12
CH ₃ CH ₂ OH (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	∞

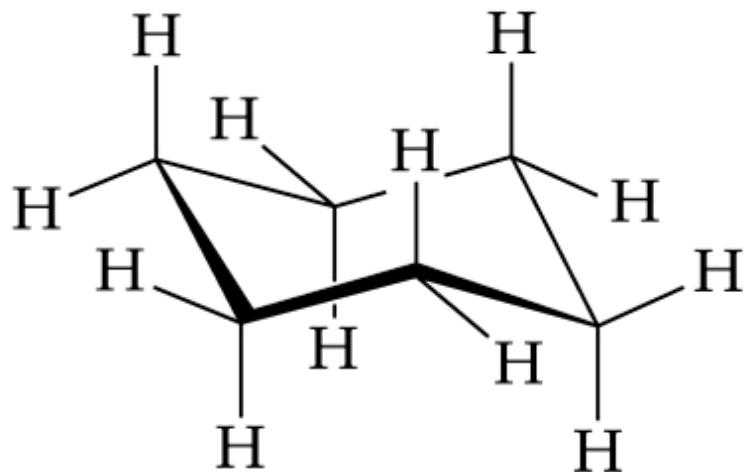
*Expressed in mol alcohol/100 g solvent at 20 °C. The infinity symbol (∞) indicates the alcohol is completely miscible with the solvent.

Factors Affecting Solubility

- **Solute–solvent** interactions
- Pressure (for gaseous solutes)
- Temperature

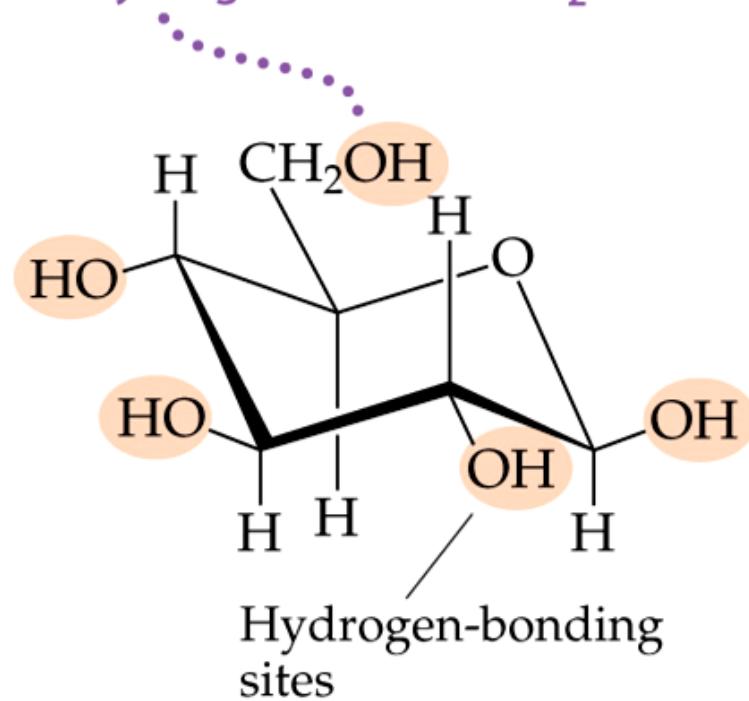


- The **more similar** the **intermolecular attractions**, the **more likely** one substance is to be **soluble** in another: **similar or stronger solute-solvent interactions**.



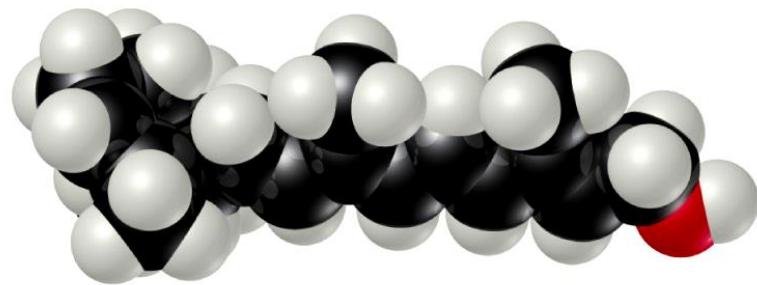
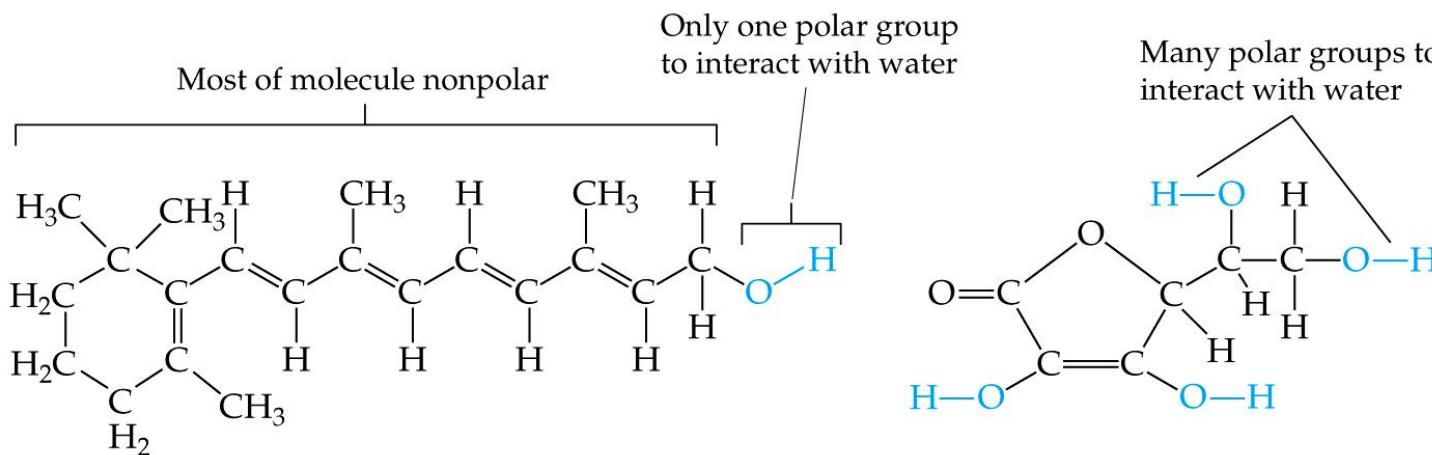
Cyclohexane, C_6H_{12} , which has no polar OH groups, is essentially insoluble in water

OH groups enhance the aqueous solubility because of their ability to hydrogen bond with H_2O .

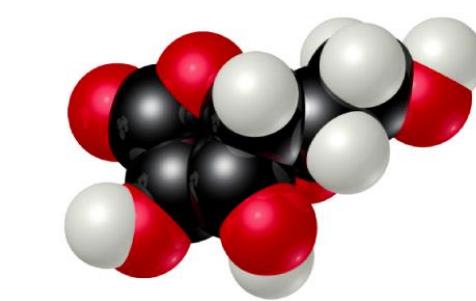


Glucose, $C_6H_{12}O_6$, has five OH groups and is highly soluble in water

- **Glucose** (which has hydrogen bonding) is very soluble in water, while **cyclohexane** (which only has dispersion forces) is not soluble in water.

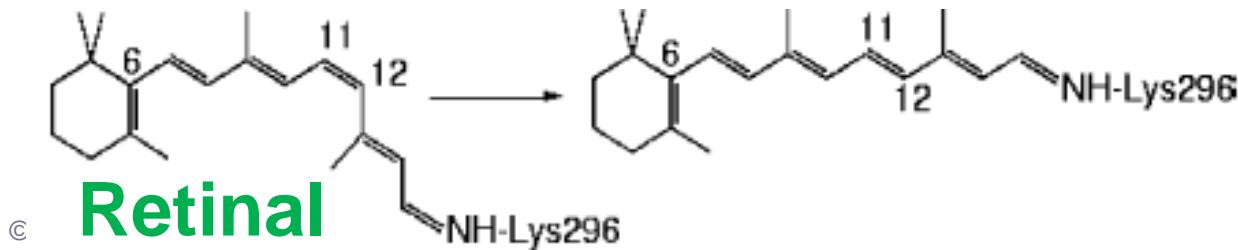


Vitamin A



Vitamin C

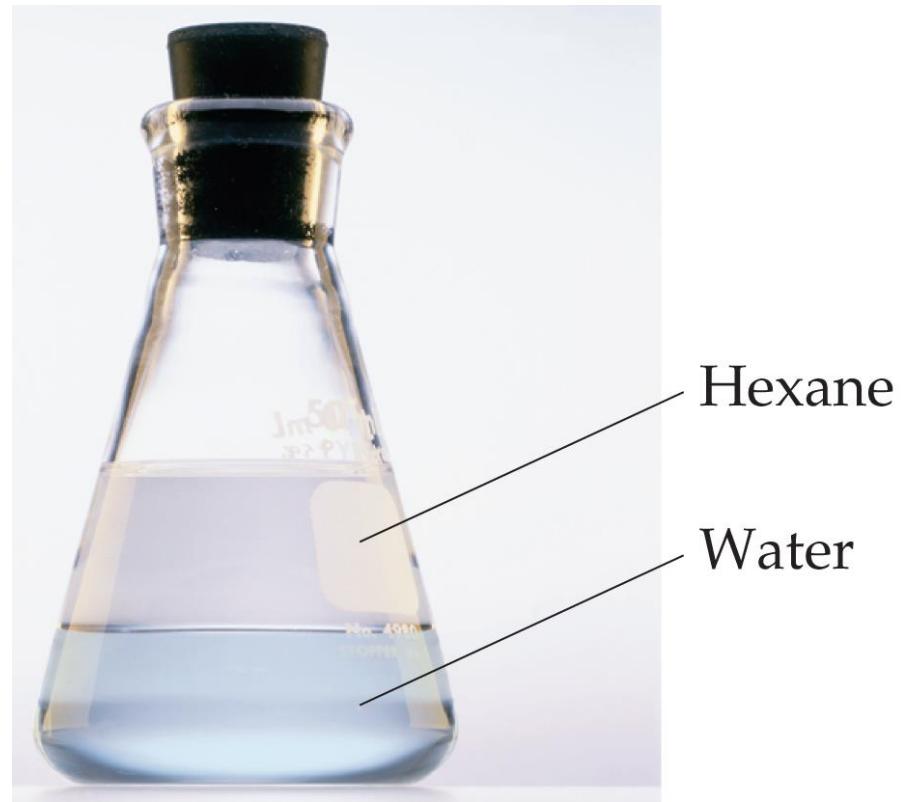
- Vitamin **A** is soluble in **nonpolar solvents** (like fats) & is readily stored in fatty tissue in the body.
- Vitamin **C** is soluble in **polar solvents**, e.g. water.



Solutions

Liquid/Liquid Solubility

- Liquids that mix in all proportions are **miscible** (互溶).
- Liquids that do *not* mix in one another are **immiscible**.
- Because hexane is nonpolar and water is polar, they are immiscible.



Solutions

Gases in Solution

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

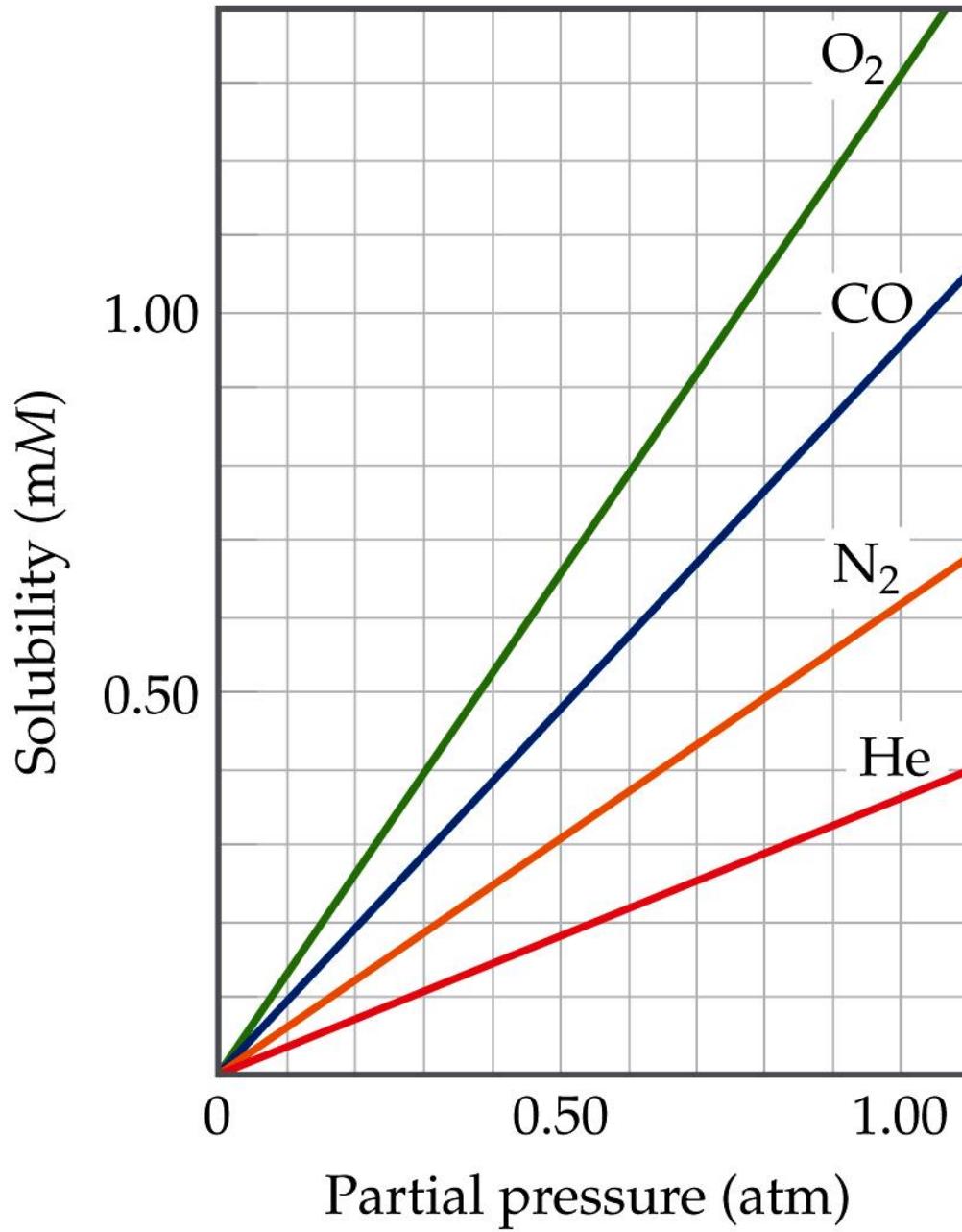
Table 13.1 Solubilities of Gases in Water at 20 °C, with 1 atm Gas Pressure

Gas	Molar Mass (g/mol)	Solubility (M)
N ₂	28.0	0.69×10^{-3}
O ₂	32.0	1.38×10^{-3}
Ar	39.9	1.50×10^{-3}
Kr	83.8	2.79×10^{-3}

Increasing mass



Pressure Effects



- The **solubility** of **liquids & solids** does not **change** appreciably with **pressure**.

- However, the **solubility** of a **gas** in a liquid is directly proportional to its **pressure**.

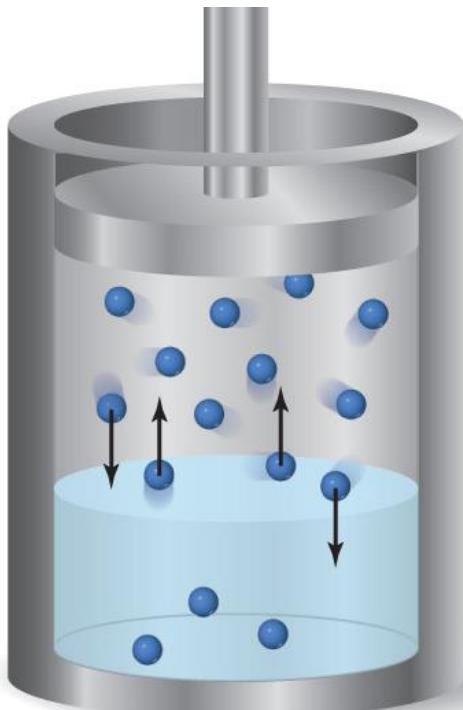
Solubility \propto Partial pressure

Henry's Law

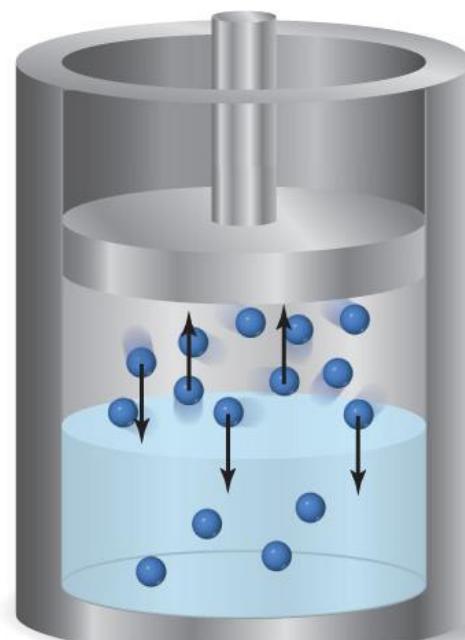
- The solubility of a gas is proportional to the partial pressure of the gas above the solution.

$$S_g = kP_g$$

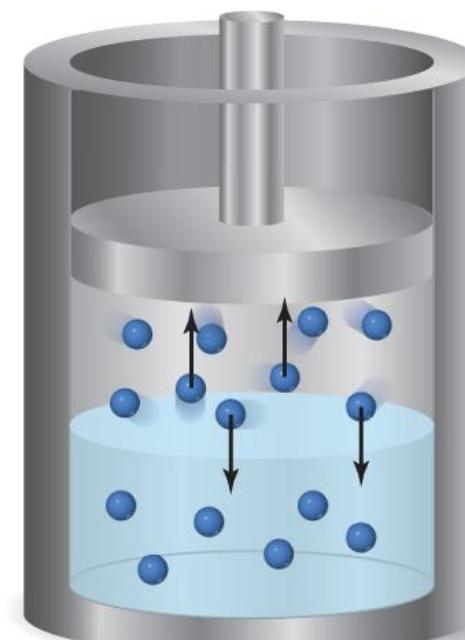
S_g : solubility (unit: molarity)
 k : Henry's Law constant
 P_g : partial pressure



Equilibrium

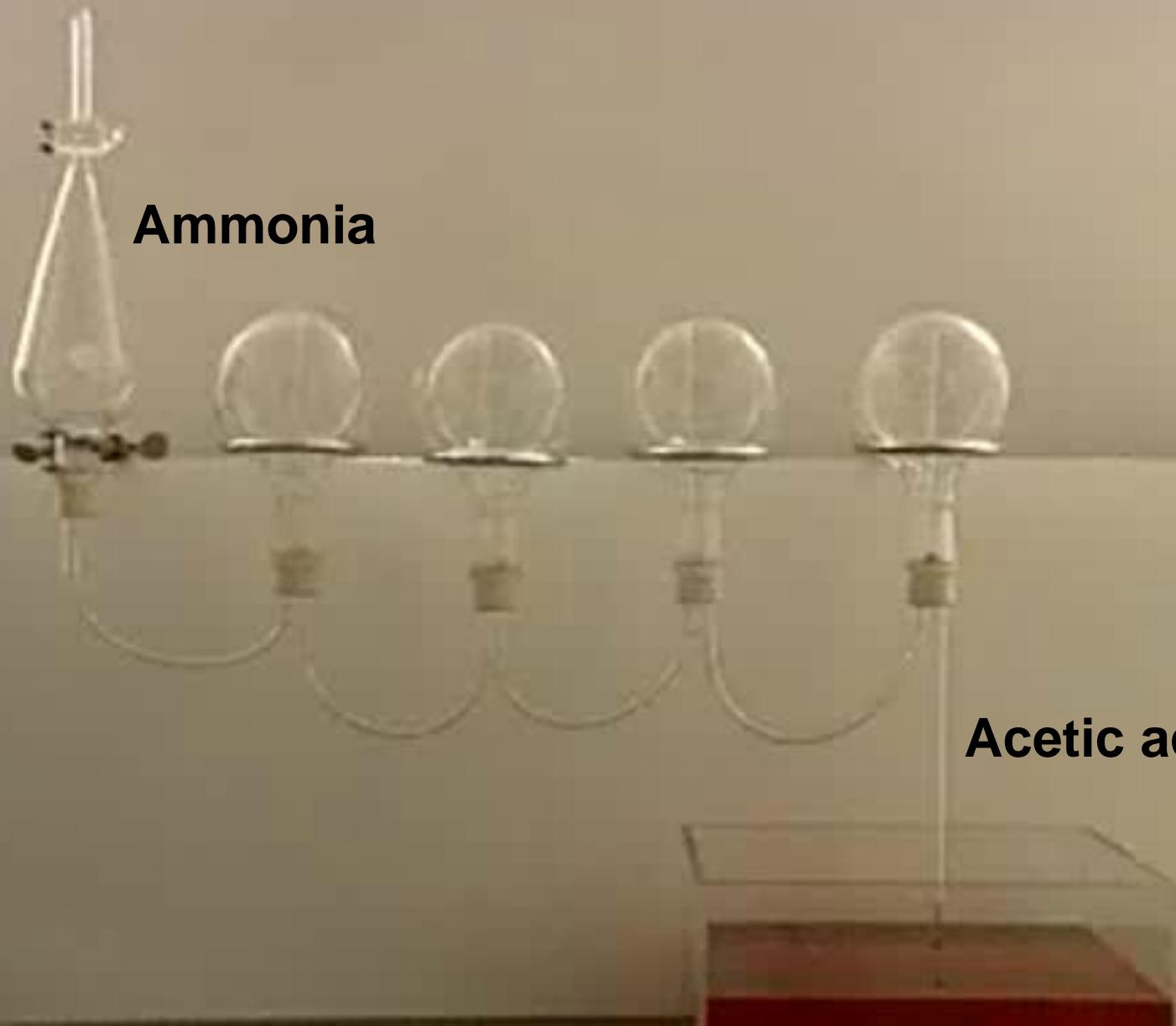


Pressure is increased.
More CO₂ dissolves

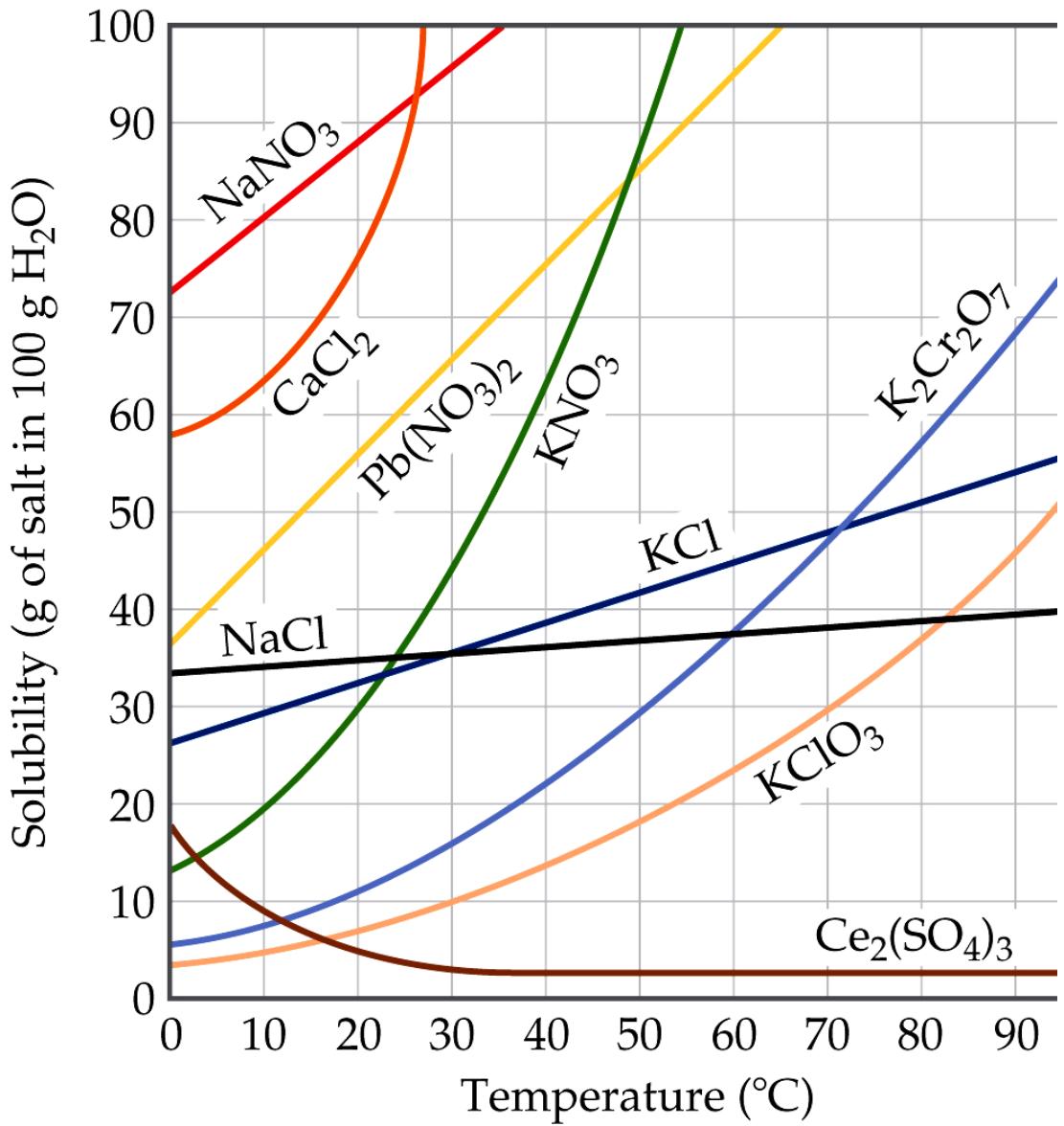


Equilibrium restored

Ammonia in Water - Ammonia Fountains

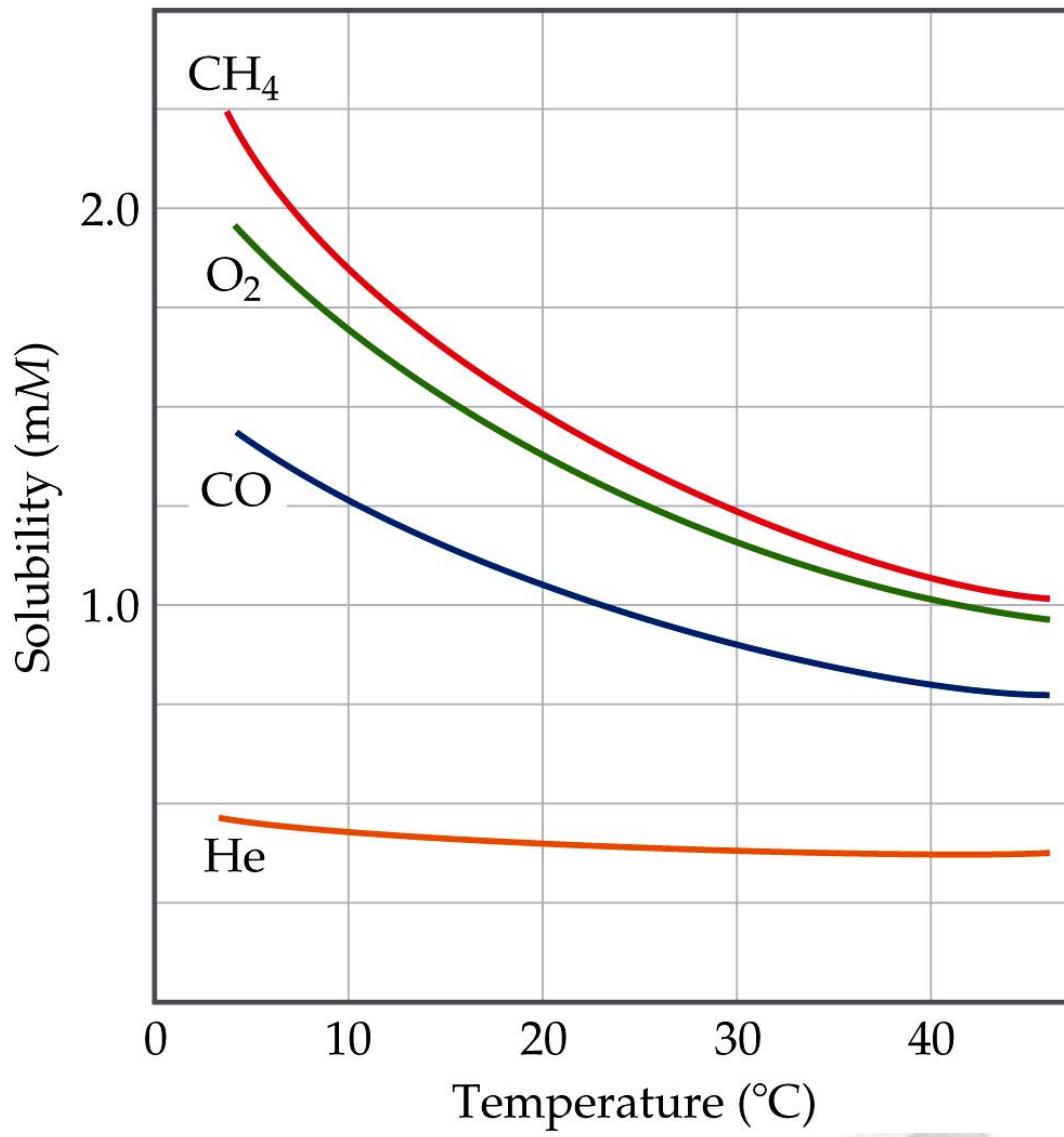


Temperature Effects



- Generally, the solubility of most **solid solutes** in liquid solvents **increases** with increasing temperature.
- However, some solid solutes remain relatively constant, and others decrease.

- For all **gases**, solubility decreases with increasing temperature.
- Carbonated soft drinks are more “bubbly” if stored in refrigerator.
- Cold rivers have higher oxygen content than warm rivers.



Mass Percentage (质量百分比)

$$\text{Mass \% of } A = \frac{\text{mass of } A \text{ in solution}}{\text{total mass of solution}} \times 100$$

Parts per million (百万分之一) (ppm)

$$\text{ppm} = \frac{\text{mass of } A \text{ in solution}}{\text{total mass of solution}} \times 10^6$$

Parts per billion (十亿分之一) (ppb)

$$\text{ppb} = \frac{\text{mass of } A \text{ in solution}}{\text{total mass of solution}} \times 10^9$$

Mole Fraction (X) (摩尔分数)

$$X_A = \frac{\text{moles of } A}{\text{total moles of all components}}$$

- Mole fraction is the **ratio of moles** of a substance to the total number of moles in a solution.
- It does not matter if it is for **a solute or for a solvent**.
- In some applications, one needs the mole fraction of *solvent*, not solute—make sure you find the quantity you need!



Solutions

Molarity (*M*) (摩尔浓度)

$$M = \frac{\text{moles of solute}}{\text{Volume (liters) of solution}}$$

- Since volume is temperature-dependent, molarity can **change with temperature**.

Molality (*m*) (重量摩尔浓度)

$$m = \frac{\text{moles of solute}}{\text{Mass (kilograms) of solvent}}$$

- Since both moles and mass do not change with temperature, molality is **not temperature-dependent**.

Solutions

Label the following processes as exothermic or endothermic:

- a. breaking solvent–solvent interactions to form separated particles;
- b. forming solvent–solute interactions from separated particles.

(a)

- A. Endothermic
- B. Endothermic
- C. Exothermic
- D. Exothermic

(b)

- Endothermic
- Exothermic
- Endothermic
- Exothermic

The rule of “like dissolves like” refers to similarities between _____ of miscible liquids.

- a. molecular weights
- b. shapes
- c. intermolecular attractive forces
- d. densities

Which of the following compounds is miscible with water?

- a. CH_3OH
- b. CH_4
- c. C_6H_6
- d. $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$



Which of the compounds below is the LEAST miscible with water?

- a. CH_3OH
- b. $\text{CH}_3\text{CH}_2\text{OH}$
- c. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$
- d. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$

_____ Law says that the solubility of a gas in a liquid increases as the pressure of the gas increases.

- a. Boyle's
- b. Charles's
- c. Henry's
- d. Raoult's



Calculate the concentration of CO₂ in a soft drink that is bottled with a partial pressure of CO₂ of 4.0 atm over the liquid at 25 °C. The Henry's law constant for CO₂ in water at this temperature is 3.4 × 10⁻² mol/L-atm.

$$S_{\text{CO}_2} = kP_{\text{CO}_2} = (3.4 \times 10^{-2} \text{ mol/L-atm})(4.0 \text{ atm}) = 0.14 \text{ mol/L} = 0.14 M$$

$$S_g = kP_g$$



Solutions

In general, as the temperature of a solution increases, the solubility of a gaseous solute

- a. increases.
- b. decreases.
- c. remains unchanged.
- d. varies from gas to gas.

The molality of a solution is defined as the amount of solute (in moles) divided by the

- a. volume of the solution (in liters).
- b. mass of the solvent (in kilograms).
- c. mass of the solution (in kilograms).
- d. total number of moles.



A solution is made by dissolving 4.35 g of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) in 25.0 mL of water at 25 °C. Calculate the molality of glucose in the solution. Water has a density of 1.00 g/mL.

$$\text{Mol C}_6\text{H}_{12}\text{O}_6 = (4.35 \text{ g C}_6\text{H}_{12}\text{O}_6) \left(\frac{1 \text{ mol C}_6\text{H}_{12}\text{O}_6}{180.2 \text{ g C}_6\text{H}_{12}\text{O}_6} \right) = 0.0241 \text{ mol C}_6\text{H}_{12}\text{O}_6$$

$$(25.0 \text{ mL})(1.00 \text{ g/mL}) = 25.0 \text{ g} = 0.0250 \text{ kg}$$

$$\text{Molality of C}_6\text{H}_{12}\text{O}_6 = \frac{0.0241 \text{ mol C}_6\text{H}_{12}\text{O}_6}{0.0250 \text{ kg H}_2\text{O}} = 0.964 \text{ m}$$



Solutions

Colligative Properties (依数性)

- Colligative properties depend only on the **quantity** (number) of **solute** particles present, **not** on the **identity** of the solute particles.

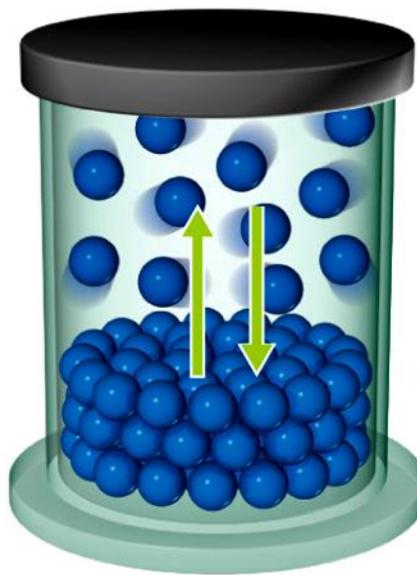
e.g. addition of (non-volatile) solute into a solvent would lower freezing point & raise boiling point of the solution.

- Among colligative properties are:
- Lowering vapor-pressure
- Raising boiling-point
- Lowering melting-point
- Osmotic pressure



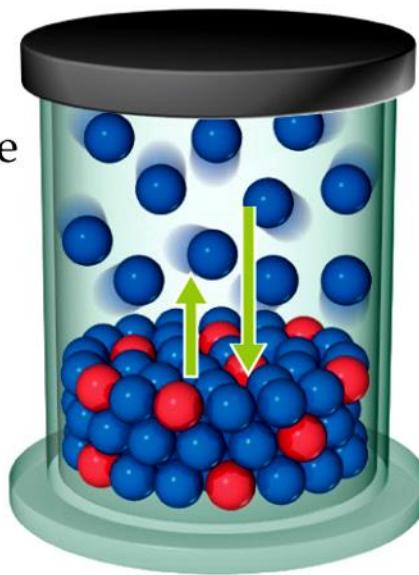
- Volatile solvent particles
- Nonvolatile solute particles

Vapor Pressure

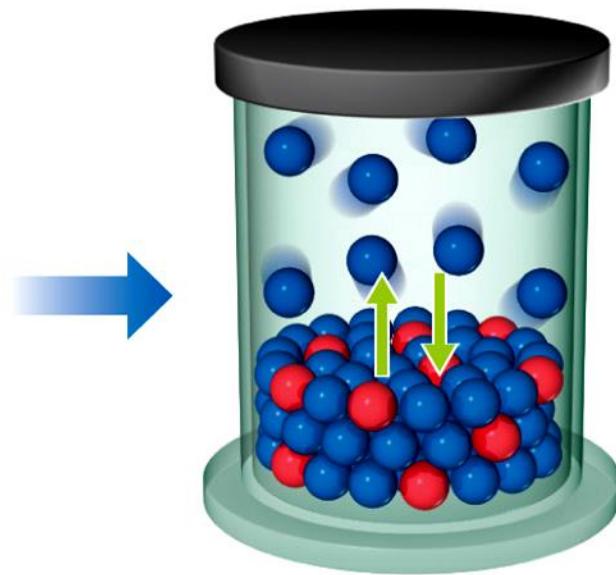


Equilibrium

Add
nonvolatile
solute



Rate of vaporization
reduced by presence
of nonvolatile solute



Equilibrium reestablished
with fewer molecules in
gas phase

- Due to strong **solute–solvent intermolecular attraction**, higher concentrations of **nonvolatile** (非挥发性) **solutes** make the **solvent harder to escape** to the vapor phase.
- So, the **vapor pressure** of a **solution** is **lower** than that of the **pure solvent**.

Raoult's Law

- **Vapor pressure** of a volatile solvent over the **solution**: the product of the **mole fraction of the solvent** (X) times the **vapor pressure** of the **pure solvent** (P).

$$P_{\text{solution}} = X_{\text{solvent}} P^{\circ}_{\text{solvent}}$$

- In ideal solutions, each substance is assumed to follow Raoult's Law.
- Dalton's law of partial pressures:

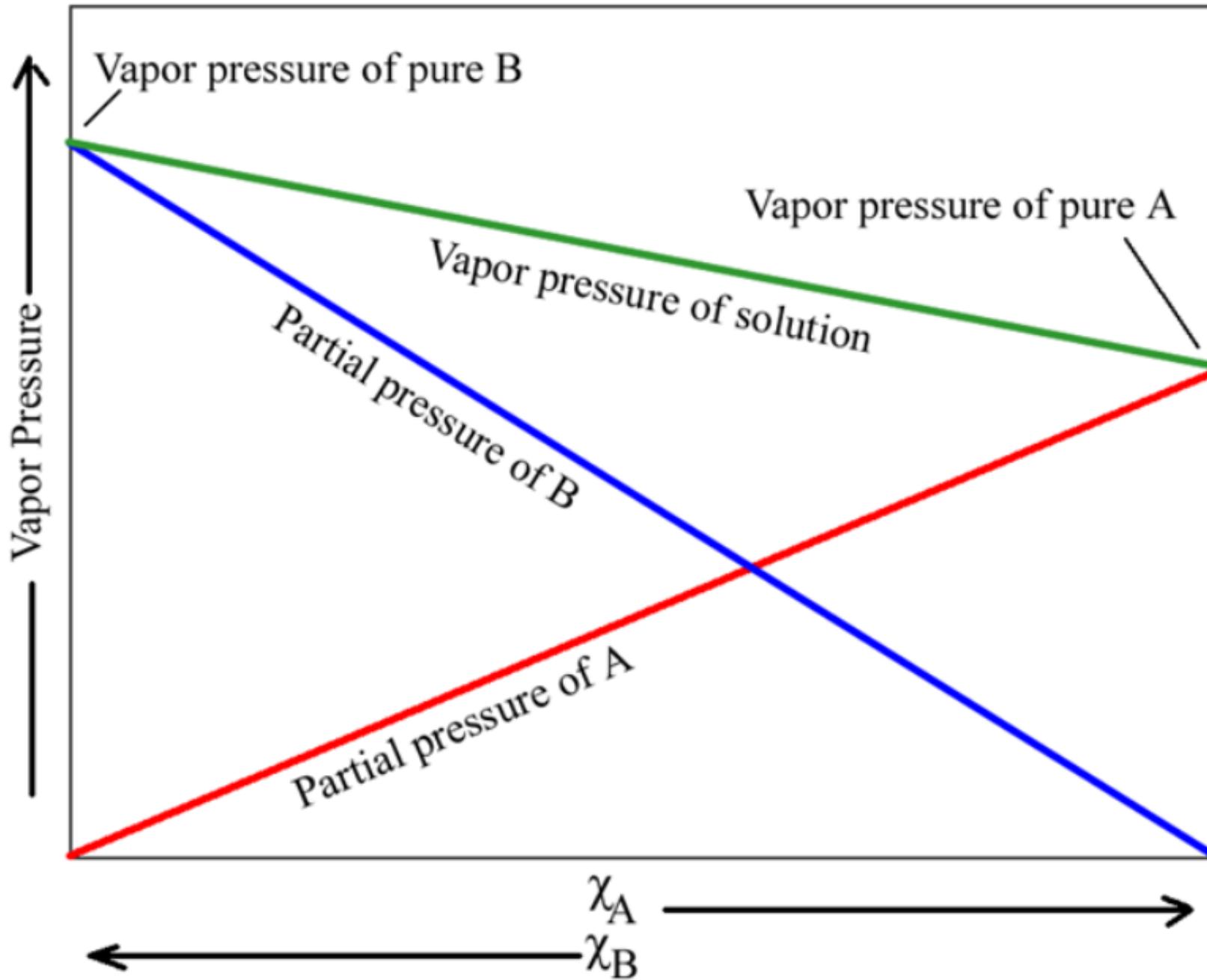
$$P_{\text{solution}} = X_A P^{\circ}_A + X_B P^{\circ}_B$$

$$\Delta P_{\text{solution}} = X_{\text{solute}} P^{\circ}_{\text{solvent}}$$

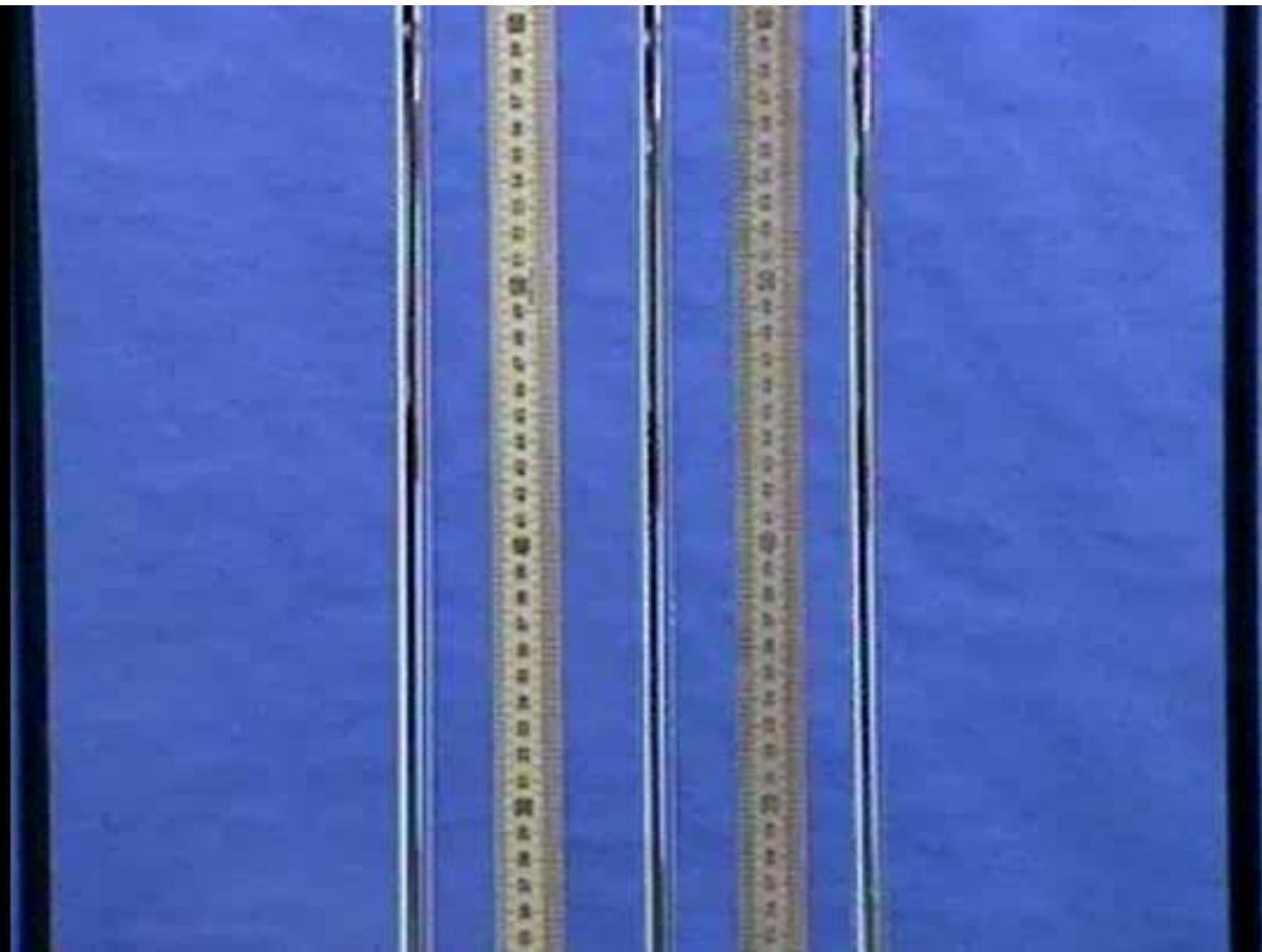
(The vapor-pressure lowering ($\Delta P_{\text{solution}}$) is determined by the mole fraction of the nonvolatile **solute**)



Ideal Solution

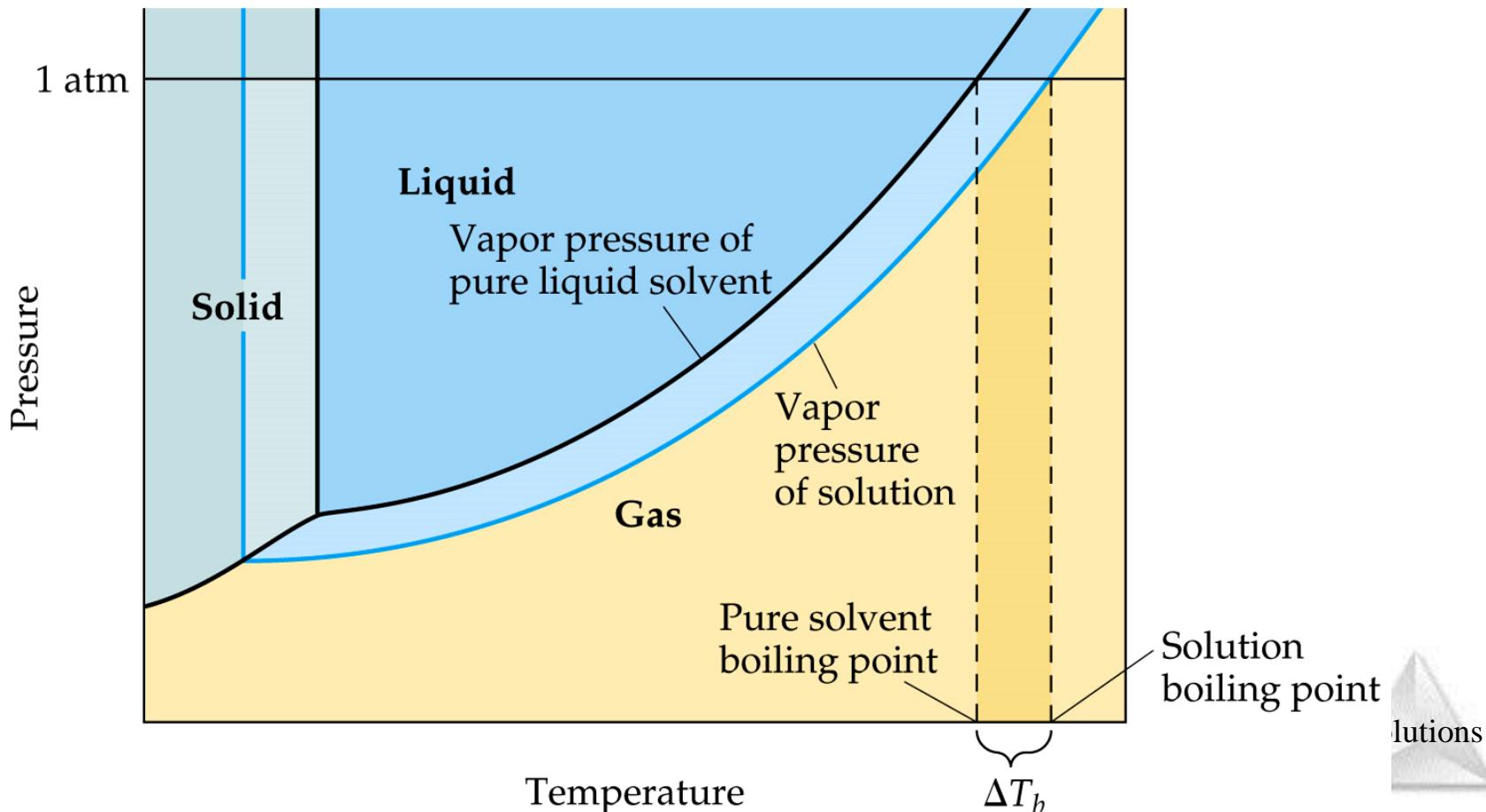


Vapor Pressure of a Mixture: Raoult's Law



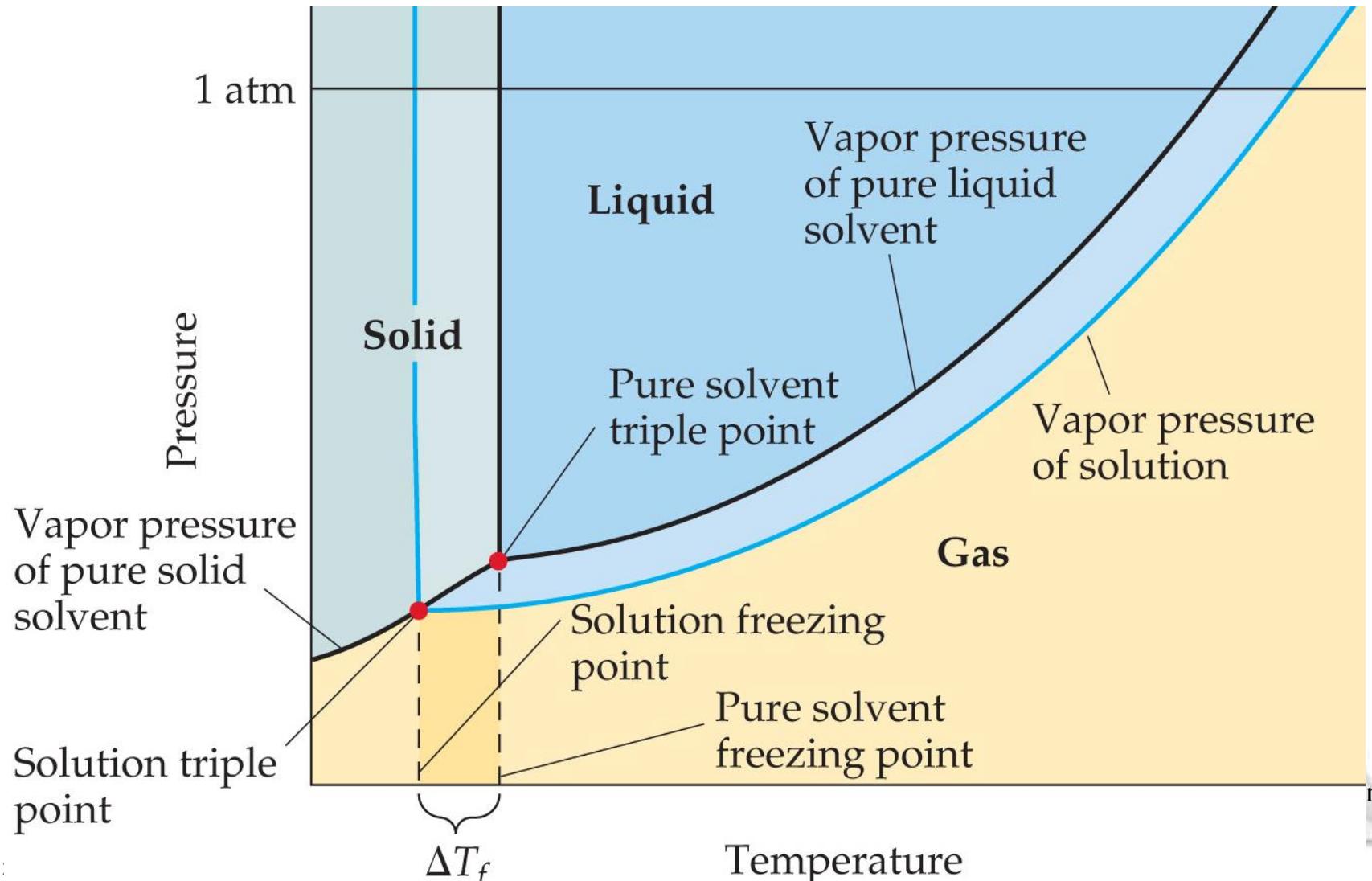
Boiling-Point Elevation

- Since **vapor pressures** are **lowered** for **solutions**, it requires a higher temperature to reach atmospheric pressure, due to **nonvolatile** solute–solvent interactions. Hence, **boiling point is raised**.



Freezing-Point Depression

- Since **vapor pressures** are **lowered** for **solutions**, the triplet and freezing points of a solution is **lowered**.



- The change in temperature is proportional to molality of the solution (not on the identity of the solute but quantity).

$$\Delta T_b = T_b(\text{solution}) - T_b(\text{solvent}) = iK_b m$$

$$\Delta T_f = T_f(\text{solution}) - T_f(\text{solvent}) = -iK_f m$$

K_b is the molal boiling-point elevation constant & K_f is the molal freezing-point-depression elevation constant.

Table 13.3 Molal Boiling-Point-Elevation and Freezing-Point-Depression Constants

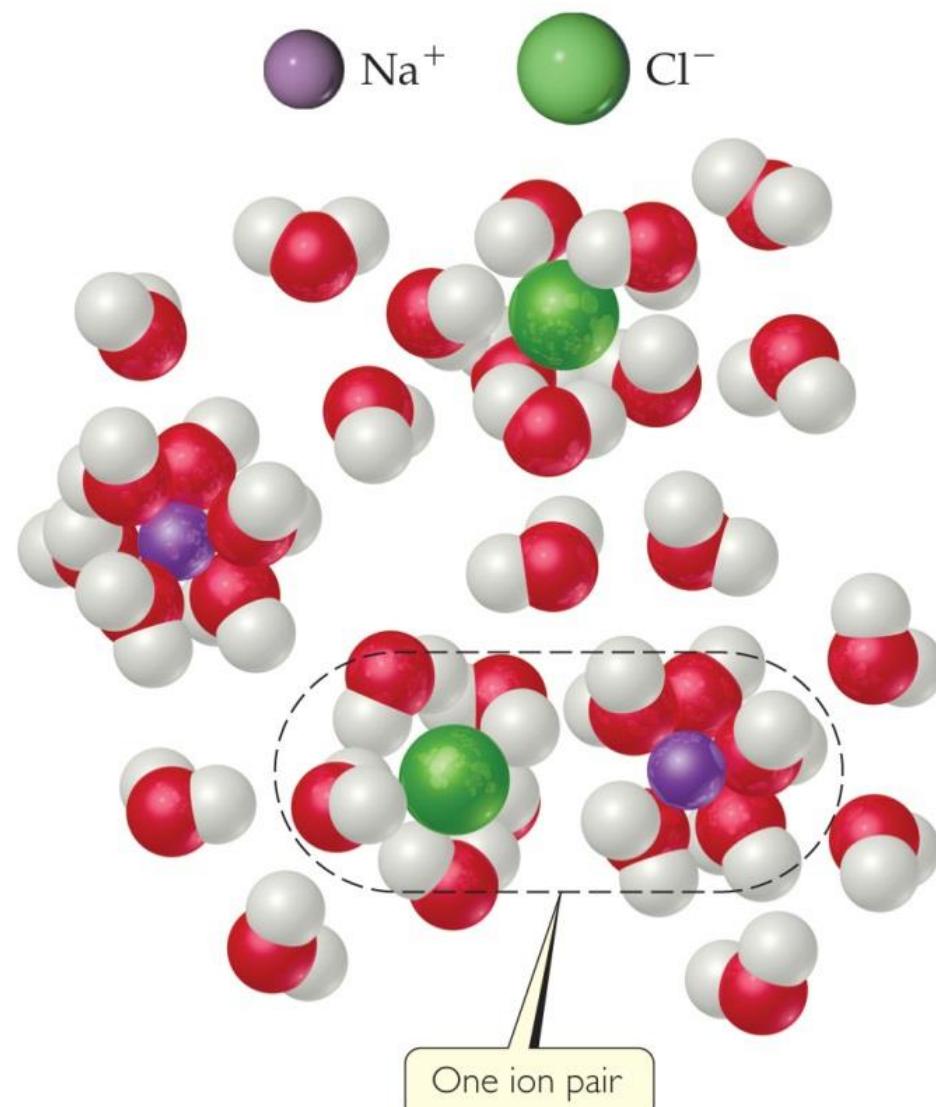
Solvent	Normal Boiling Point (°C)	K_b (°C/m)	Normal Freezing Point (°C)	K_f (°C/m)
Water, H ₂ O	100.0	0.51	0.0	1.86
Benzene, C ₆ H ₆	80.1	2.53	5.5	5.12
Ethanol, C ₂ H ₅ OH	78.4	1.22	-114.6	1.99
Carbon tetrachloride, CCl ₄	76.8	5.02	-22.3	29.8
Chloroform, CHCl ₃	61.2	3.63	-63.5	4.68

Colligative Properties of Electrolytes

- Since the **colligative properties** of electrolytes depend on the number of **particles** dissolved to form **ions**, **solutions** of electrolytes (which dissociate in solution) should show greater **changes** than those of nonelectrolytes.



- However, a **1M** solution of NaCl does **not show twice** the change in freezing point that a **1M** solution of methanol does.



- One mole of NaCl in water does **not really give two moles of ions**.
- Some Na^+ & Cl^- **reassociate** for a short time, so the **true concentration** of ions is somewhat **less than** two times the concentration of NaCl.



Solutions

The van't Hoff Factor (*i*)

- It takes into account dissociation in solution.
- Theoretically, we get 2 particles when NaCl dissociates → $i = 2$.
- In fact, the **true amount** that particles remain together is **dependent on the concentration** of the solution.

Table 13.4 Measured and Expected van't Hoff Factors for Several Substances at 25 °C

Compound	Concentration			Expected Value
	0.100 m	0.0100 m	0.00100 m	
Sucrose	1.00	1.00	1.00	1.00
NaCl	1.87	1.94	1.97	2.00
K ₂ SO ₄	2.32	2.70	2.84	3.00
MgSO ₄	1.21	1.53	1.82	2.00

Table 13.4 Measured and Expected van't Hoff Factors for Several Substances at 25 °C

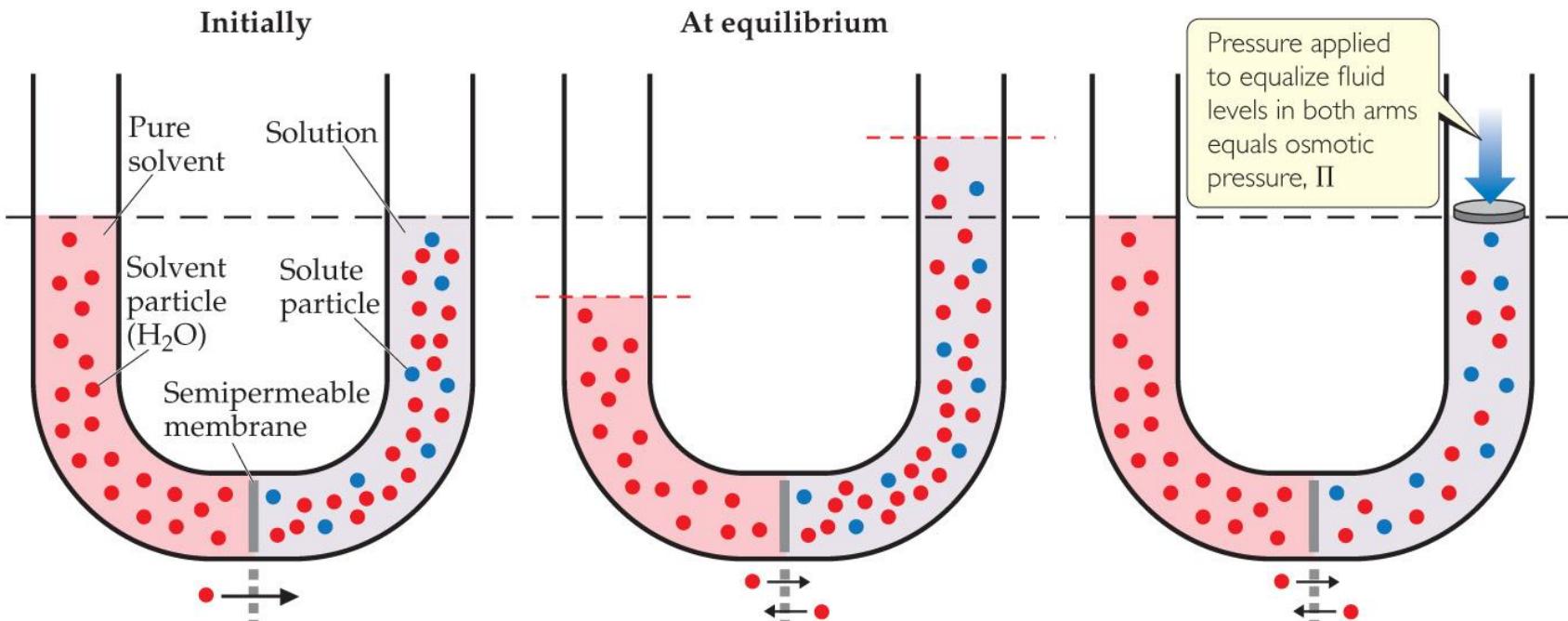
Compound	Concentration			Expected Value
	0.100 m	0.0100 m	0.00100 m	
Sucrose	1.00	1.00	1.00	1.00
NaCl	1.87	1.94	1.97	2.00
K ₂ SO ₄	2.32	2.70	2.84	3.00
MgSO ₄	1.21	1.53	1.82	2.00

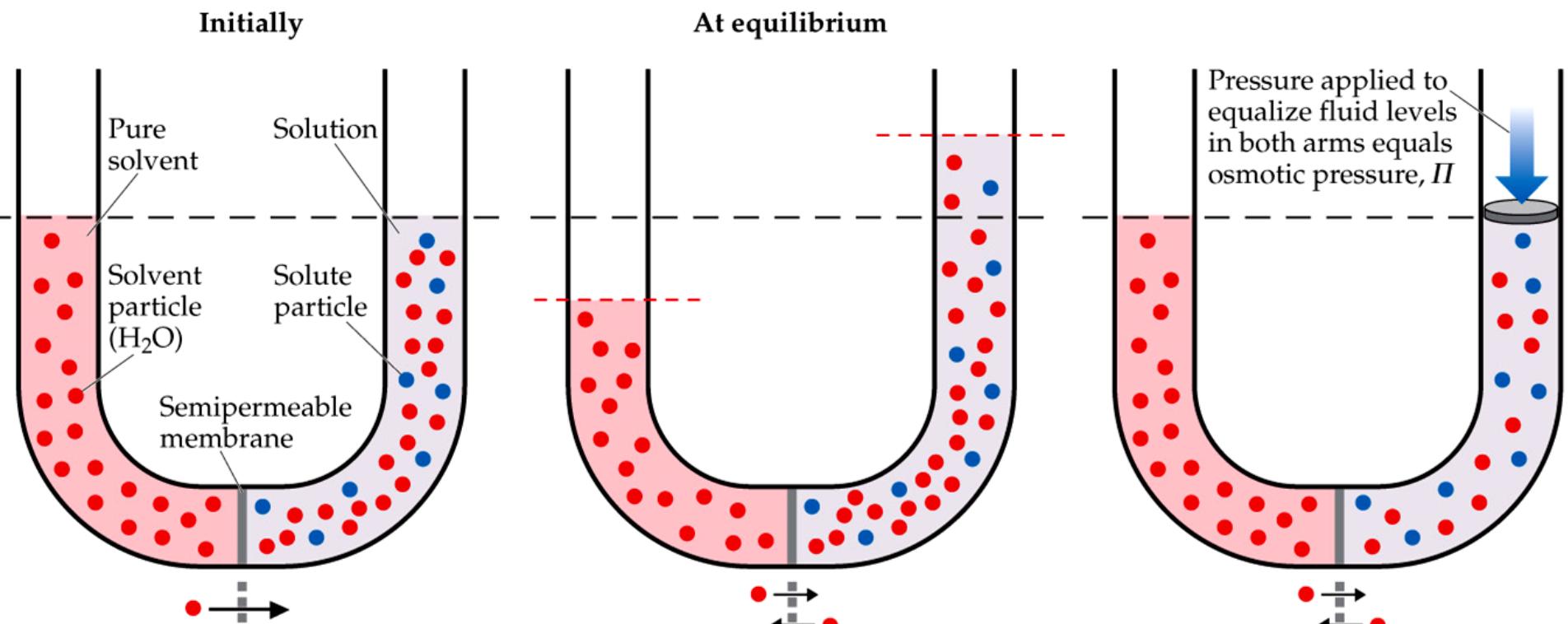
- **Reassociation** is **more likely** at **higher** concentration.
- Therefore, the number of particles present is **concentration-dependent**.
- The previous temperature-change equations (ΔT_b & ΔT_f) is also depended on the **van't Hoff factor, *i***:

$$\Delta T = K \cdot m \cdot i$$

Osmosis (渗透)

- Some substances form **semipermeable** (半渗透性) **membranes**, allowing some **smaller** particles (e.g. H_2O) to **pass through**, but **blocking** other larger particles.
- In osmosis, there is **net movement of solvent** from the area of **higher solvent concentration** (*lower solute concentration*) **to** the area of **lower solvent concentration** (*higher solute concentration*).





Net movement of H_2O is from pure water side to solution side

Flow of H_2O same in both directions.
No net movement of H_2O

Flow of H_2O same in both directions.
No net movement of H_2O

- In biological systems, most semipermeable membranes allow water to pass through, but not for solutes.
- The applied pressure to stop it is **osmotic pressure**.

Osmosis



Osmotic Pressure

- Osmotic pressure is a **colligative property**.

$$\Pi = i \left(\frac{n}{V} \right) RT = iMRT$$

where **M is the molarity of the solution** and R is ideal-gas constant.

- If two solutions separated by a semipermeable membrane have the *same* osmotic pressure (i.e., the concentrations are the same), no osmosis will occur. These two solutions are **isotonic** (等滲溶液).

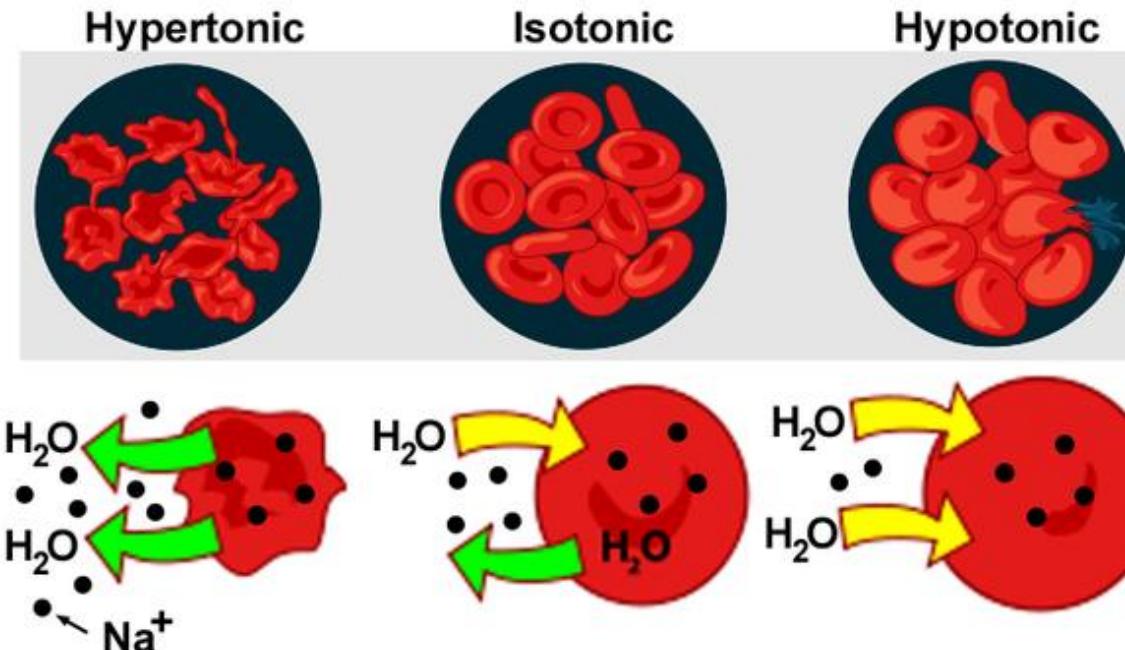


Types of Solutions & Osmosis

Isotonic solutions: **Same** osmotic pressure; solvent passes the membrane at the same rate both ways.

Hypotonic solution: **Lower** osmotic pressure; solvent leaves this solution at a higher rate than it enters with.

Hypertonic solution: **Higher** osmotic pressure; solvent enters this solution at a higher rate than it leaves

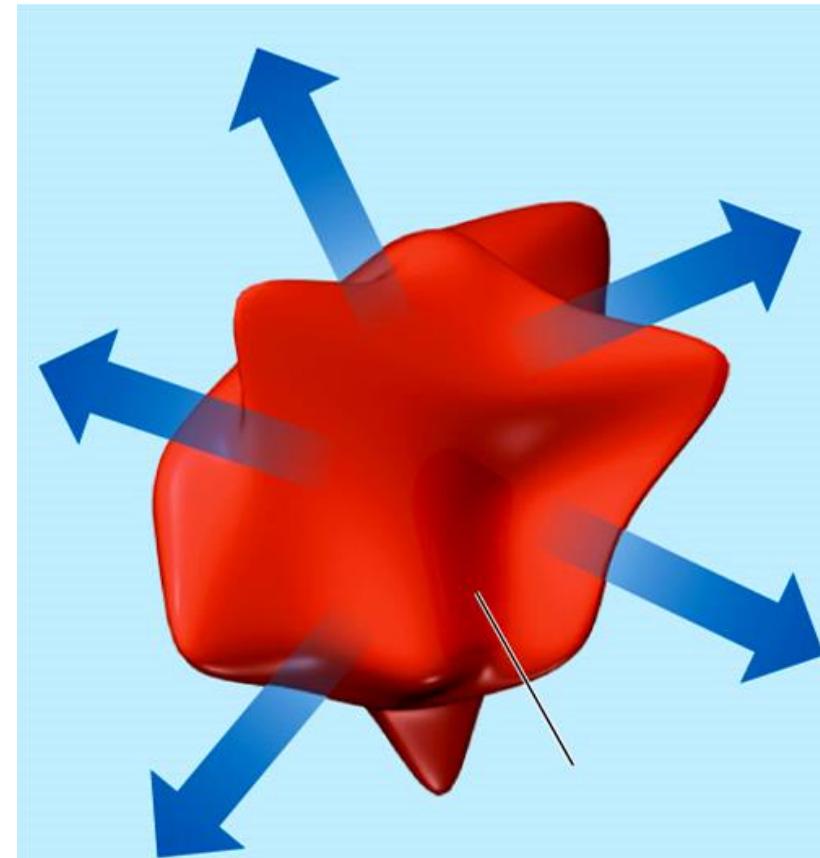


Osmosis in Blood Cells

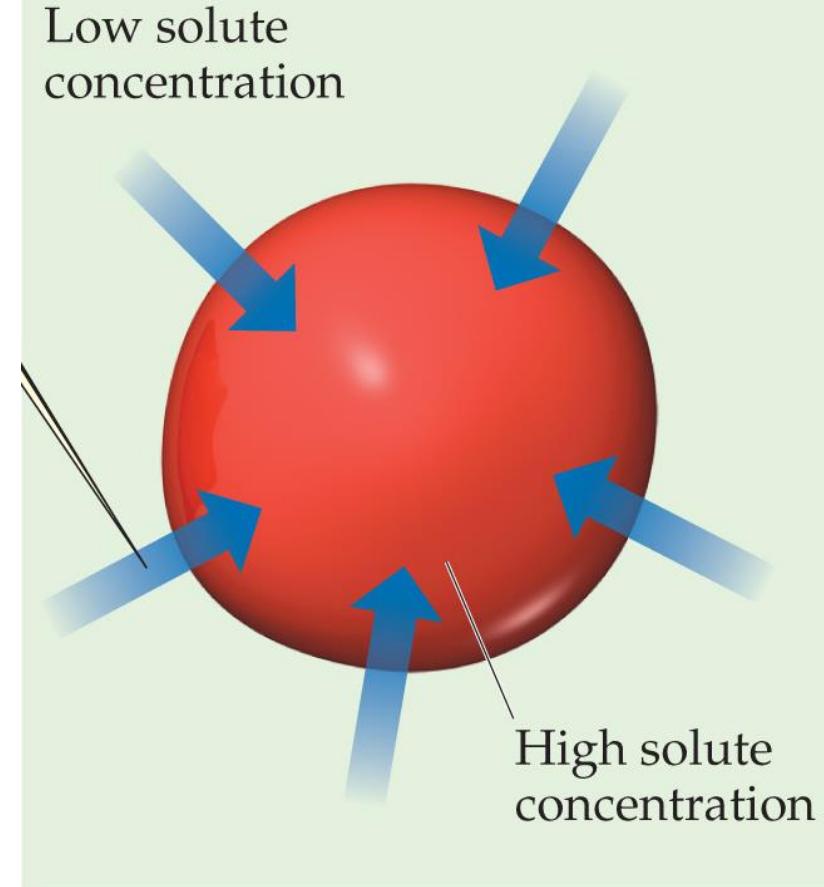
- If the **solute concentration outside** the cell is **greater** than that **inside** the cell, the solution is **hypertonic** (高滲的).
- Water will flow out of the cell, and crenation (皱缩) results.

The average osmotic pressure of blood is 7.7 atm at 25 °C.

The blue arrows represent the net movement of water molecules.



- If the solute concentration outside the cell is less than that inside the cell, the solution is hypotonic (低滲的).
- Water will flow into the cell, and hemolysis (溶血) results.

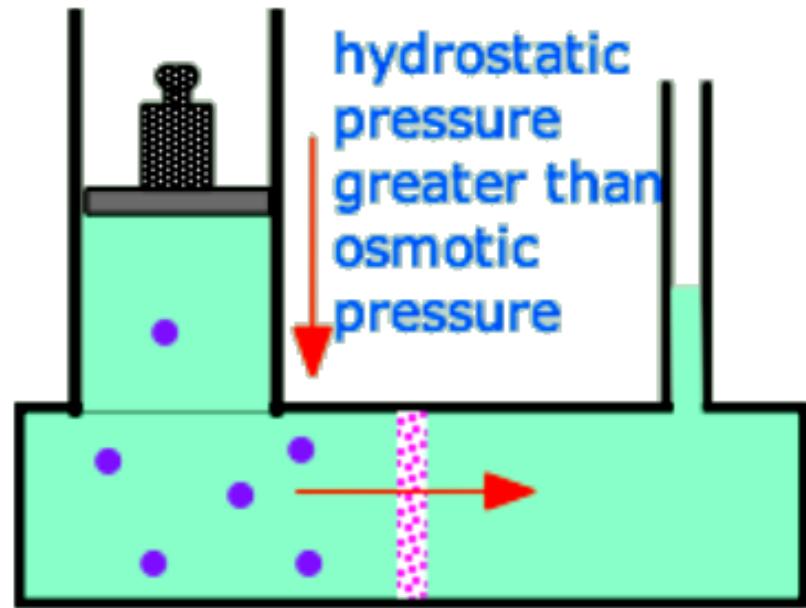


Hemolysis of red blood cell placed in hypotonic environment

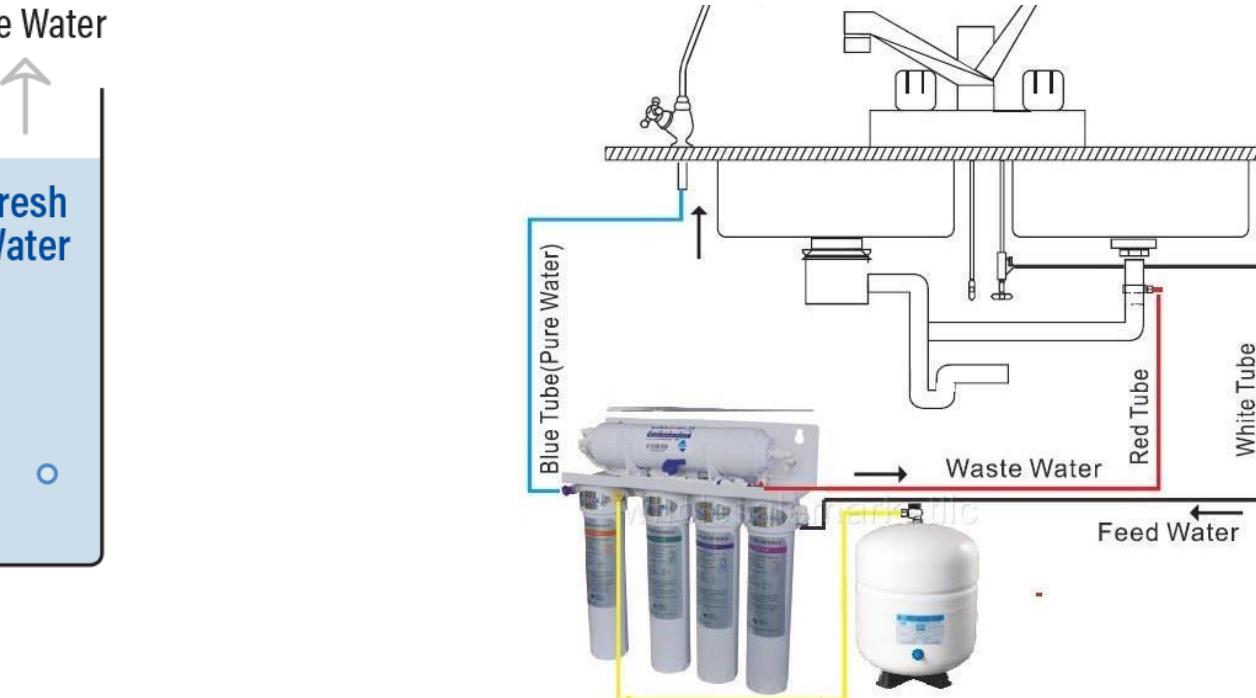
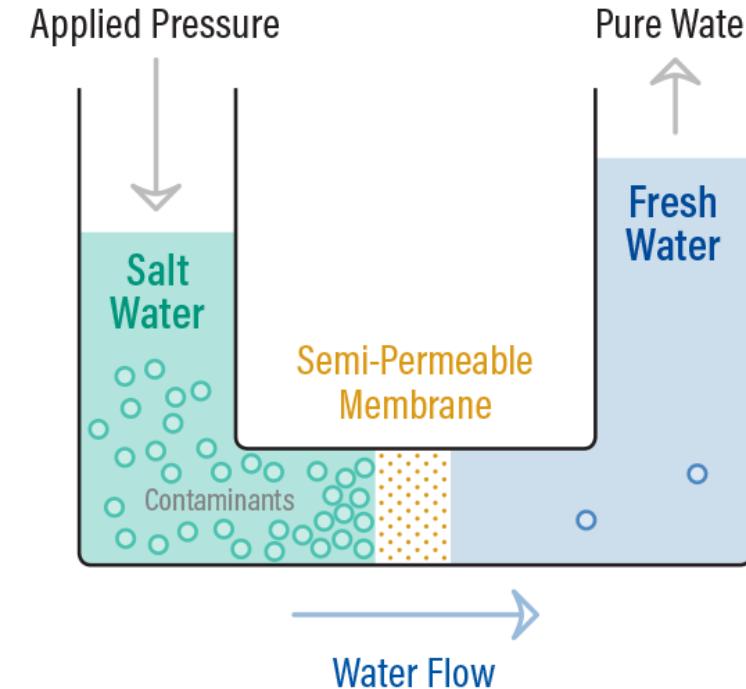
The blue arrows represent the net movement of water molecules.



Reverse Osmosis (反滲)



- Applying a hydrostatic (静水) pressure greater than this to the high-solute side of an osmotic cell will **force water** to flow back into the fresh-water side. This process is now the major technology employed to **desalinate ocean water** and to **reclaim "used" water** from power plants, runoff, and even from sewage.



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Solutions

Colloids (胶体)

- **Suspensions** (悬浮) of particles larger than individual ions or molecules, but too small to be settled out by gravity, are called **colloids**.

Phase of Colloid	Dispersing (solvent-like) Substance	Dispersed (solute-like) Substance	Colloid Type	Example
Gas	Gas	Gas	—	None (all are solutions)
Gas	Gas	Liquid	Aerosol	Fog
Gas	Gas	Solid	气溶胶	Aerosol
Liquid	Liquid	Gas	泡沫	Foam
Liquid	Liquid	Liquid	乳状液	Emulsion
Liquid	Liquid	Solid	Sol	Paint
Solid	Solid	Gas	Solid foam	Marshmallow
Solid	Solid	Liquid	Solid emulsion	Butter
Solid	Solid	Solid	Solid sol	Ruby glass

Solutions

	GAS	LIQUID	SOLID
GAS	NONE All gases are mutually miscible, so they do not form any sort of colloid.	LIQUID AEROSOLS Fog, hair sprays, clouds	SOLID AEROSOLS Smoke, air particulates
LIQUID	LIQUID FOAM Whipped cream, shaving cream	EMULSION Milk, mayonnaise, hand lotion	SOL Pigmented ink, blood, paint
SOLID	SOLID FOAM Styrofoam, pumice	GEL Gelatin, jelly	SOLID SOL Cranberry glass

Source: Wikipedia

Tyndall Effect (丁达尔效应)



solution

Colloidal dispersion

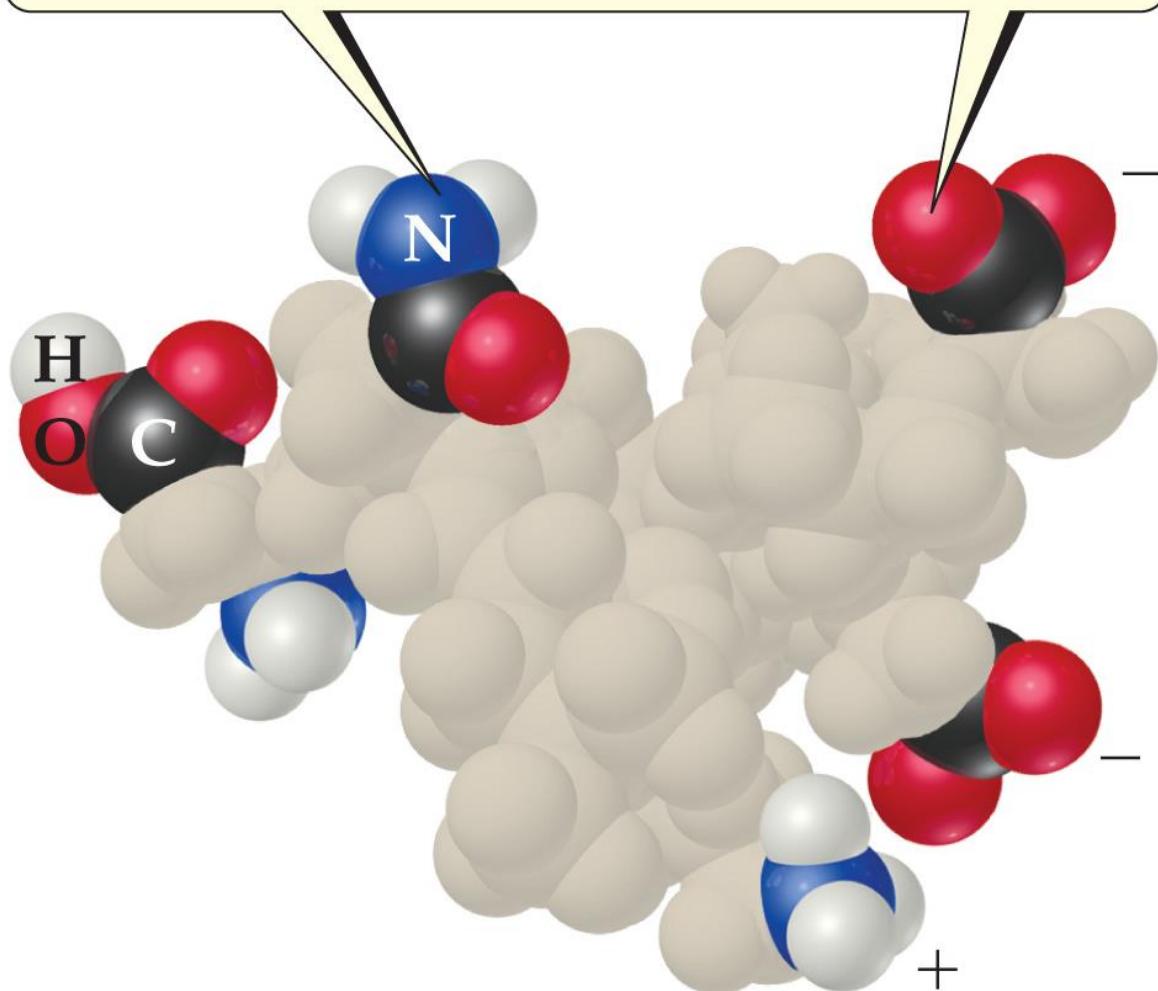
- Colloidal suspensions can **scatter rays of light**.
- This phenomenon is known as the **Tyndall effect**.

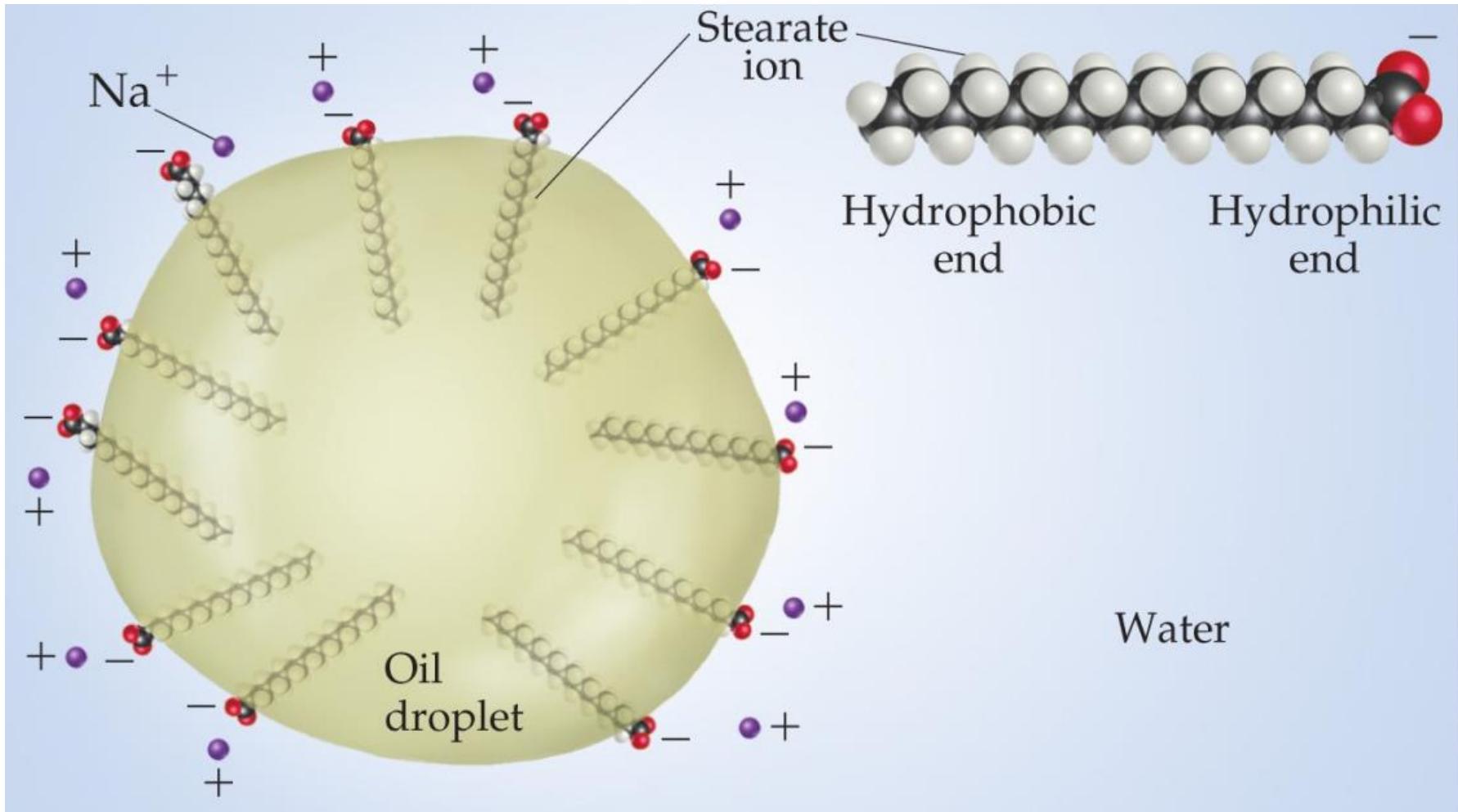


Colloids in Biological Systems

- Some molecules have a polar, **hydrophilic** (*water-loving*) end and a nonpolar, **hydrophobic** (*water-fearing*) end.
- Hydrophobic groups are **away from water**, on the “inside” of molecules.

Hydrophilic polar and charged groups on molecule surface help molecule remain dispersed in water and other polar solvents





- These molecules can help in the emulsification (乳化) of fats and oils in aqueous solutions.
- An emulsifier causes something that normally does *not* dissolve in a solvent to do so.

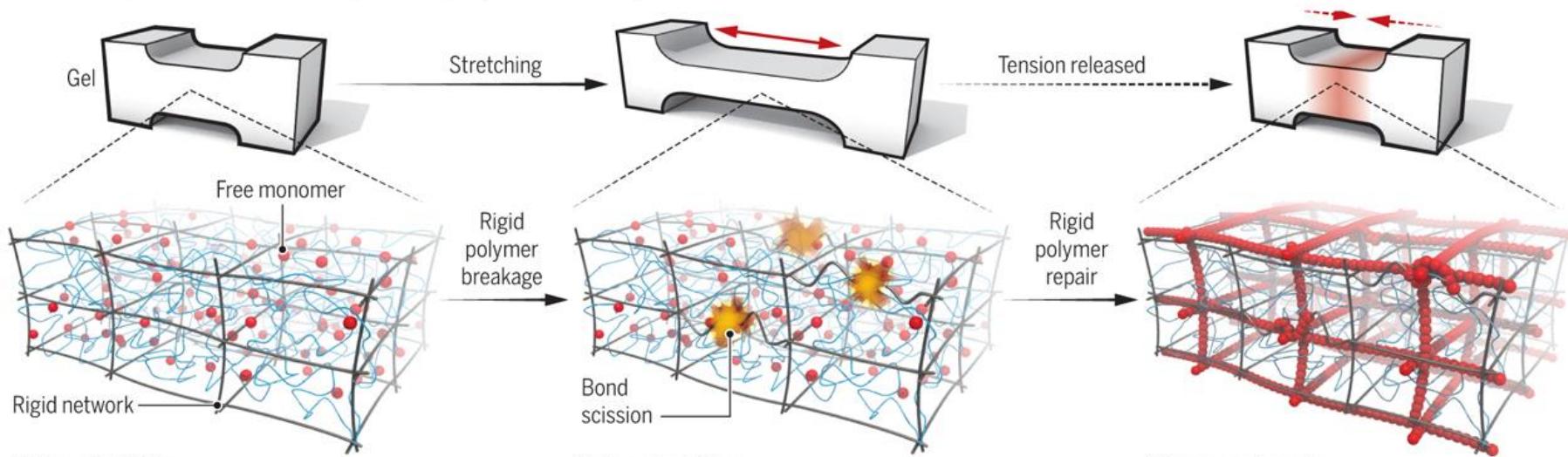


(extra info.) Hydrogel (水凝胶)

Science 363, 504–508 (2019)

Intertwined gels execute a fix

Matsuda *et al.* use double-network hydrogels to enable fixing of damage from mechanical stress. A rigid polymer (gray) executes repair while a more flexible polymer (blue) maintains shape.



Before stretching

Unreacted monomers (red) for the rigid polymer are part of the hydrogel. The water forming much of the gel is not shown.

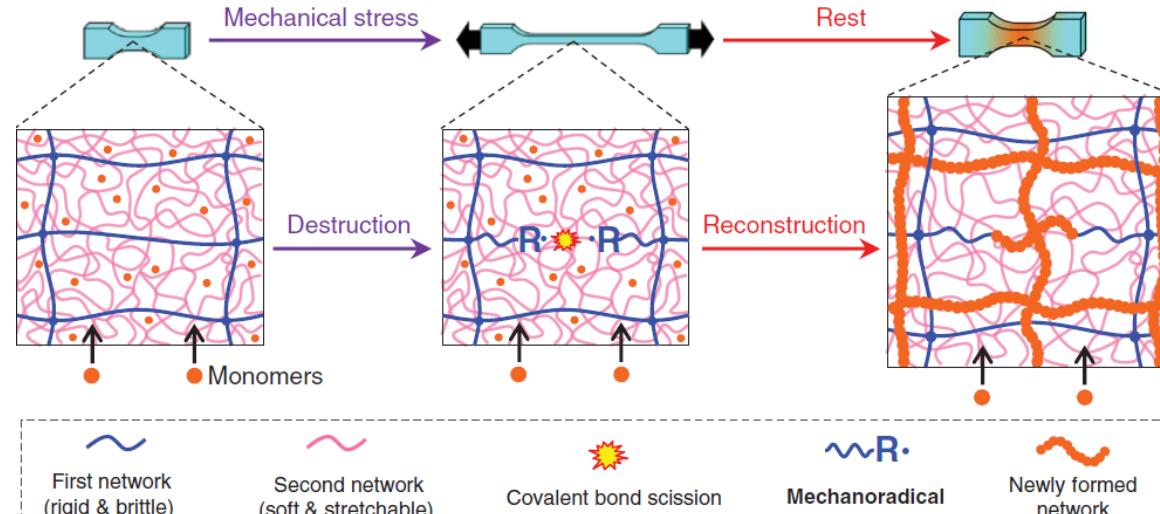
During stretching

The rigid polymer breaks during stretching and creates reactive radicals that can initiate polymerization reactions.

Release and repair

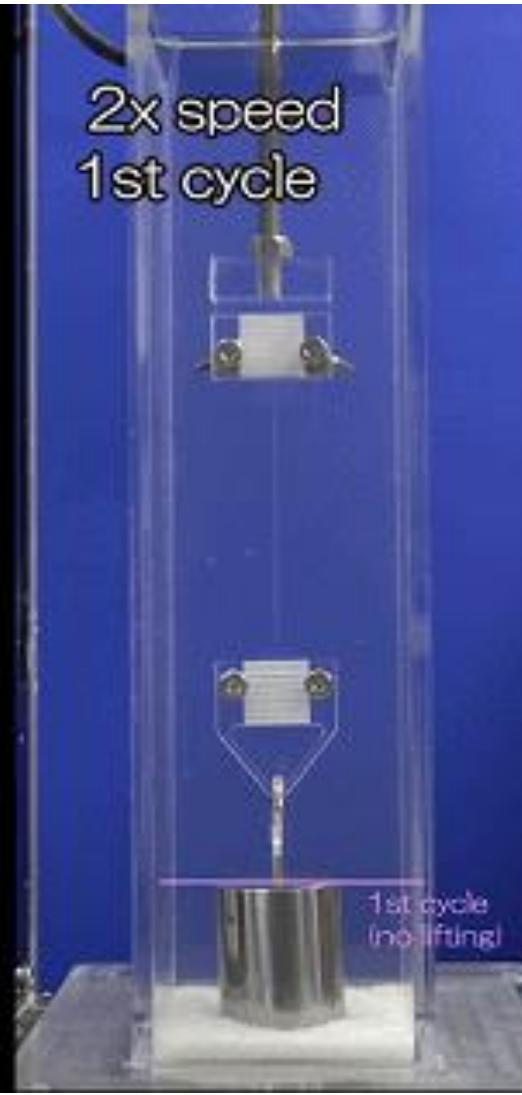
When tension is released, the flexible polymer recovers the original shape. The monomers react and create a new rigid polymer.

C Mechanical training of a double-network gel



Solutions

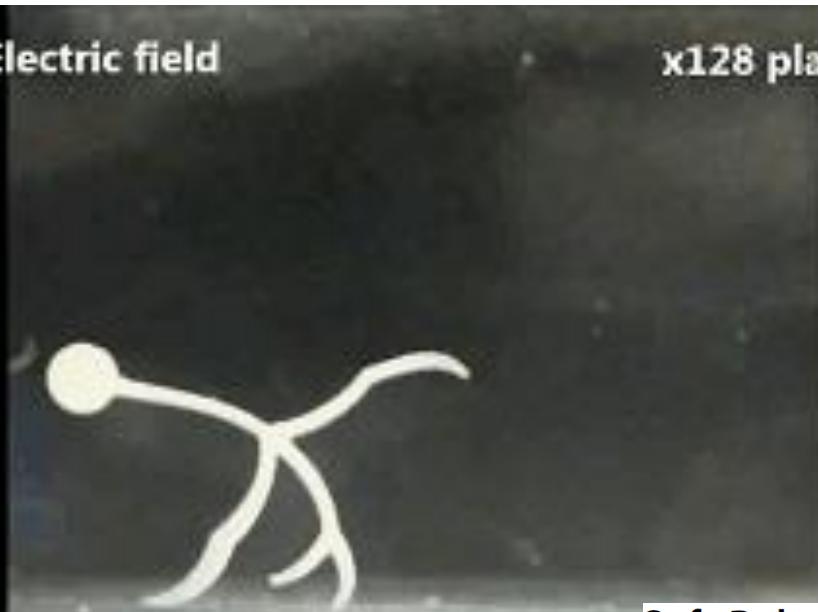
(extra info.) Hydrogel (水凝胶)



Solutions

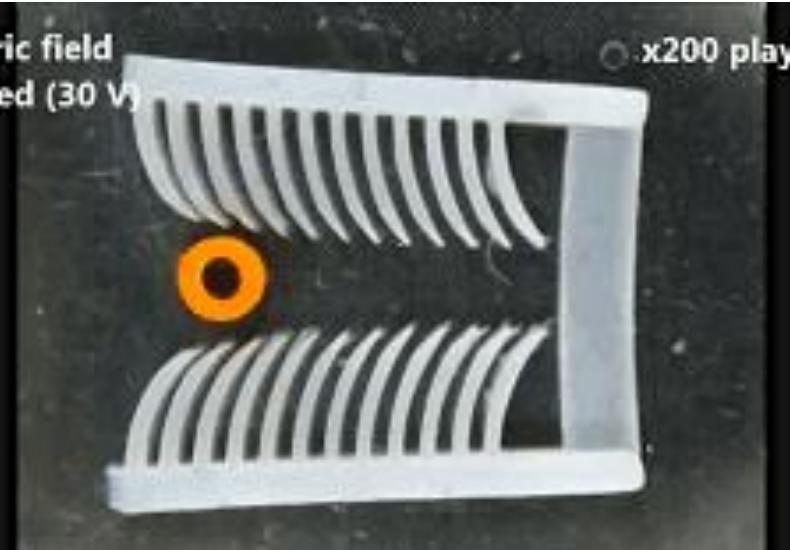
(extra info.) Hydrogel (水凝胶)

w/o Electric field



x128 playback

Electric field
applied (30 V)



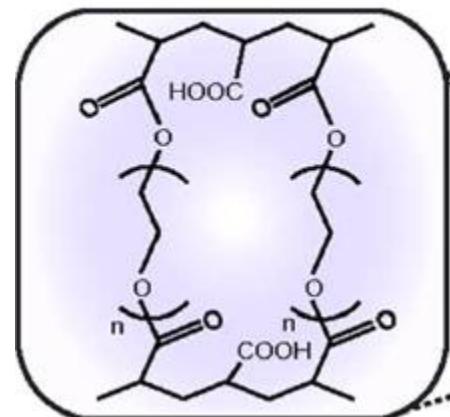
x200 play

Soft Robotic Manipulation and Locomotion with a 3D Printed Electroactive Hydrogel

x6 playback

ACS Appl. Mater. Interfaces 2018, 10, 17512

electroactive hydrogel



Solutions

_____ Law says that the vapor pressure of a solution is proportional to the mole fraction of the solvent.

- a. Boyle's
- b. Charles's
- c. Henry's
- d. Raoult's

What is the freezing point of a 2.00 m aqueous solution of sucrose? The value of K_f for water is 1.86 degrees C/molal.

- a. -3.72 degrees C
- b. -1.86 degrees C
- c. +1.86 degrees C
- d. +3.72 degrees C



Solutions

What is the vapor pressure of a solution containing 0.500 mol of glucose and 5.000 mol of water at 29.0 deg.? Vapor pressure of pure water is 30.0 Torr.

- a. 30.0 Torr
- b. 27.3 Torr
- c. 25.0 Torr
- d. 2.7 Torr

$$P_{\text{solution}} = X_{\text{solvent}} P_{\text{solvent}}^{\circ}$$

Two solutions that are isotonic have the same

- a. density.
- b. volume.
- c. vapor pressure.
- d. osmotic pressure.



At 298 K, 25.00 mL of solution containing 27.55 mg of protein has an osmotic pressure of 3.22 Torr. The molecular weight of the protein is

- a. 2,340,000.
- b. 159,000.
- c. 6360.
- d. 254.

$$\text{Molarity} = \frac{\Pi}{iRT} = \frac{(\quad \text{torr}) \left(\frac{1 \text{ atm}}{760 \text{ torr}} \right)}{(1) \left(0.0821 \frac{\text{L-atm}}{\text{mol-K}} \right) (298 \text{ K})}$$

The average osmotic pressure of blood is 7.7 atm at 25 deg.. What molarity of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) will be isotonic with blood?

$$\Pi = iMRT$$

$$M = \frac{\Pi}{iRT} = \frac{(7.7 \text{ atm})}{(1) \left(0.0821 \frac{\text{L-atm}}{\text{mol-K}} \right) (298 \text{ K})} = 0.31 M$$



Which substance below is NOT a colloid?

- a. Butter
- b. Smoke
- c. Whipped cream
- d. Salt water

Light scattering by colloidally dispersed particles is an example of the _____ effect.

- a. Tyndall
- b. Raoult
- c. Hall
- d. Meissner



Summary of Chapter 13

Dissolution: Entropy/Randomness, Intermolecular Interactions

Saturated/Supersaturated/Unsaturated Solution ;
Crystallization, Solubility, Miscible/Immiscible, Henry's Law

Mass Percentage (ppm & ppb), Mole Fraction, Molarity,
Molality

Colligative Properties: Raoult's Law, Van't Hoff Factor,
Osmosis (Osmotic Pressure)

**Thank You for Your
Attention!
Any Questions?**

