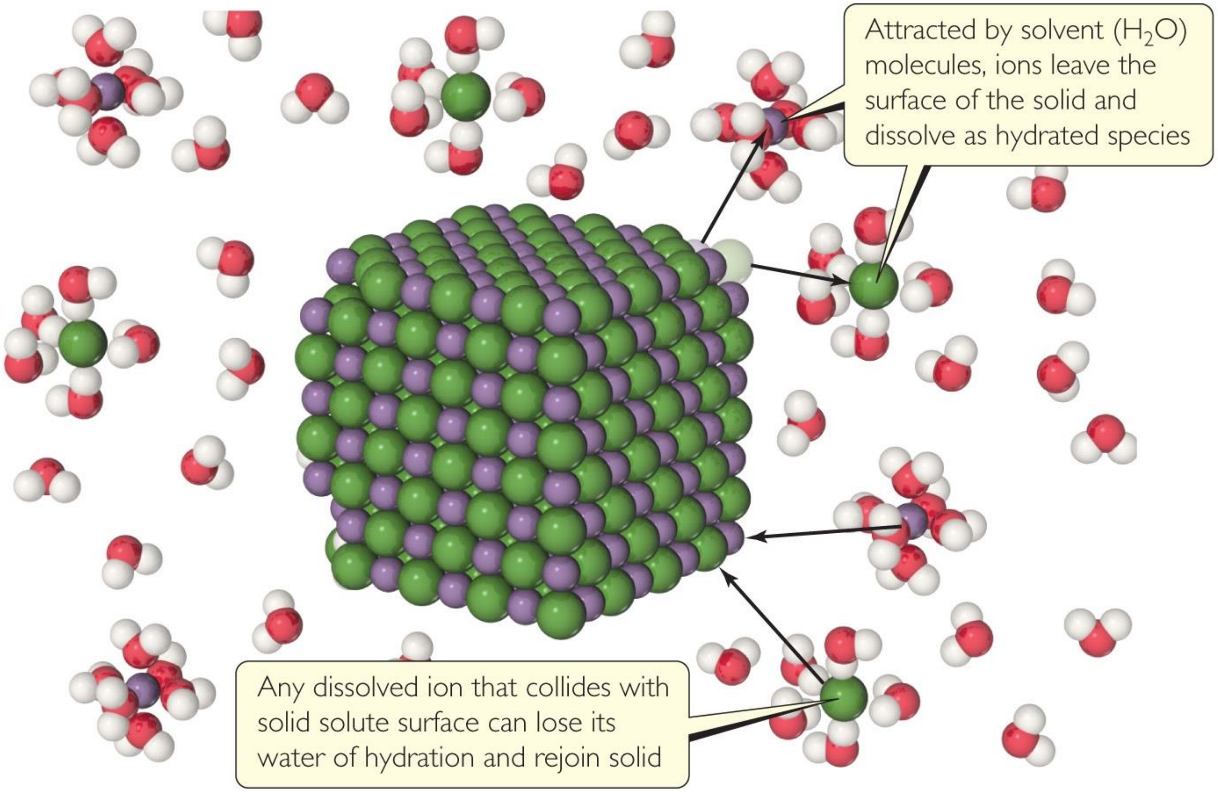
Chapter 13

Properties of Solutions

Solutions



- **Solutions (溶液)** are homogeneous mixtures of two or more pure substances.
- In a solution, the **solute (**溶质**)** is dispersed (**分散**) uniformly throughout the **solvent (**溶剂**)**.
- **Solutions, however, can also be solids or gases.**

The solution process

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

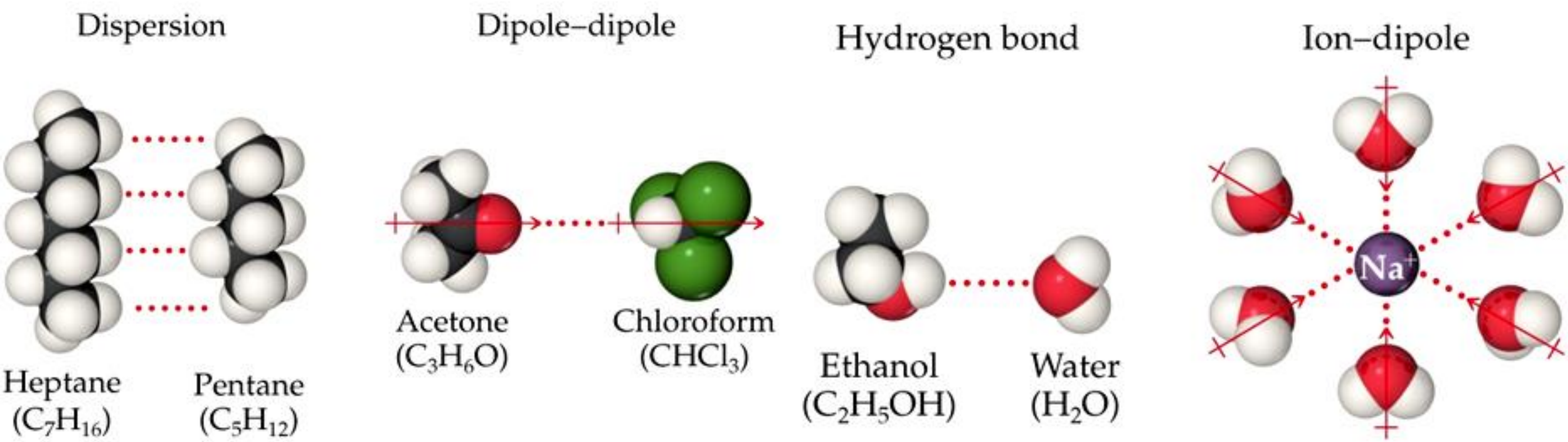
(1) the natural tendency of substances to mix and spread into larger volumes when not restrained**(抑制)** in some way

Entropy (熵) increase: (the *formation of solutions is favored by the increase in entropy that accompanies mixing*.)

熵：体系混乱程度的度量

(2) the types of intermolecular interactions involved in the solution process.

Intermolecular Interactions in Solutions



对于非极性物质，色散力占主导

对于离子物质，离子-偶极作用占主导

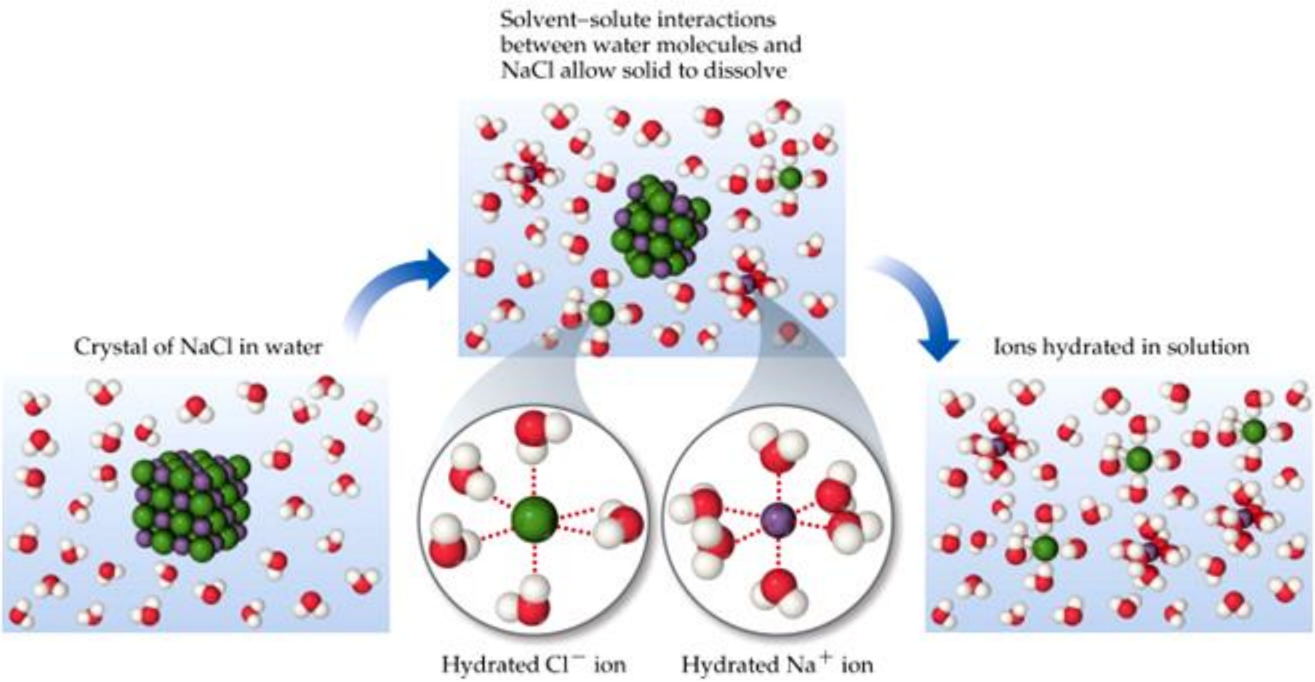
- Dispersion forces dominate when one nonpolar substance, such as C_7H_{16}, dissolves in C_5H_{12},
- Ion–dipole forces dominate in solutions of ionic substances in water.

How Does a Solution Form?

Three kinds of intermolecular interactions are involved in solution formation:

- **Solute–solute** interactions between solute particles must be overcome in order to disperse the solute particles through the solvent.
- **Solvent–solvent** interactions between solvent particles must be overcome to make room for the solute particles in the solvent.
- **Solvent–solute** interactions between solvent and solute particles occur as the particles mix.

Solutions

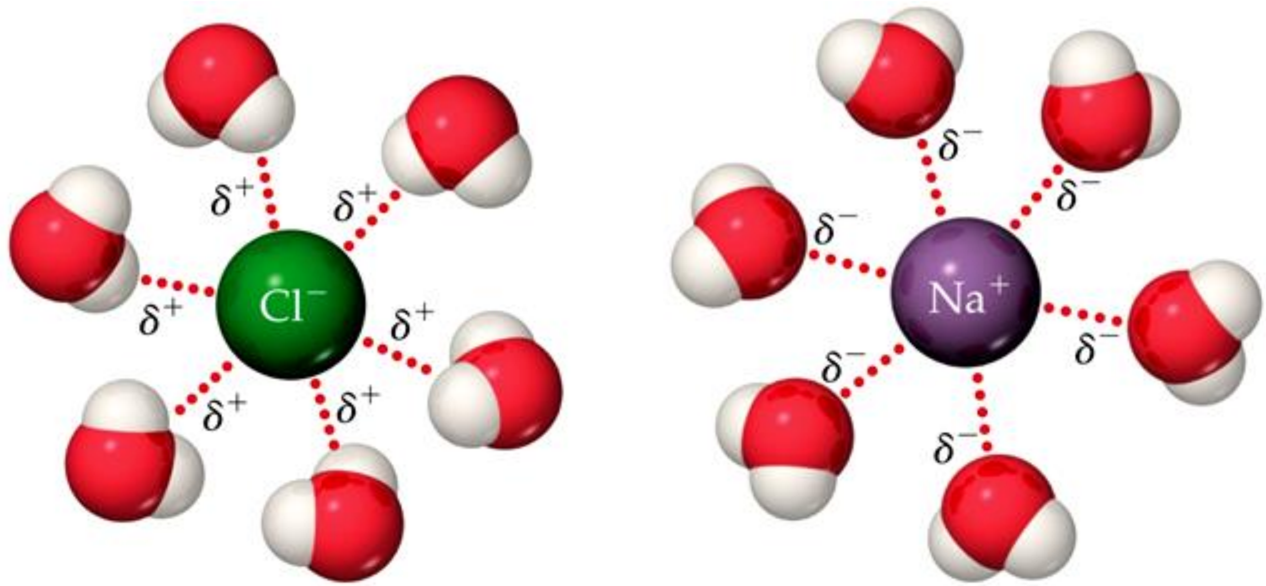


The intermolecular forces between solute and solvent particles must be strong enough to compete (竞争) with those between solute particles and those between solvent particles.

As a solution forms, the solvent pulls solute particles apart and surrounds-----called **solvation (溶剂化)**.

If the solvent is water, the interactions are referred to as **hydration**.

How Does a Solution Form?



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.

Lattice energy 晶格能又叫点阵能。它是在反应时1mol离子化合物中的阴、阳离子从相互分离的气态结合成离子晶体时所放出的能量。

Energy Changes in Solution

1. $(\text{solute})_n \longrightarrow$ n solute ΔH_{solute}

2. $(\text{solvent})_n \longrightarrow$ n solvent $\Delta H_{solvent}$

3. n solute + n solution $\longrightarrow$ solution ΔH_{mix}

---

4. $(\text{solute})_n + (\text{solvent})_n \longrightarrow$ solution ΔH_{soln}

$$\Delta H_{soln} = \underbrace{\Delta H_{solute}}_{>0} + \underbrace{\Delta H_{solvent}}_{>0} + \underbrace{\Delta H_{mix}}_{<0}$$

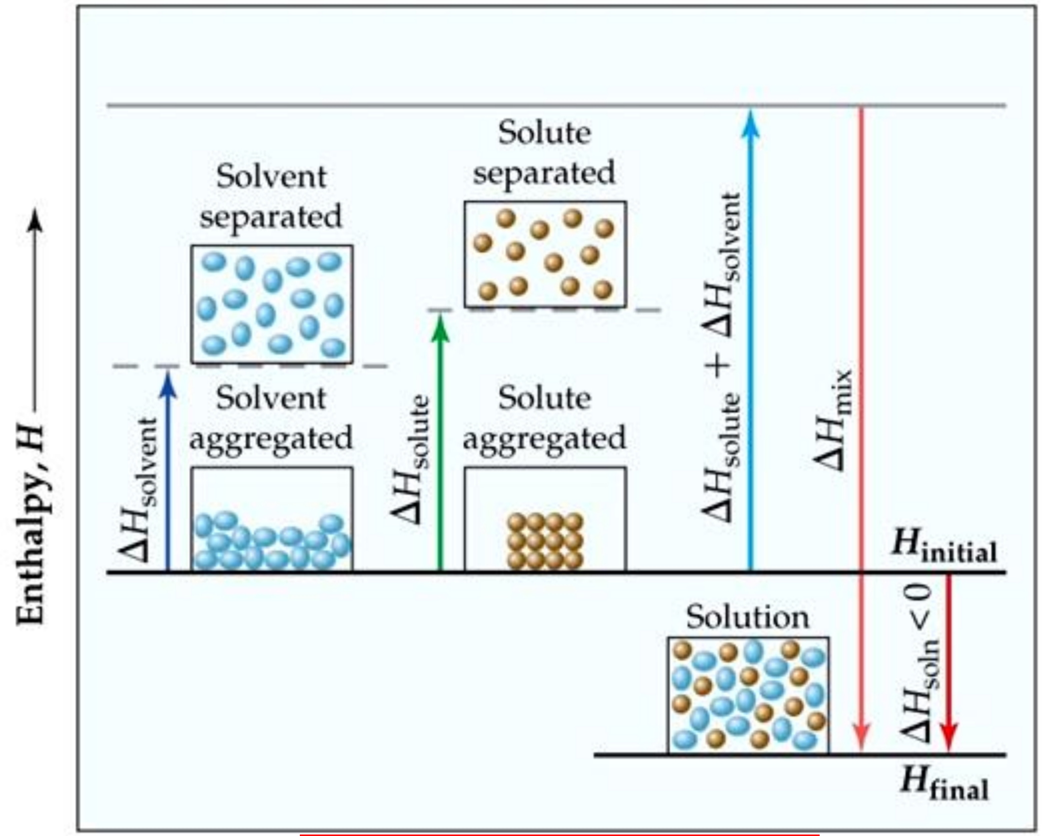
Energy Changes in Solution

The enthalpy change of the overall process depends on ΔH for each of these steps.

ΔH_{solv} <0

Exothermic solution process

放热过程



Exothermic solution process

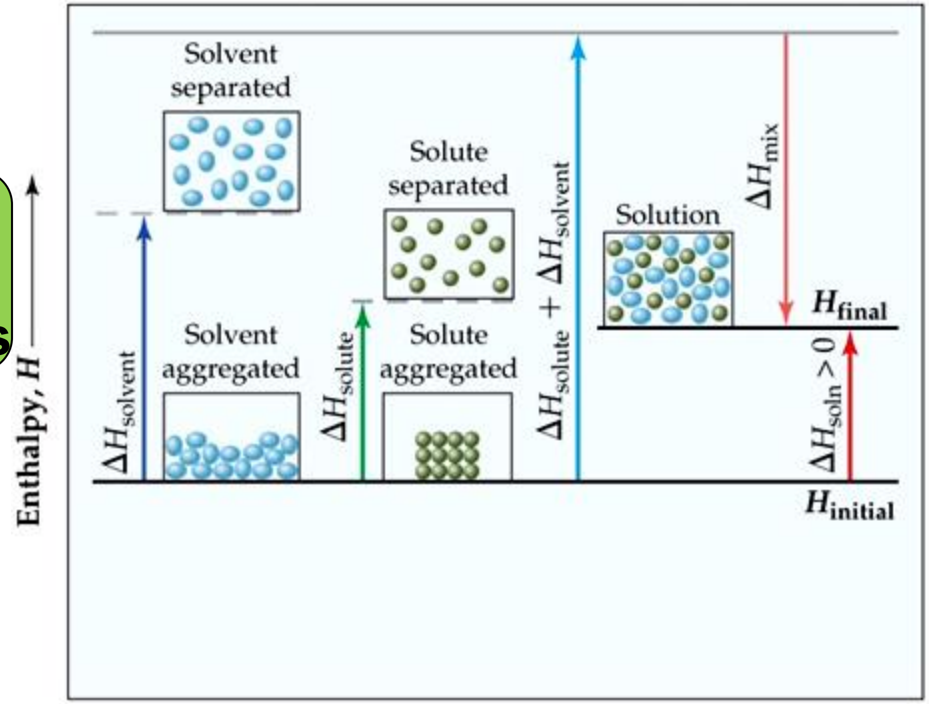
Magnesium Sulfate ($MgSO_4$)

Why Do Endothermic Processes Occur?

$\Delta H_{solv} > 0$

Endothermic solution process

吸热过程



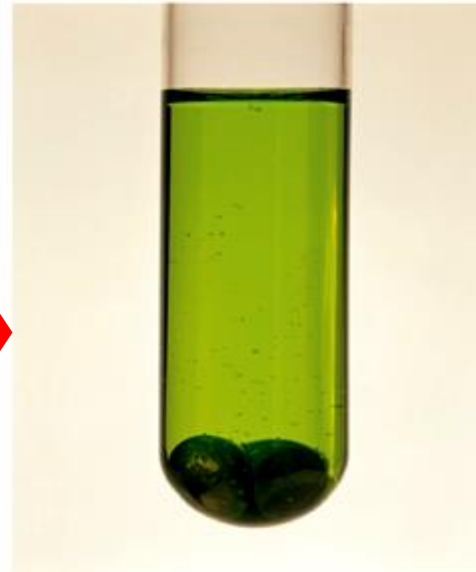
Endothermic solution process

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

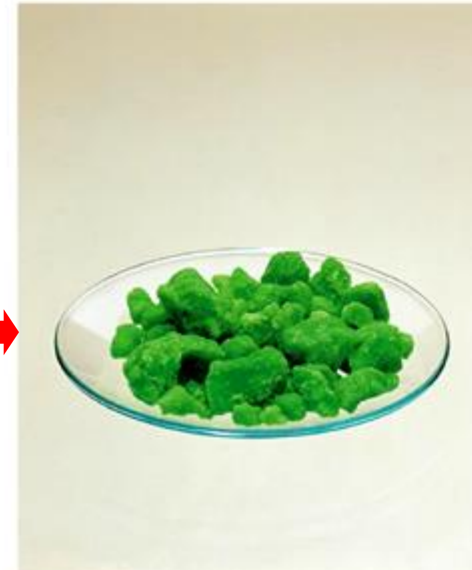
Ammonium nitrate instant ice pack

Reaction to form Solution

Nickel metal and hydrochloric acid



Nickel reacts with hydrochloric acid, forming $NiCl_2(aq)$ and $H_2(g)$. The solution is of $NiCl_2$, not Ni metal

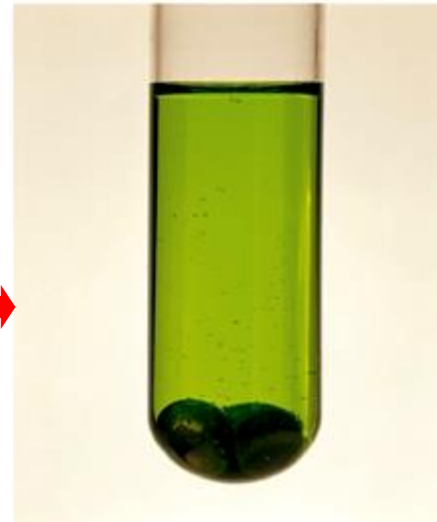


$NiCl_2{\cdot}6H_2O(s)$ remains when solvent evaporated

Just because a substance disappears when it comes in contact with a solvent, it doesn't mean the substance dissolved. It may have reacted (Chemical reaction).

Dissolution Check

Nickel metal and hydrochloric acid



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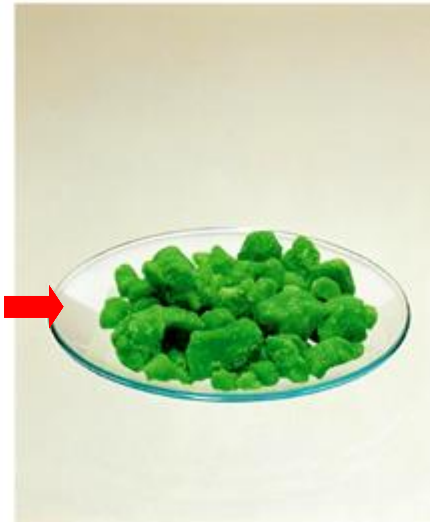


$NiCl_2 \cdot 6H_2O(s)$ remains when solvent evaporated

- 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, it reacted.

(把硫酸铜放入水中是溶解过程吗?)

当硫酸铜（$CuSO_4$）加入水中时，发生以下过程：

1. 电离作用：
- 硫酸铜是离子化合物，在水中会解离成带电离子：
- 铜离子（Cu^{2+}）使溶液呈现蓝色，这是判断溶解的重要视觉标志。

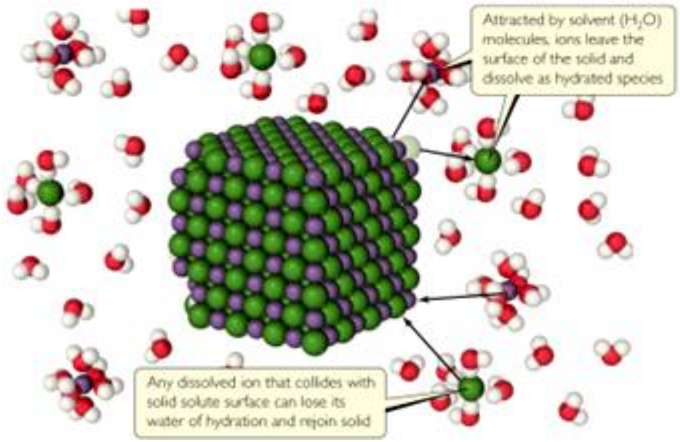
2. 水合作用：
- 水分子是极性分子，会包围 Cu^{2+} 和 $SO_4{}^{2-}$ 离子，形成“水合离子”，防止它们重新结合。
- 例如：$[Cu(H_2O)_6]^{2+}$ 是蓝色的水合铜离子。

3. 是否生成新物质?
- 没有发生化学反应生成全新的化合物。
- 只是物理分散 + 电离，属于物理化学过程，但仍归类为溶解。

结论：这是一个典型的溶解过程，伴随着电离，但不改变物质的化学本质。

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 and reattach,



i.e. opposite of dissolution process, called crystallization

Dissolved solute is in dynamic equilibrium with solid solute particles

$$\boxed{\text{Solute} + \text{solvent} \underset{\text{crystallize}}{\overset{\text{dissolve}}{\rightleftharpoons}} \text{solution}}$$

Types of Solutions

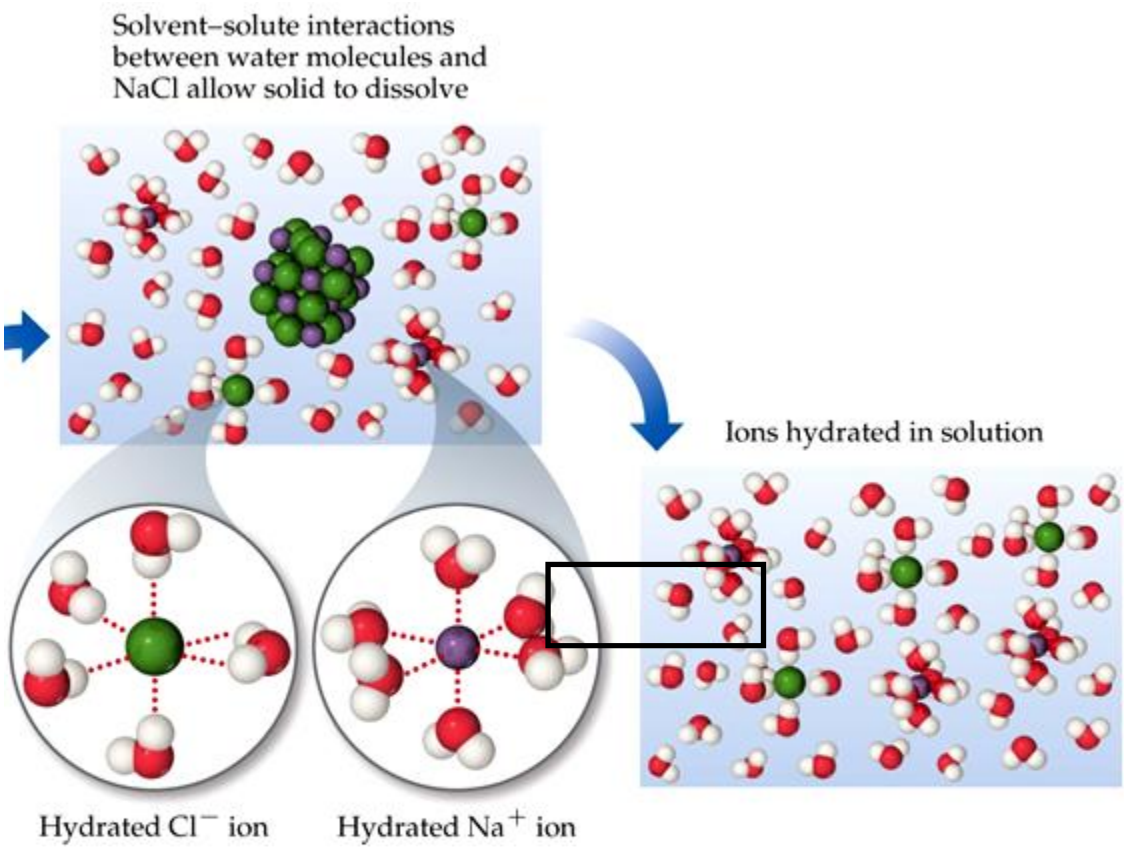
$$\text{Solute} + \text{solvent} \underset{\text{crystallize}}{\overset{\text{dissolve}}{\rightleftharpoons}} \text{solution}$$

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

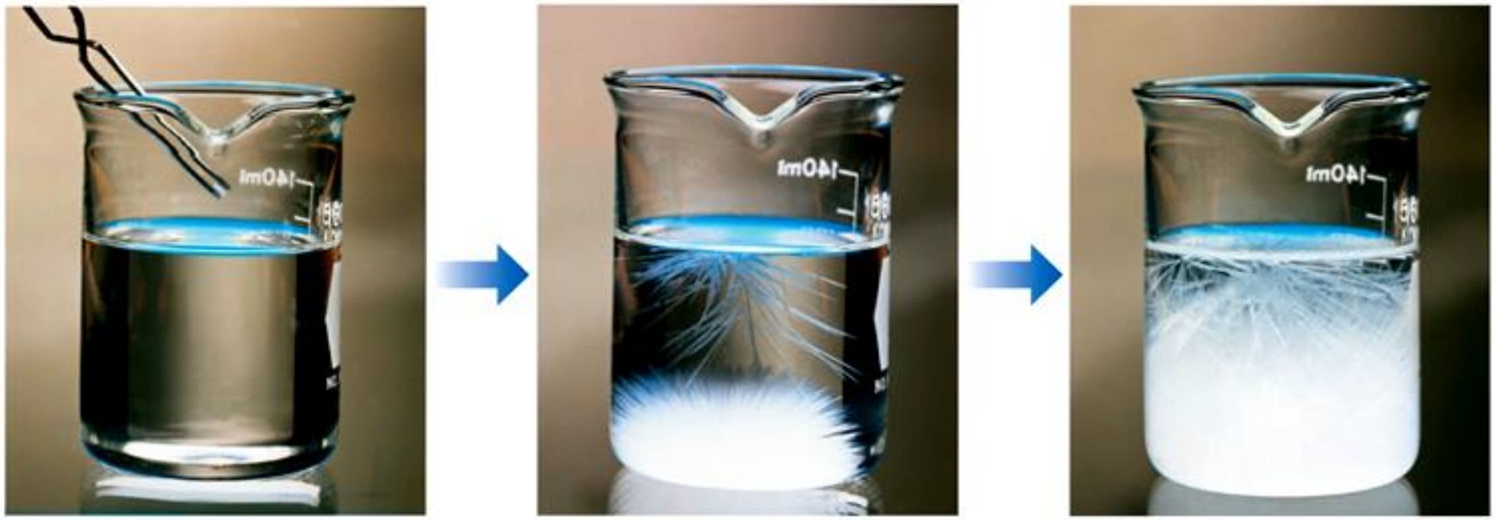
溶解度 (Solubility)：在一定温度下，某固态物质在100g溶剂中达到饱和状态时所溶解的质量，叫做这种物质在这种溶剂中的溶解度。

Types of Solutions

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



Types of Solutions



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.

Factors Affecting Solubility

Chemists use the concept "like dissolves like." 相似相溶

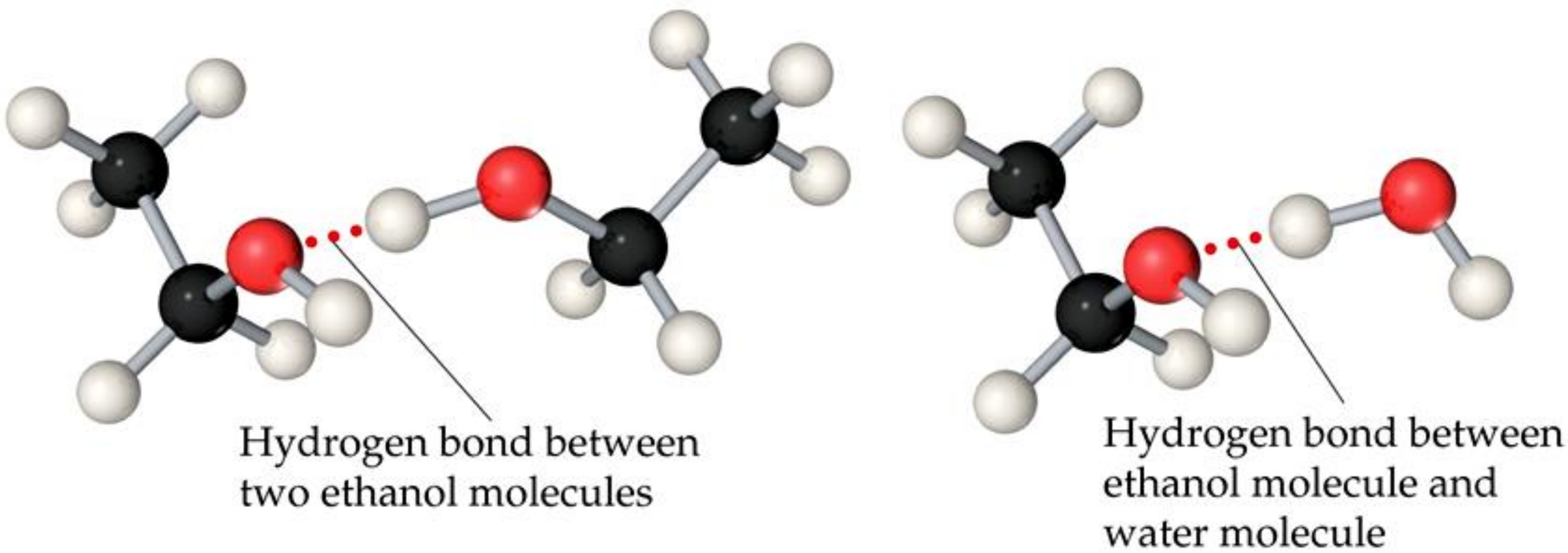
- Polar substances tend to dissolve in polar solvents.
- Nonpolar substances tend to dissolve in nonpolar solvents.

TABLE 13.2 • Solubilities of Some Alcohols in Water and in Hexane*

Alcohol	Solubility in H_2O	Solubility in C_6H_{14}
CH_3OH (methanol)	∞	0.12
CH_3CH_2OH (ethanol)	∞	∞
$CH_3CH_2CH_2OH$ (propanol)	∞	∞
$CH_3CH_2CH_2CH_2OH$ (butanol)	0.11	∞
$CH_3CH_2CH_2CH_2CH_2OH$ (pentanol)	0.030	∞
$CH_3CH_2CH_2CH_2CH_2CH_2OH$ (hexanol)	0.0058	∞

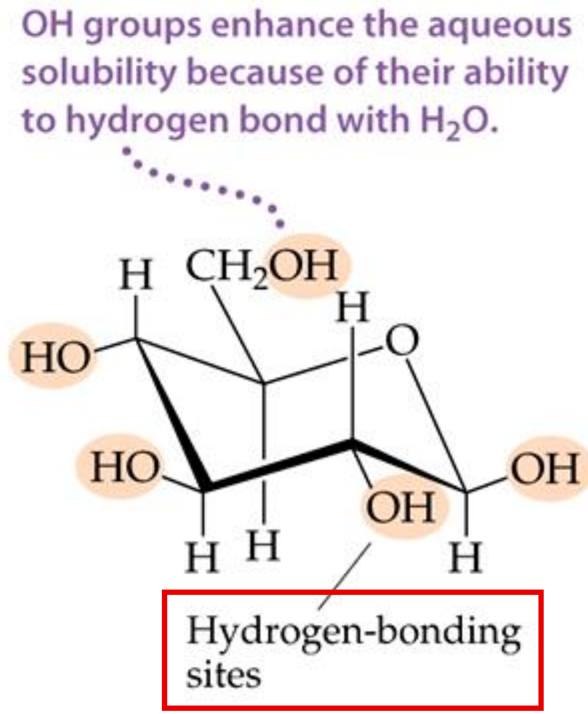
*Expressed in mol alcohol/100 g solvent at 20 °C. The infinity symbol (∞) indicates that the alcohol is completely miscible with the solvent.

Factors Affecting Solubility



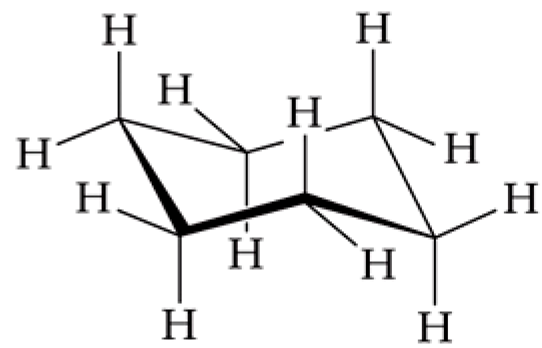
The more similar the intermolecular attractions, the more likely one substance is to be soluble in another.

Factors Affecting Solubility



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

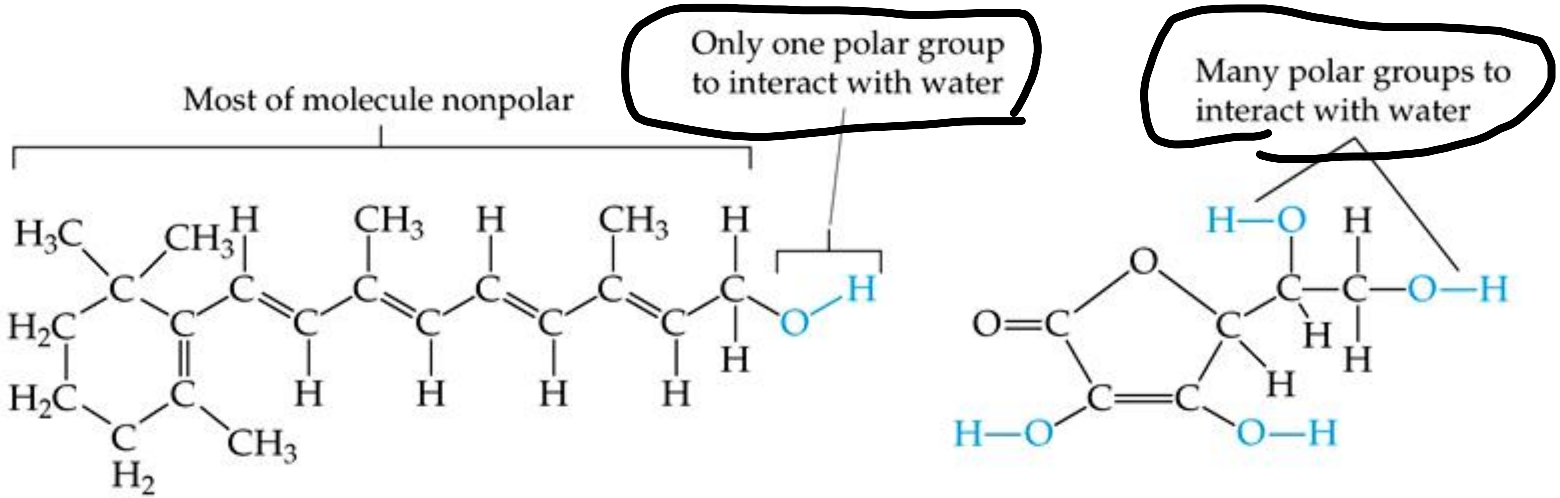
葡萄糖



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

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

Factors Affecting Solubility



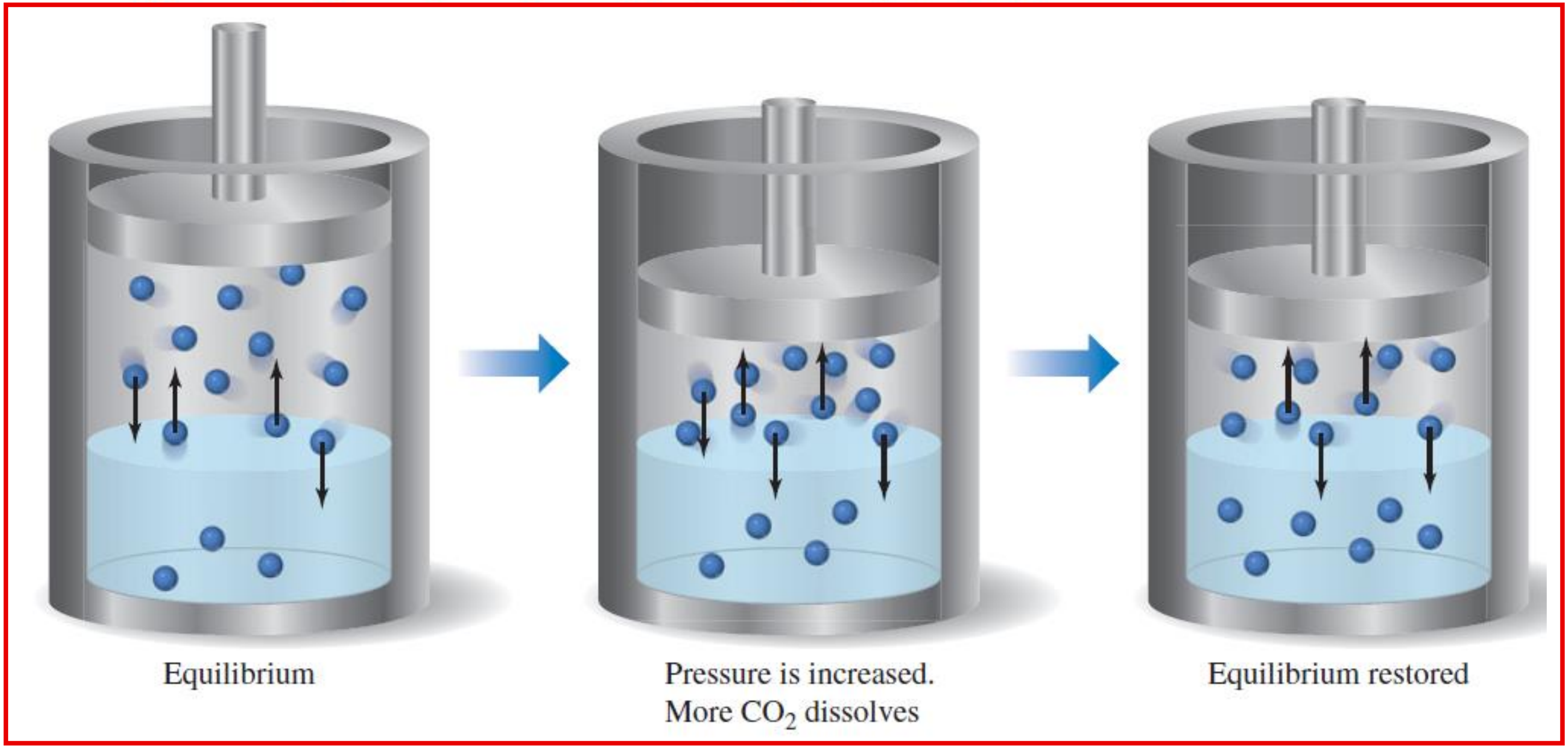
大分子物质，不考虑整个分子，考虑其中的groups，如—CH_3, —OH

Vitamin A　　Vitamin C

- Vitamin A is soluble in nonpolar solvents (like fats).
- Vitamin C is soluble in polar solvents, e.g. water.

Solubility-Pressure effect

If the partial pressure of a gas over a solution is doubled, how has the concentration of gas in the solution changed after equilibrium is restored?



▲ FIGURE 13.14 **Effect of pressure on gas solubility.**

Factors Affecting Solubility-Pressure effect

Gases in Solution

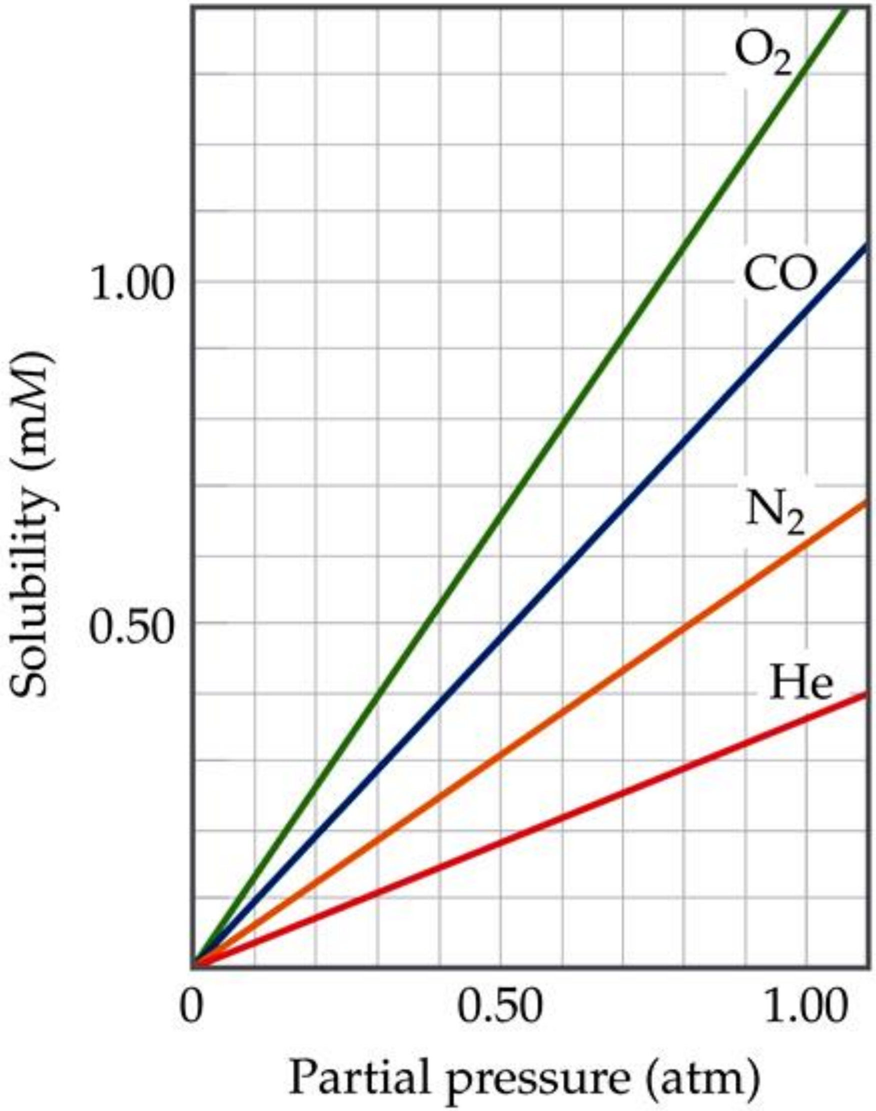
- In general, the solubility of gases in water increases with increasing mass.
- Larger molecules have stronger dispersion forces (higher polarizability).

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

Gas	Solubility (*M*)
N_2	0.69×10^{-3}
CO	1.04×10^{-3}
O_2	1.38×10^{-3}
Ar	1.50×10^{-3}
Kr	2.79×10^{-3}

Increasing mass

Gases in Solution



- The solubility of liquids and solids does not change appreciably with pressure.
- But 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 in a liquid solvent increases in direct proportion to the partial pressure of the gas above the solution

亨利定律(Henry's law)："在等温等压下，某种气体在溶液中的溶解度与液面上该气体的平衡压力成正比。"这一定律对于稀溶液中挥发性溶质也同样有用。

$$\boxed{S_g = kP_g}$$

where

- S_g is the solubility of the gas (unit: molarity),
- k is the Henry's Law constant for that gas in that solvent, and
- P_g is the partial pressure of the gas above the liquid.

Exercise A Henry's Law Calculation

Calculate the concentration of CO_2 in a soft drink that is bottled with a partial pressure of CO_2 of 4.0 atm over the liquid at 25 °C. The Henry's law constant for CO_2 in water at this temperature is 3.4×10^{-2} mol/L-atm.

Solution

Plan: With the information given, we can use Henry's law to calculate the solubility, S_{CO_2}.

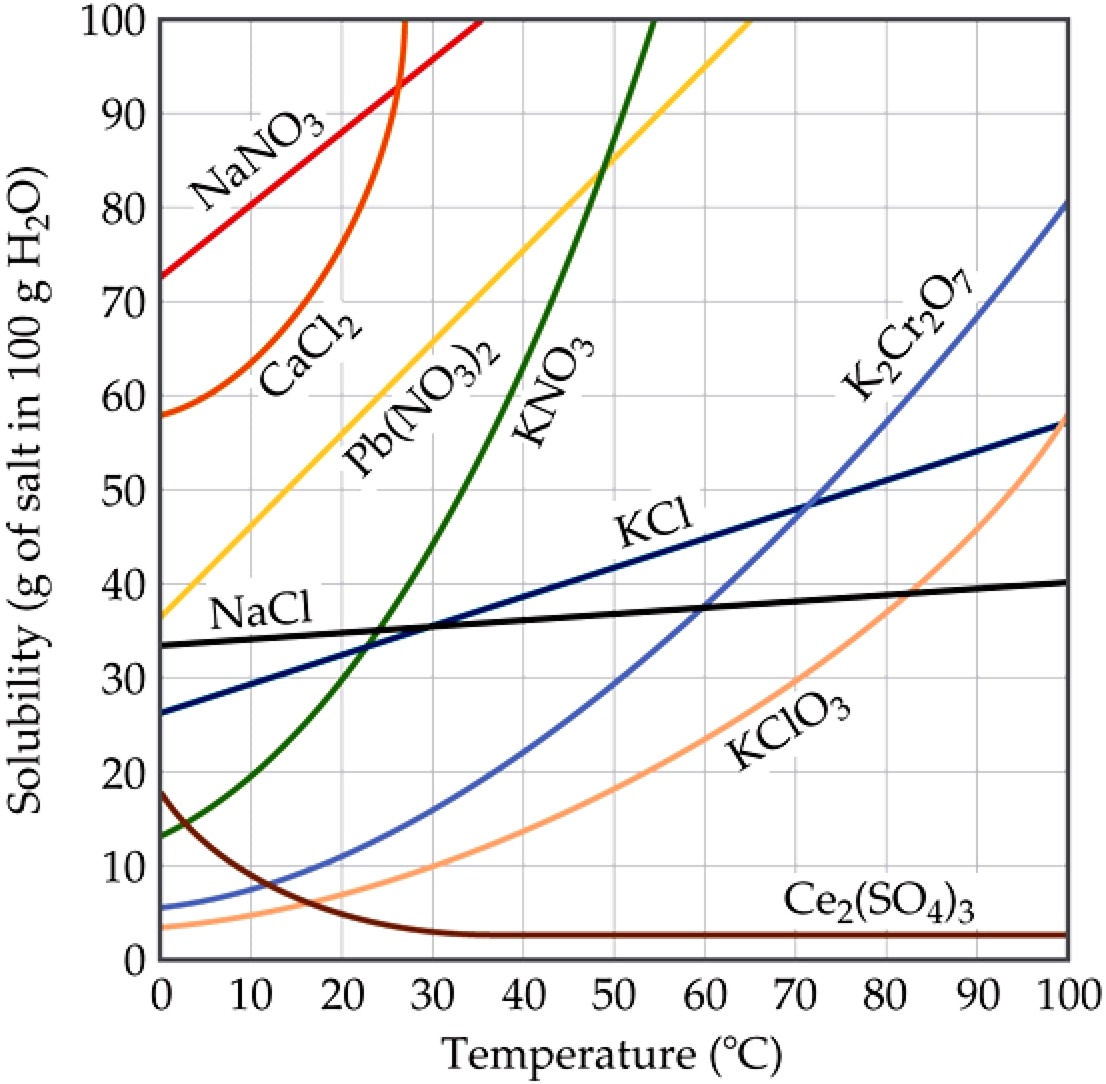
$$S_g = kP_g$$

Solve

$S_{CO_2} = kP_{CO_2} = (3.4 \times 10^{-2}\ \text{mol/L-atm})(4.0\ \text{atm}) = 0.14\ \text{mol/L} = 0.14\ M$

Check The units are correct for solubility, and the answer has two significant figures consistent with both the partial pressure of CO_2 and the value of Henry's constant.

Temperature

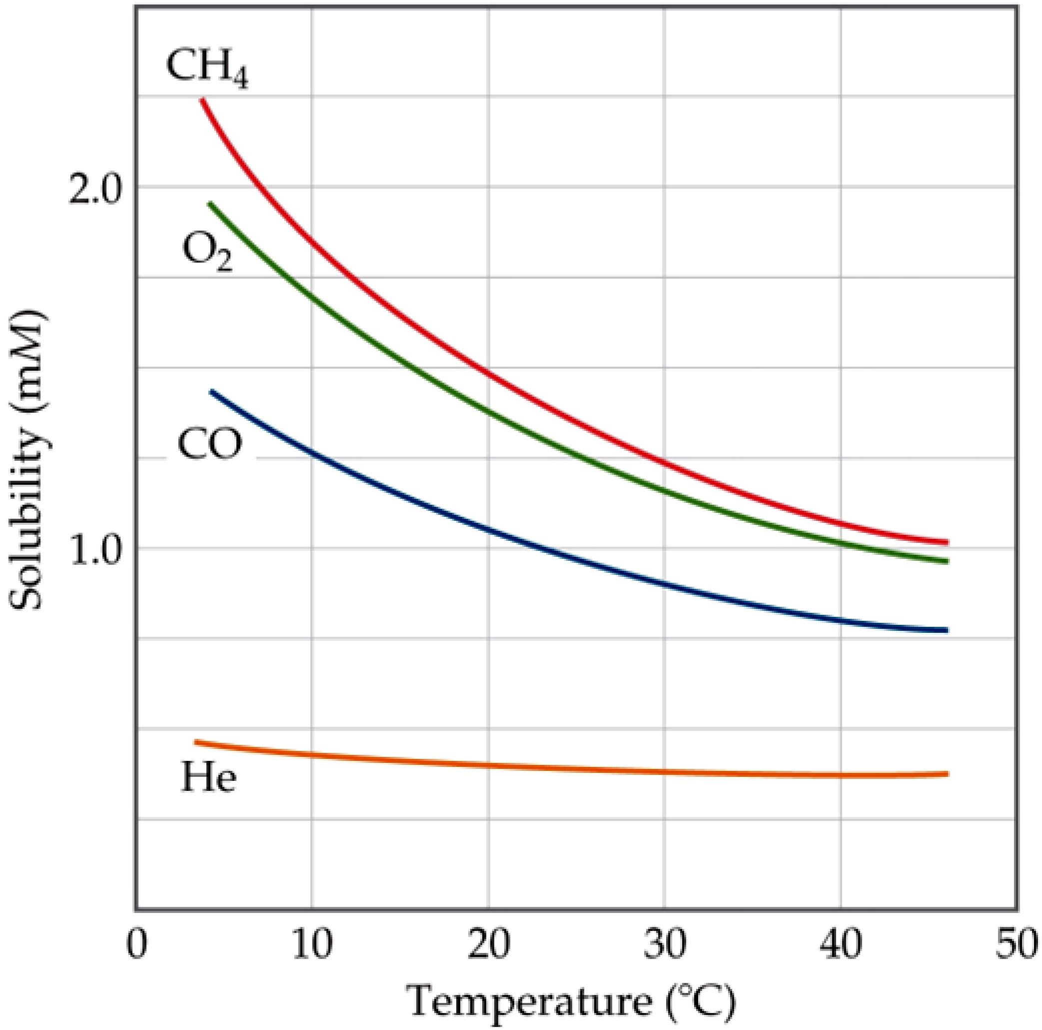


Generally, the solubility of solid solutes in liquid solvents increases with increasing temperature.

Temperature

The opposite is true of gases.

- Solubility decreases with increasing temp.
- Carbonated soft drinks are more “bubbly” if stored in refrigerator.
- Warm lakes have less O_2 dissolved in them than cool lakes.



Ways of Expressing (表达) Concentrations of Solutions

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 and Parts per Billion

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)

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

In some applications, one needs the mole fraction of *solvent*, not solute—make sure you find the quantity you need!

Molarity (M)
(摩尔浓度)

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

You will recall this concentration measure from Chapter 4.

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

Molality (m)
(重量摩尔浓度)

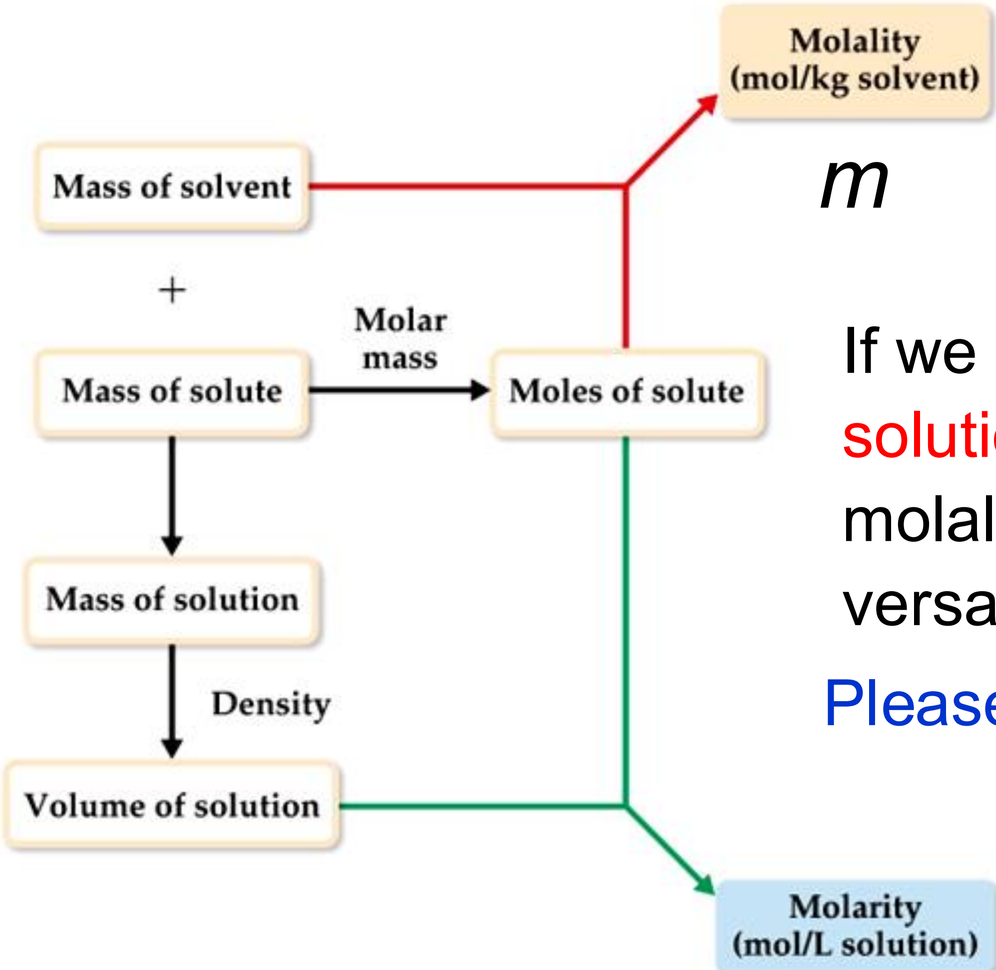
$$m = \frac{\text{moles of solute}}{\text{Mass (kilograms) of solvent}}$$

Since both moles and mass do not change with temperature, molality (unlike molarity) is *not* temperature-dependent,

(temperature-independent).

当涉及温度变化时，常用重量摩尔浓度

Changing Molarity to Molality



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

If we know the density of the solution, we can calculate the molality from the molarity, and vice versa.

Please see Sample Exercise 13.6

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

$$M = \frac{1000\rho \times \text{mass\%}}{\text{M}}$$

$M_{con.HCl}$ = 11.6 M

$M_{con.H2SO4}$ = 18.4 M

For a fixed(specific) kind of solution:

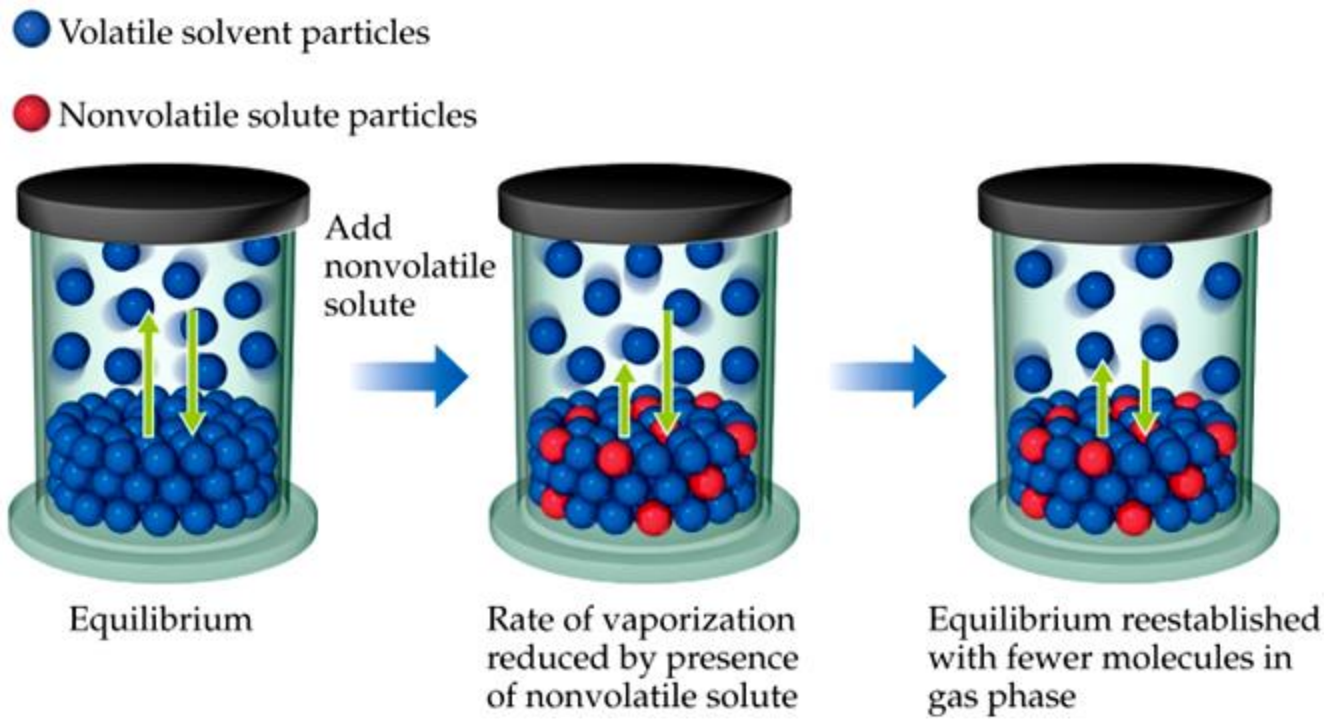
Colligative Properties (依数性)

- Addition of solute into a solvent would lower freezing point and raise boiling point
- These properties depends only on the quantity (number) of solute particles present, not on the identity of the solute particles, called **colligative properties**.

稀溶液中溶剂的蒸气压下降、凝固点降低、沸点升高和渗透压的数值，只与溶液中溶质的量有关，与溶质的本性无关，故称这些性质为稀溶液的依数性(溶液的通性)

- Among colligative properties are
  - Lowering of vapor-pressure
  - Raising of boiling-point
  - Lowering of melting-point
  - Osmotic pressure 渗透压

Lowering Vapor Pressure



Because of solute–solvent intermolecular attraction, higher concentrations of nonvolatile (非挥发性) solutes make the solvent harder to escape to the vapor phase.

Therefore, the vapor pressure of a solution is lower than that of the pure solvent.

Raoult's Law

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

拉乌尔定律 (Raoult's Law): 理想溶液在一固定温度下，每一组元的蒸气分压与溶液内各该组元的摩尔分数成正比。

–X is the mole fraction, and

normal vapor pressure = 某物质在给定温度下、纯物质状态时的蒸气压。

–P° is the normal vapor pressure at that temperature.

If A or B is solid, $P^{\circ} = 0$

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

(含有非挥发性溶质的稀溶液) 拉乌尔定律:“在某一温度下，稀溶液的蒸气压等于纯溶剂的蒸气压乘以溶剂的摩尔分数”。

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

(The vapor-pressure lowering is directly proportional to the mole fraction of the solute)

核心在于：溶剂的摩尔分数 = 1 − 溶质的摩尔分数

稀溶液（溶质不挥发）时，拉乌尔定律给：

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

其中

$$X_{\text{solvent}} = 1 - X_{\text{solute}}$$

蒸气压降低定义为：

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

代入上面的表达式：

$$\Delta P = P^{\circ}_{\text{solvent}} - (1 - X_{\text{solute}}) P^{\circ}_{\text{solvent}}$$

展开：

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

于是蒸气压降低**刚好**等于“溶质摩尔分数 × 纯溶剂蒸气压”。

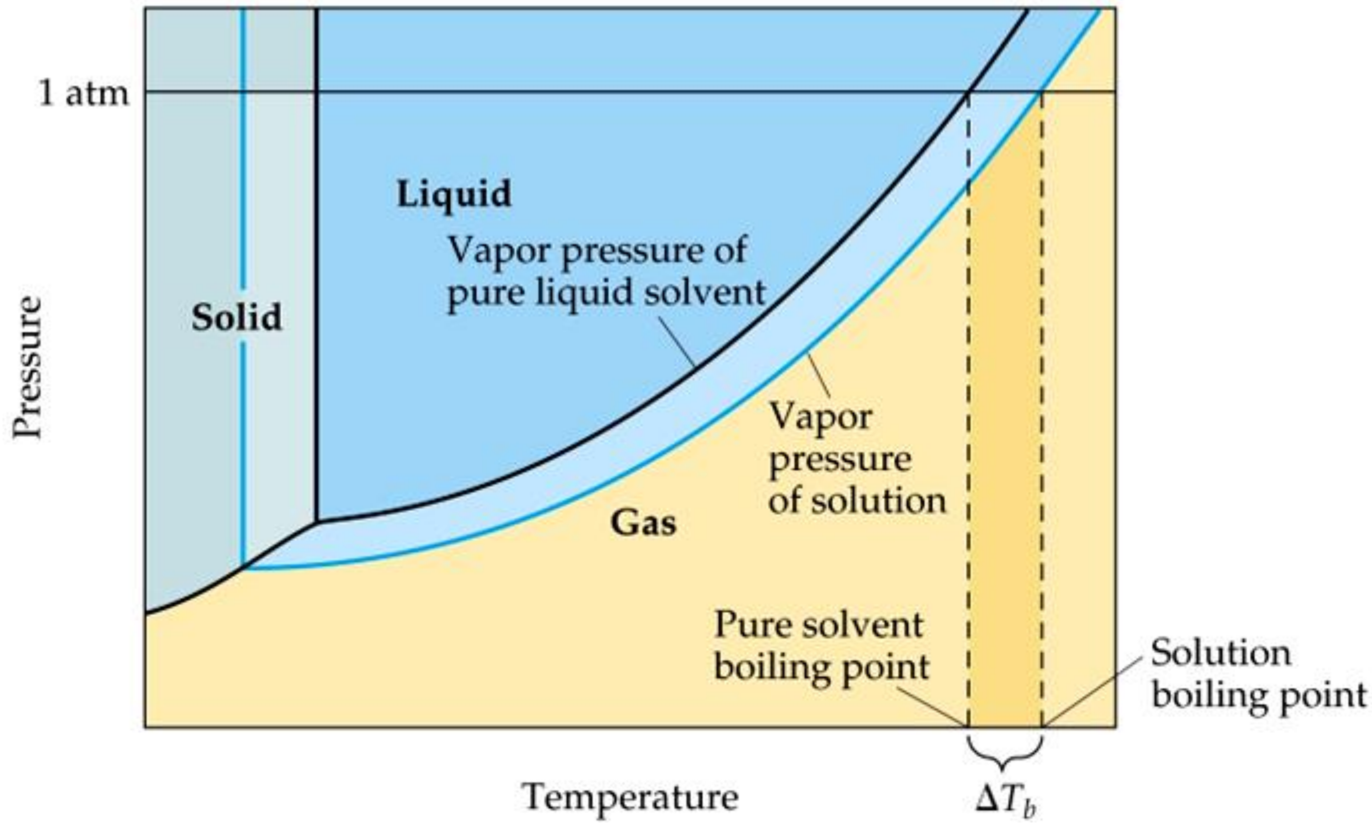
Ideal solution

is defined as one that obeys Raoult's law

The molecules in an ideal solution all influence one another in the same way

- **The solute concentration is low and dilute**
- **Solvent and Solute have similar molecular sizes**
- **Take part in similar types of intermolecular attractions.**

Boiling-Point Elevation (升高) and Freezing-Point Depression (降低)



Nonvolatile solute–solvent interactions also cause solutions to have higher boiling points and lower freezing points than the pure solvent.

Boiling-Point Elevation

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_2O	100.0	0.51	0.0	1.86
Benzene, C_6H_6	80.1	2.53	5.5	5.12
Ethanol, C_2H_5OH	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

The change in boiling point is proportional to the molality (m) of the solution:

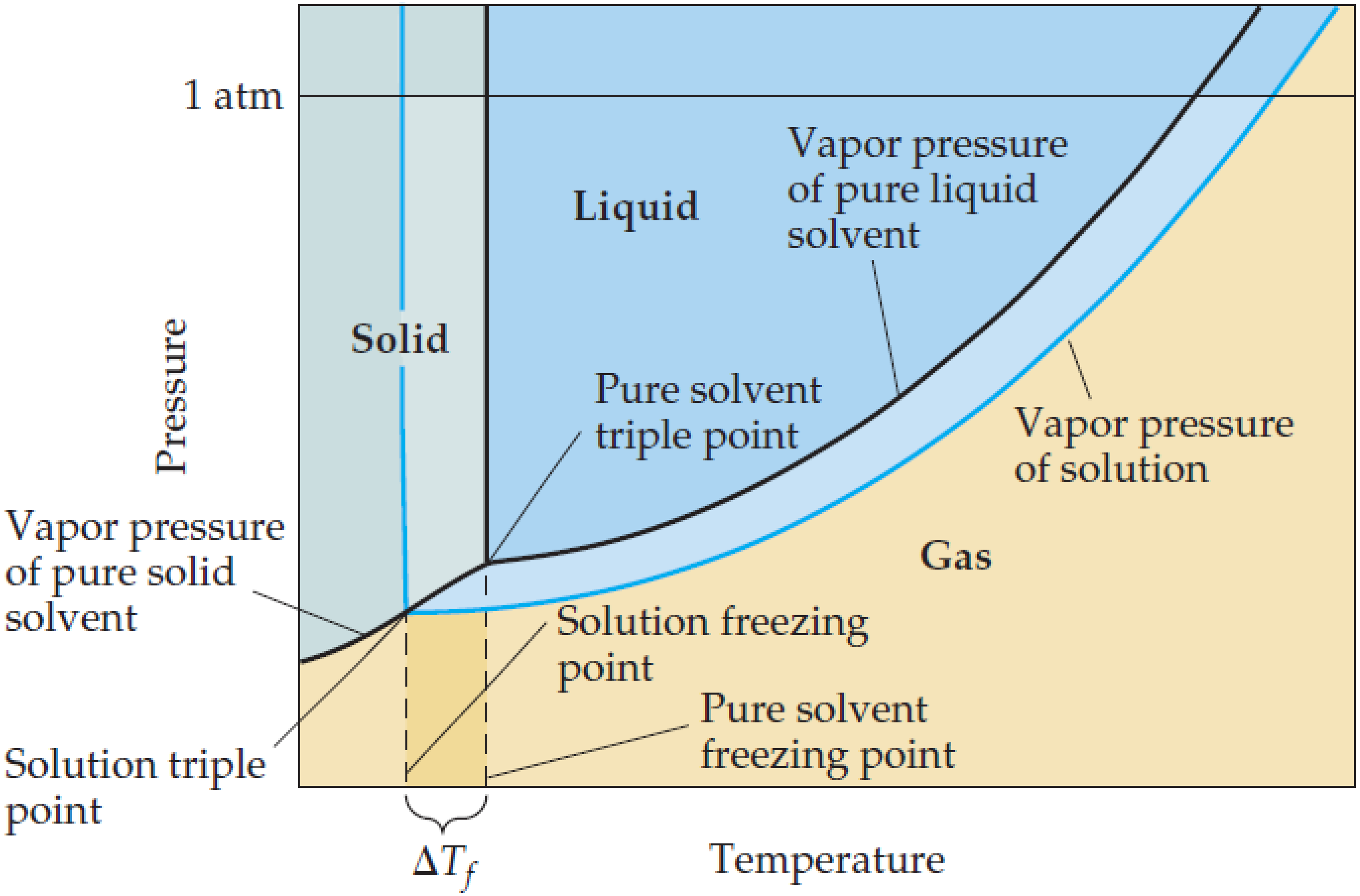
$$\boxed{\Delta T_b = K_b \cdot m}$$

where K_b is the molal boiling-point elevation constant (摩尔沸点升高常数), a property of the solvent.

$$\rightarrow \quad T_b = T^o_b + \Delta T_b$$

(T^o_b = normal boiling point)

Freezing-Point Depression



▲ **FIGURE 13.24** **Phase diagram illustrating freezing-point depression.**

Freezing-Point Depression

TABLE 13.3 • Molal Boiling-Point-Elevation and Freezing-Point-Depression Constants

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Ethanol, C_2H_5OH	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

The change in freezing point can be found similarly:

$$\boxed{\Delta T_f = K_f \bullet m}$$

Here K_f is the molal freezing-point depression constant of the solvent.

$$M_B = \frac{K_f \bullet m_B}{\Delta T_f m_A}$$ （求摩尔质量） $$T_f = T^o_f - \Delta T_f$$

(T^o_f = normal freezing point)

$$M_B = \frac{K_f\, m_B}{\Delta T_f\, m_A}$$

其实这是在表达：

- 求 **溶质B 的摩尔质量** M_B
- 以 **溶剂A**（质量 m_A）和 **溶质B**（质量 m_B）配成某浓度的溶液
- 根据凝固点降低 ΔT_f 求得 M_B

公式更标准的写法应是：

$$\Delta T_f = K_f \cdot \frac{n_B}{m_A}$$

又因为：

$$n_B = \frac{m_B}{M_B}$$

代入：

$$\Delta T_f = K_f \cdot \frac{m_B/M_B}{m_A}$$

整理，得到：

$$\boxed{M_B = \frac{K_f\, m_B}{\Delta T_f\, m_A}}$$

Antifreeze:

抗冻剂有甲醇、乙醇、乙二醇、水溶性酰胺和氯化钙、盐水等。其中乙二醇的抗冻性能优异，是最主要的抗冻剂。例如：乙二醇含量为40%（质量）的水溶液，冰点为 −24℃；而含乙二醇58%（质量）的水溶液，其冰点为−48℃。世界上需用抗冻剂的系统中，约90%采用乙二醇及其衍生物作抗冻剂。

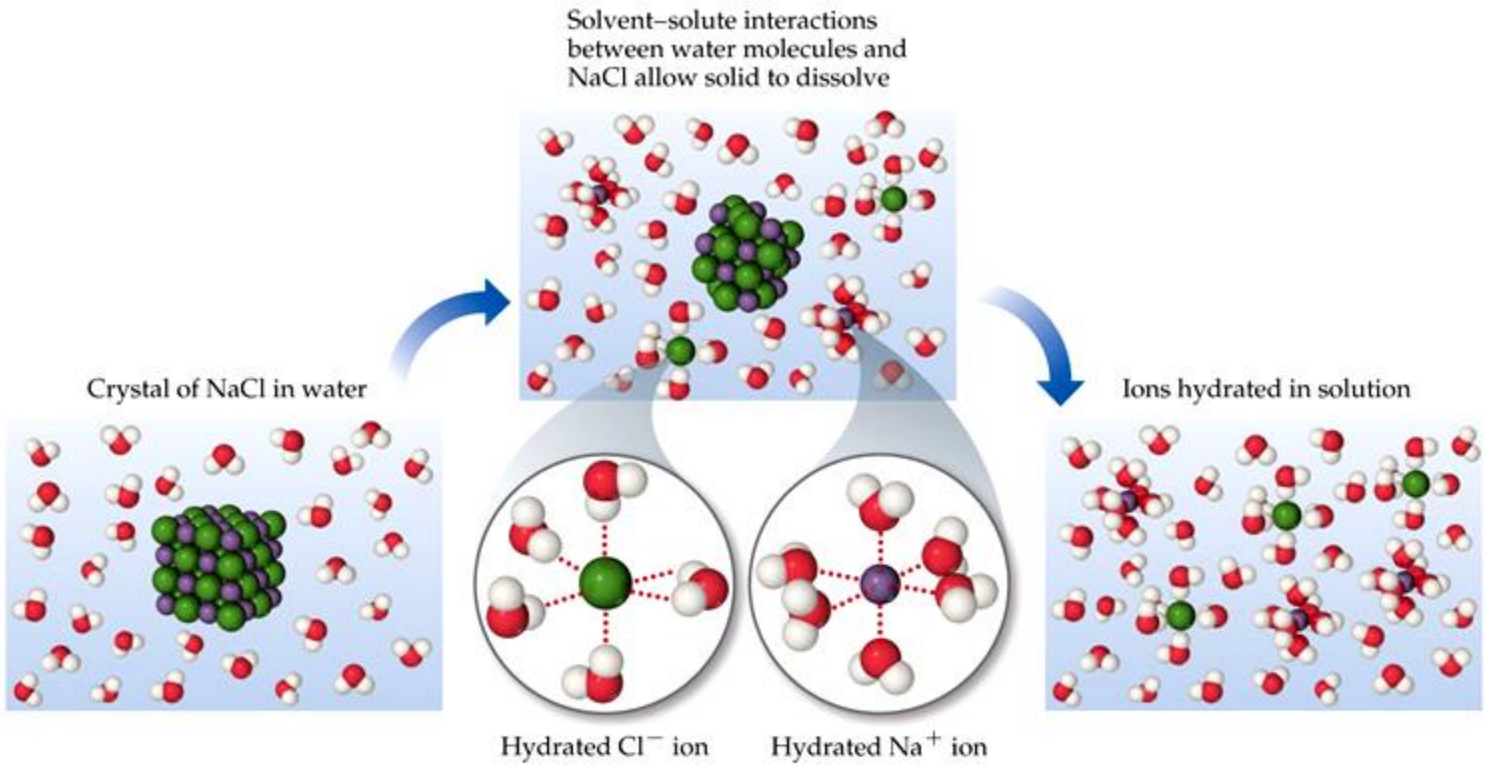
乙二醇 编辑

乙二醇（ethylene glycol）又名“甘醇”、“1,2-亚乙基二醇”，简称EG。化学式为(CH2OH)2，是最简单的二元醇。乙二醇是无色无臭、有甜味液体，对动物有毒性，人类致死剂量约为1.6 g/kg。乙二醇能与水、丙酮互溶，但在醚类中溶解度较小。用作溶剂、防冻剂以及合成涤纶的原料。乙二醇的高聚物聚乙二醇（PEG）是一种相转移催化剂，也用于细胞融合；其硝酸酯是一种炸药。

中文名	乙二醇	水溶性	与水互溶
英文名	Ethylene glycol	密　度	1.1155(20℃)
别　称	甘醇，EG，甘醇型防冻液，MEG	外　观	无色
化学式	(CH2OH)2	闪　点	111.1℃
分子量	62.068	危险性描述	吞食有害
CAS登录号	107-21-1	临界压力	7699KPa
EINECS登录号	203-473-3	临界温度	372℃
熔　点	-12.9℃	偏心因子	0.27
沸　点	197.3℃	临界摩尔体积	186C3/mol [1]

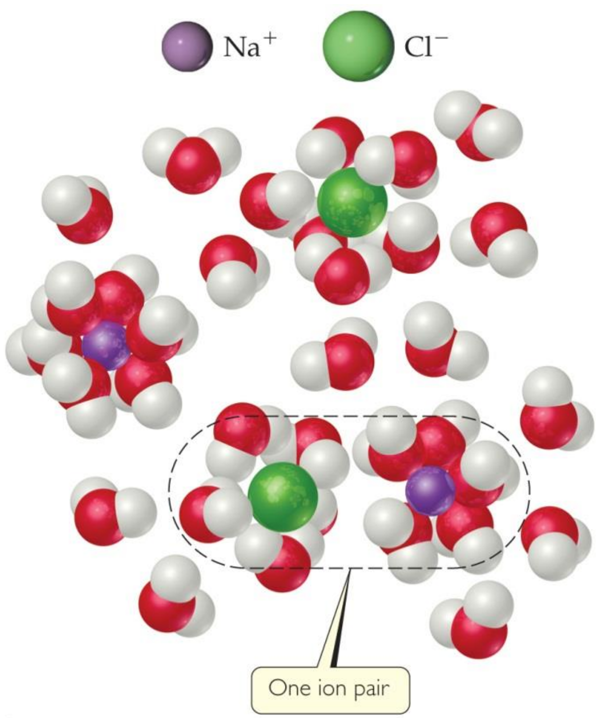
Colligative Properties of Electrolytes (电解质的依数性)

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



Colligative Properties of Electrolytes

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



One mole of NaCl in water does not really give rise to two moles of ions.

Some Na^+ and Cl^- reassociate (重新关联) for a short time, so the true concentration of particles is somewhat less than two times the concentration of NaCl.

van’t Hoff Factor
范特霍夫

- Reassociation is more likely at higher concentration.
- Therefore, the number of particles present is concentration-dependent.

TABLE 13.4 • van’t Hoff Factors for Several Substances at 25 °C

	Concentration			
Compound	0.100 *m*	0.0100 *m*	0.00100 *m*	Limiting Value
Sucrose	1.00	1.00	1.00	1.00
NaCl	1.87	1.94	1.97	2.00
K_2SO_4	2.32	2.70	2.84	3.00
$MgSO_4$	1.21	1.53	1.82	2.00

- We modify the previous equations by multiplying by the van’t Hoff factor, *i:*

$$\boxed{\Delta T = K \bullet m \bullet i}$$

Jacobus **Henricus** van’t Hoff

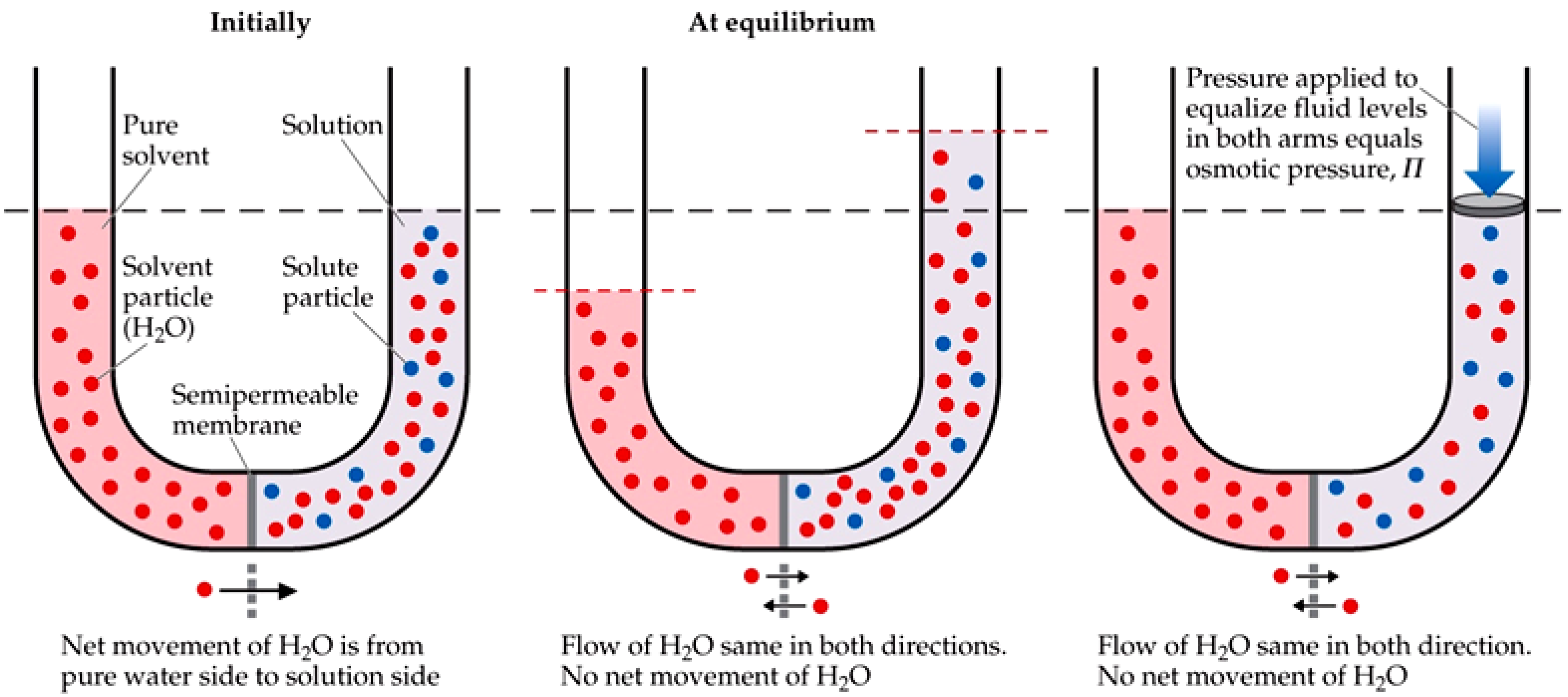
范特霍夫

1901年，诺贝尔化学奖的第一道灵光降临在荷兰化学家范特霍夫身上。这位一生痴迷实验的化学巨匠，不仅在<u>化学反应速度</u>、<u>化学平衡</u>和<u>渗透压</u>方面取得了骄人的研究成果，而且<u>开创了以有机化合物为研究对象的立体化学</u>。

Osmosis (渗透)

- Some substances form semipermeable (半透性的) membranes（薄膜）, allowing some smaller particles to pass through, but blocking other larger particles.
- In biological systems, most semipermeable membranes allow water to pass through, but not for solutes.

Osmosis



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*).

Osmotic Pressure

The pressure required to stop osmosis, known as **osmotic pressure**, π, is

$$\boxed{\pi = \left(\frac{n}{V}\right)RT = iMRT}$$

（范特霍夫方程式）

i：范特霍夫因子
van't Hoff factor
单位：无单位
（纯数字）
它只是表示溶质在溶液中解离成几个粒子，例如：
NaCl → 2
$CaCl_2$ → 3
葡萄糖 → 1

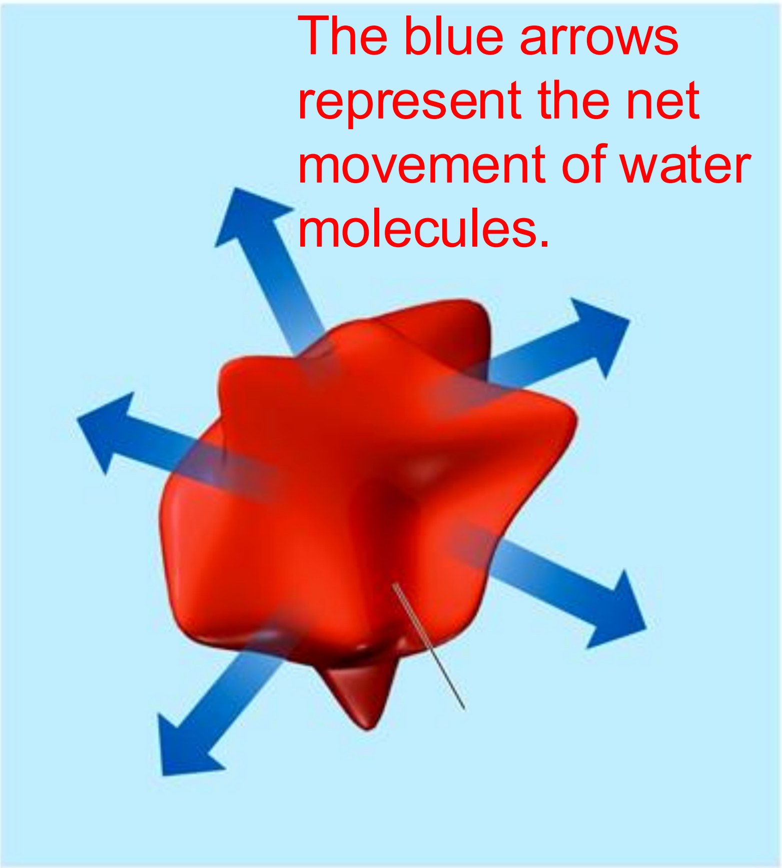
where M is the molarity of the solution，摩尔浓度；
i, the van't Hoff factor .

If the osmotic pressure is the same on both sides of a membrane (i.e., the concentrations are the same), the two solutions are **isotonic (等渗溶液)**.

Osmosis in Blood Cells

- If the solute concentration outside the cell is greater than that inside the cell, the solution is hypertonic (高渗的).

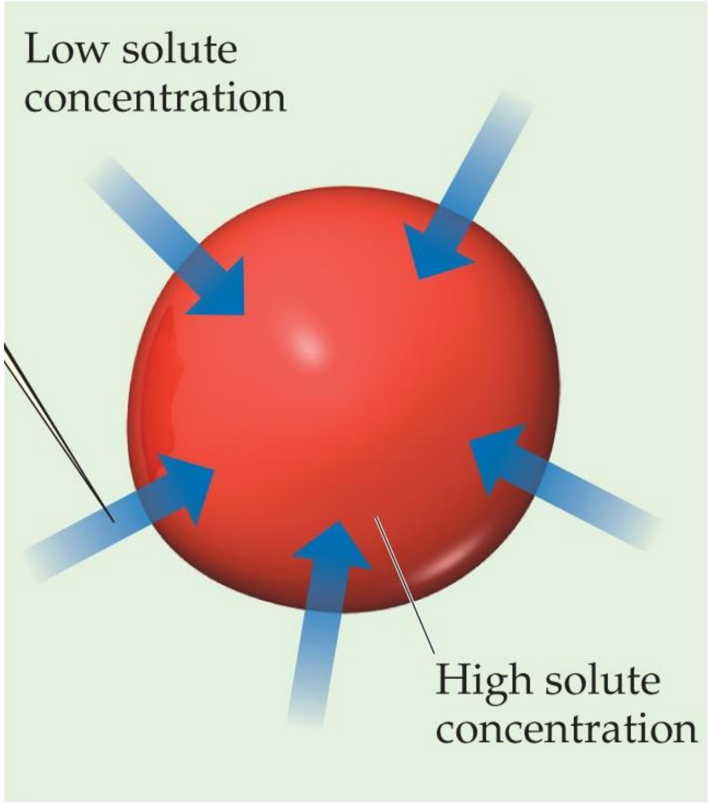
- Water will flow out of the cell, and crenation (皱缩) results.



Osmosis in Blood Cells

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

- What molarity of NaCl solution will be isotonic with blood? (a physiological saline solution)

What is the mass percentage?

A 0.16 M solution of NaCl is 0.9% mass in NaCl.

SAMPLE EXERCISE 13.11 Molar Mass from Freezing-Point Depression

A solution of an unknown nonvolatile nonelectrolyte was prepared by dissolving 0.250 g of the substance in 40.0 g of CCl_4. The boiling point of the resultant solution was 0.357 °C higher than that of the pure solvent. Calculate the molar mass of the solute. K_b for the solvent (CCl_4), $K_b = 5.02\ °C/m$.

$$\text{Molality} = \frac{\Delta T_b}{K_b} = \frac{0.357\ °C}{5.02\ °C/m} = 0.0711\ m$$

$$(0.0400\ \text{kg } CCl_4)\left(0.0711\ \frac{\text{mol solute}}{\text{kg } CCl_4}\right) = 2.84 \times 10^{-3}\ \text{mol solute}$$

$$\text{Molar mass} = \frac{0.250\ \text{g}}{2.84 \times 10^{-3}\ \text{mol}} = 88.0\ \text{g/mol}$$

$\Delta T_b = iK_b m$

Molar Mass from Freezing-Point Depression

Camphor ($C_{10}H_{16}O$) melts at 179.8 °C, and it has a particularly large freezing-point-depression constant, $K_f = 40.0\ °C/m$. When 0.186 g of an organic substance of unknown molar mass is dissolved in 22.01 g of liquid camphor, the freezing point of the mixture is found to be 176.7 °C. What is the molar mass of the solute?

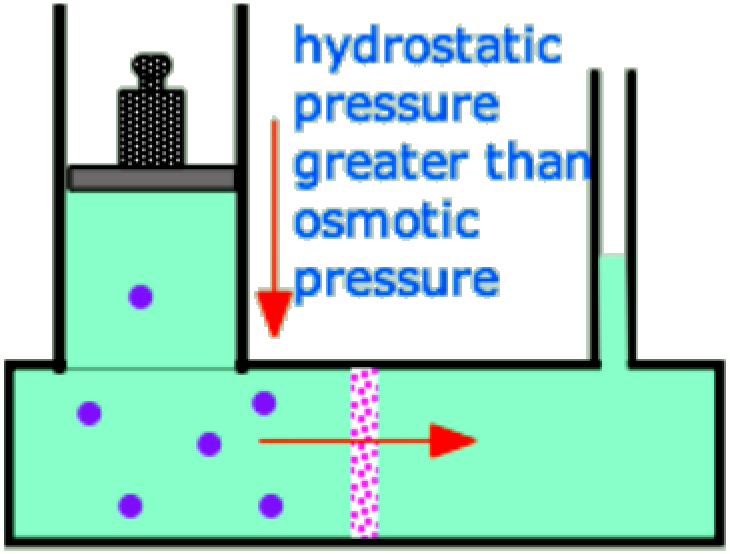
$\Delta T_f = iK_f m$

SAMPLE EXERCISE 13.12 Molar Mass from Osmotic Pressure

The osmotic pressure of an aqueous solution of a certain protein was measured to determine the protein's molar mass. The solution contained 3.50 mg of protein dissolved in sufficient water to form 5.00 mL of solution. The osmotic pressure of the solution at 25 °C was found to be 1.54 torr. Treating the protein as a nonelectrolyte, calculate its molar mass.

$\pi = iMRT$

Reverse Osmosis (反渗)



Applying a hydrostatic pressure (流体静压) 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 (海水淡化) and to reclaim “used” water from power plants, runoff, and even from sewage.

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**.

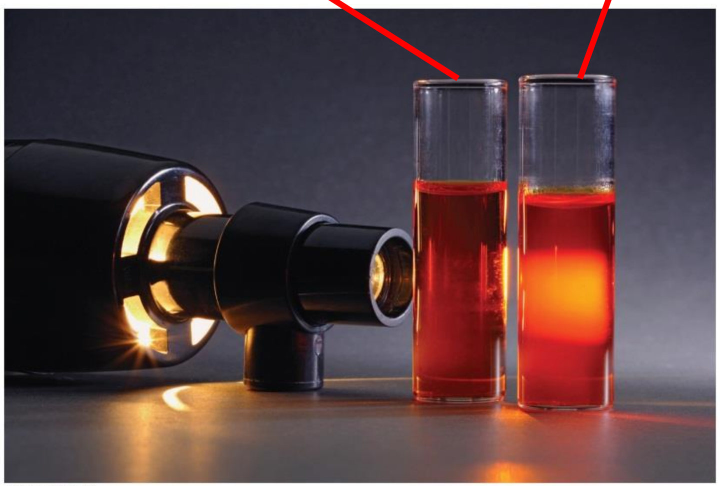
Colloid particles range in diameter from 5 to 1000 nm

TABLE 13.5 • Types of 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	Aerosol	Smoke
Liquid	Liquid	Gas	Foam	Whipped cream
Liquid	Liquid	Liquid	Emulsion	Milk
Liquid	Liquid	Solid	Sol	Paint
Solid	Solid	Gas	Solid foam	Marshmallow
Solid	Solid	Liquid	Solid emulsion	Butter
Solid	Solid	Solid	Solid sol	Ruby glass

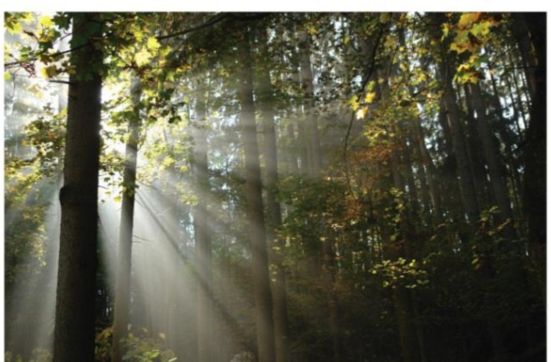
Tyndall Effect (丁达尔效应)

solution **Colloidal dispersion**



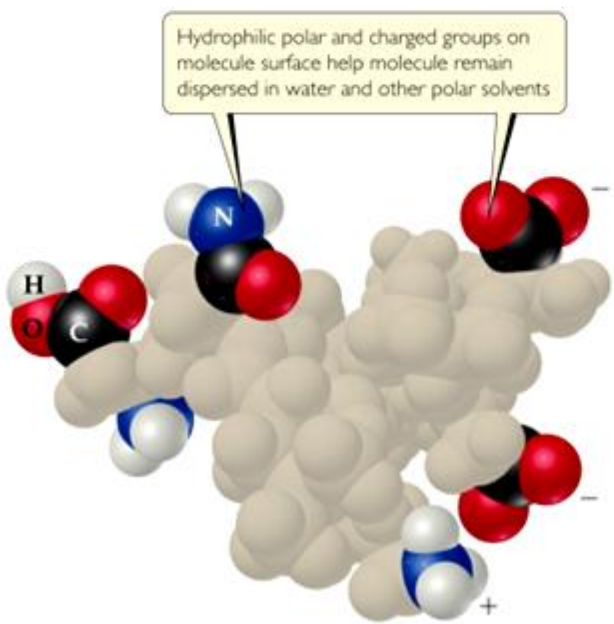
- Colloidal 胶体 suspensions can scatter rays of light.
- This phenomenon is known as the **Tyndall effect**.

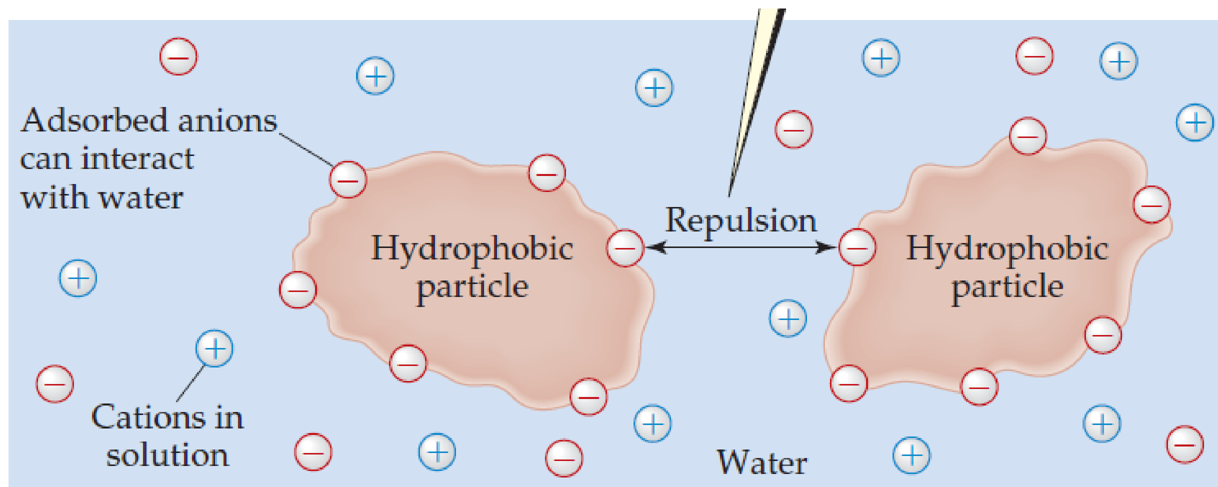
丁达尔效应：
当一束光线透过胶体，从入射光的垂直方向可以观察到胶体里出现的一条光亮的“通路”，这种现象叫（Tyndall effect）



Hydrophilic and Hydrophobic Colloids

The most important colloids are those in which the dispersing medium is water. These colloids may be hydrophilic (water loving) or hydrophobic (water fearing).





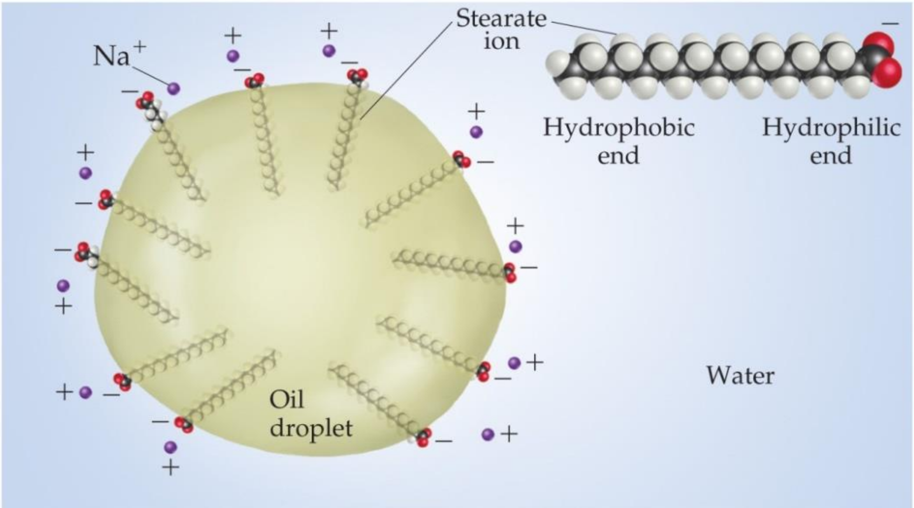
▲ **FIGURE 13.31** **Hydrophobic colloids stabilized by adsorbed anions.**

Emulsifying agents: 乳化剂

Some molecules have a polar, hydrophilic (*water-loving*) end and a nonpolar, hydrophobic (*water-hating*) end.

Hydrophobic groups are away from water, on the "inside" of molecules.

These molecules can help in the emulsification (乳化) of fats and oils in aqueous solutions.



Soap: $C_{17}H_{35}COONa$

乳化作用形成的分散体系属于胶体，更具体地说属于**乳状液（emulsion）**这一类液–液胶体。

Removal of Colloidal Particles

- Heating a colloidal dispersion or

- adding an electrolyte may bring about coagulation. (Coagulation: 聚沉)

- A semipermeable membrane can be used to separate ions from colloidal particles (Dialysis：渗析)

The rule of “like dissolves like” refers to similarities between ________ of miscible（混溶) liquids.

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

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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. $CH_3CH_2OCH_2CH_3$

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a. CH_3OH
b. CH_4
c. C_6H_6
d. $CH_3CH_2OCH_2CH_3$

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

a. CH_3OH
b. CH_3CH_2OH
c. $CH_3CH_2CH_2OH$
d. $CH_3CH_2CH_2CH_2OH$

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

a. CH_3OH
b. CH_3CH_2OH
c. $CH_3CH_2CH_2OH$
d. $CH_3CH_2CH_2CH_2OH$

________ 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

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

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

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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.

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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.

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a. increases.

$\boxed{\text{b.}}$ decreases.

c. remains unchanged.

d. varies from gas to gas.

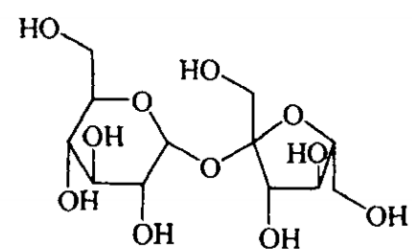
What is the freezing point of a 2.00 m aqueous solution of sucrose? The value of K_f for water is 1.86 degrees C/molal.

$\boxed{\text{a.}}$ –3.72 degrees C
b. –1.86 degrees C
c. +1.86 degrees C
d. +3.72 degrees C

蔗　糖

Zhetang

Sucrose



$C_{12}H_{22}O_{11}$ 342.30

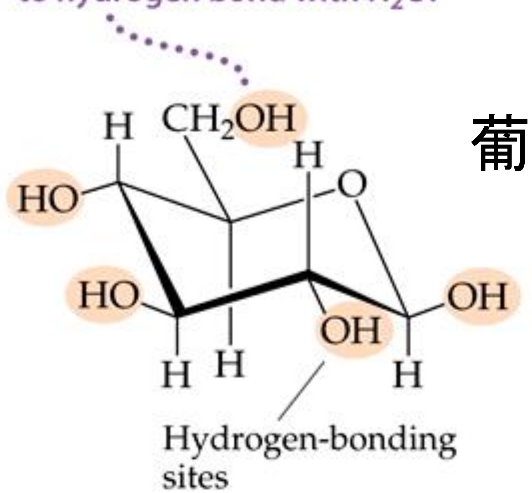
[57-30-1]

本品为 β-D-呋喃果糖基-α-D-吡喃葡萄糖苷。

What is the vapor pressure of a solution containing 0.500 mol of glucose and 5.000 mol of water at 29 degrees C?

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

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



葡萄糖

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

A 0.100 molal solution of which compound below will have the lowest freezing point?

a. NaCl
b. $CaCl_2$
c. KI
d. $LiNO_3$

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.

R 的值	单位
8.3144621(75)	$J \cdot K^{-1} \cdot mol^{-1}$
0.08205746(14)	$L \cdot atm \cdot K^{-1} \cdot mol^{-1}$
$8.20574587 \times 10^{-5}$	$m^3 \cdot atm \cdot K^{-1} \cdot mol^{-1}$
8.3144621(75)	$cm^3 \cdot MPa \cdot K^{-1} \cdot mol^{-1}$
8.3144621(75)	$L \cdot kPa \cdot K^{-1} \cdot mol^{-1}$
8.3144621(75)	$m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}$
62.36367(11)	$L \cdot mmHg \cdot K^{-1} \cdot mol^{-1}$
62.36367(11)	$L \cdot Torr \cdot K^{-1} \cdot mol^{-1}$
1.9858775(34)	$cal \cdot K^{-1} \cdot mol^{-1}$
8.63×10^{-5}	$eV \cdot K^{-1} \cdot atom^{-1}$

What is the molecular weight of adrenaline if 0.64 grams of adrenaline dissolved in 36.0 g of CCl_4 raises the boiling point by 0.49 degrees Celsius? (K_b = 5.02 $^oC/m$)

$\boxed{\text{a.}}$ 180 g/mole   b. 360 g/mole

c. 720 g/mole   d. 1800 g/mole

Which substance below is NOT a colloid?

a. Butter
b. Smoke
c. Whipped cream（生奶油）
d. Salt water

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

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