



General Chemistry II

Chem 102



Lecture 7

Solutions

Ahmad Alakraa

Solution

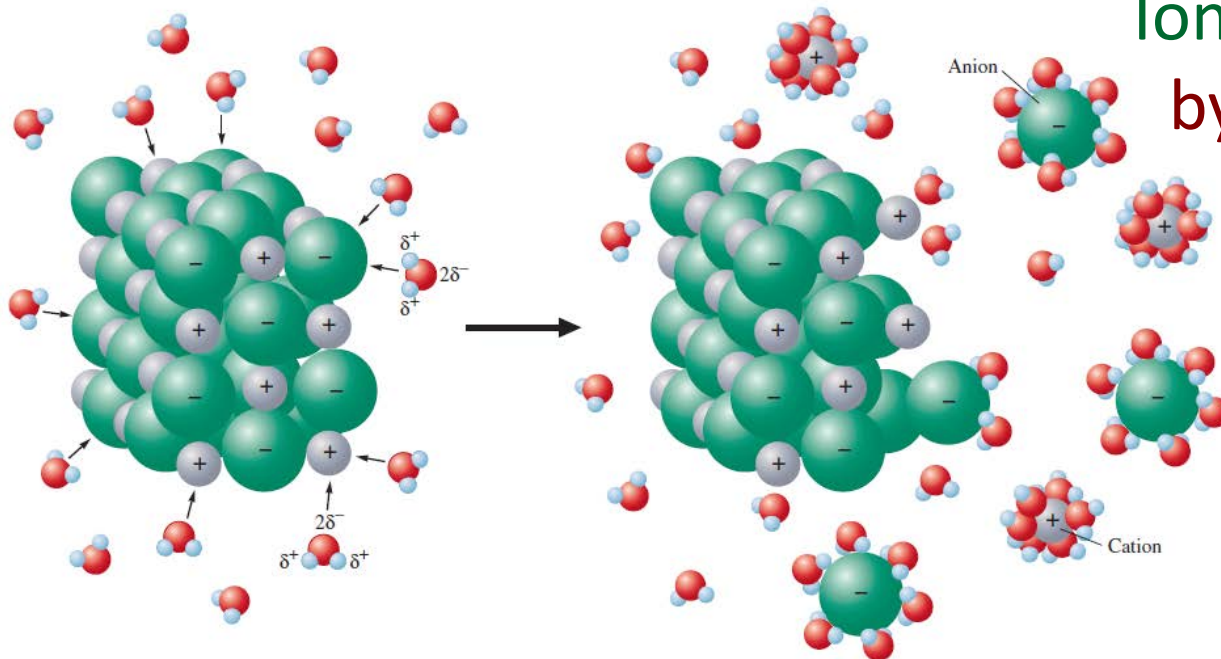
- ✚ is a homogeneous mixture of two or more **components**.
- ✚ The component whose phase remains (~~1~~7) is called “**Solvent**” and the other component whose phase disappears is called “**Solute**”.
- ✚ If all components are in the same phase, the one in greatest amount will be the “**Solvent**” and other components are “**Solutes**”.
- ✚ Solutions, in which **water** is the **solvent** are called **aqueous solutions**.
- ✚ The polarity in **H₂O** is responsible of its great ability to dissolve several compounds.

Types of Solutions

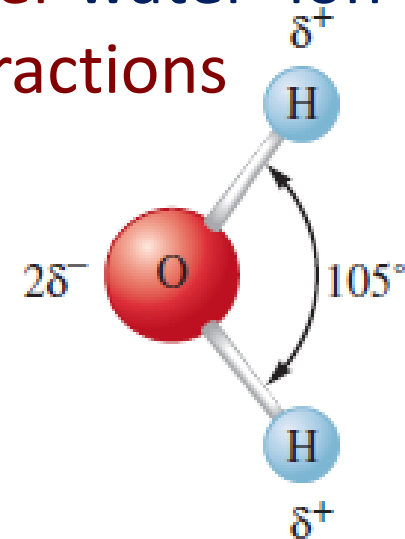
Solute	Solvent	Solution	Example
Gas	Gas	Gas	Air , natural gas
Gas	Liquid	Liquid	O ₂ in H ₂ O, Soda
Gas	Solid	Solid	H ₂ in Pt
Liquid	Gas	Gas	Moisture in air
Liquid	Liquid	Liquid	Alcohol in H ₂ O
Liquid	Solid	Solid	Hg in Ag, Drops f H ₂ O in sugar
Solid	Gas	Gas	Dust in air
Solid	Liquid	Liquid	NaCl in H ₂ O, sea water
Solid	Solid	Solid	Alloys (Brass, steel)

Hydration in Aqueous Solutions

When water dissolves an ionic solid, the “positive ends” of water molecules are attracted to the negatively charged anions and the “negative ends” are attracted to the positively charged cations. This process is called “hydration”.

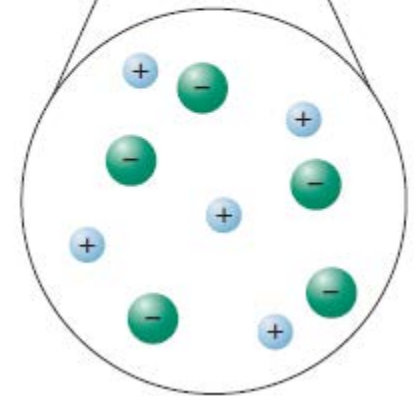
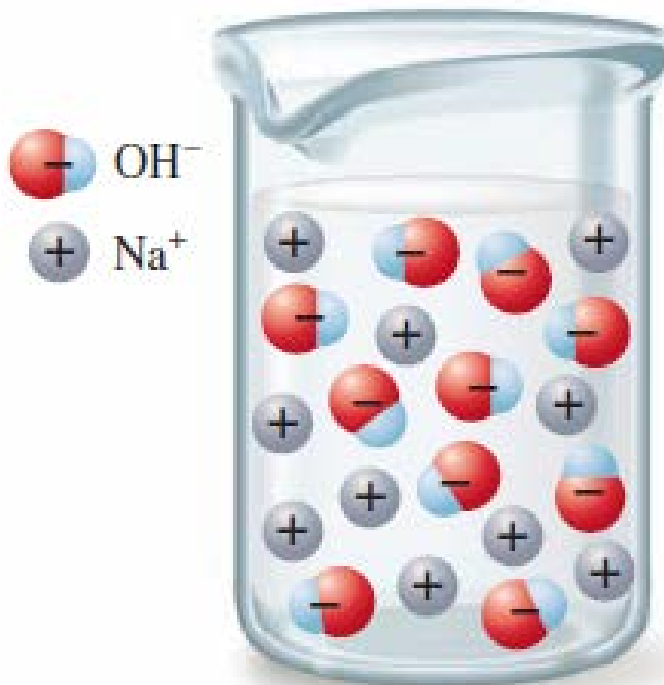
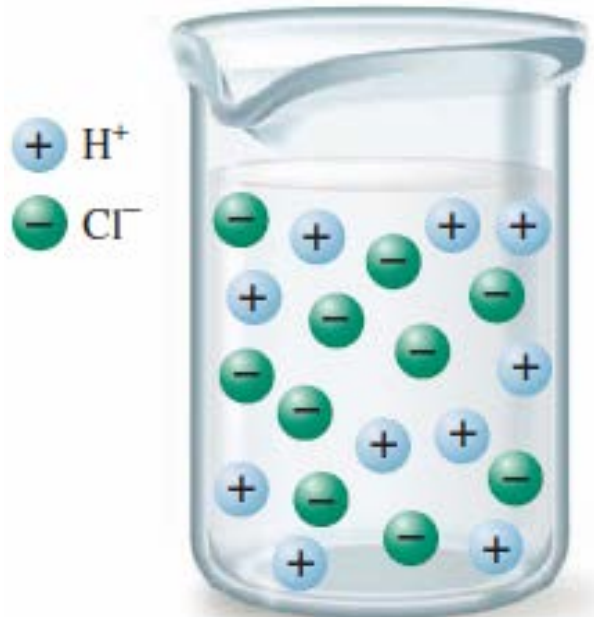


Ionic forces are replaced by stronger water-ion interactions



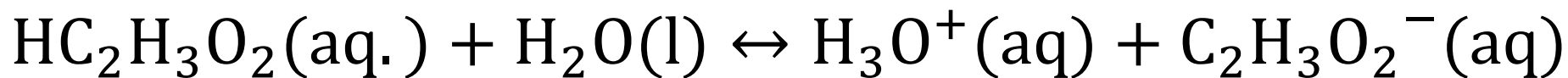
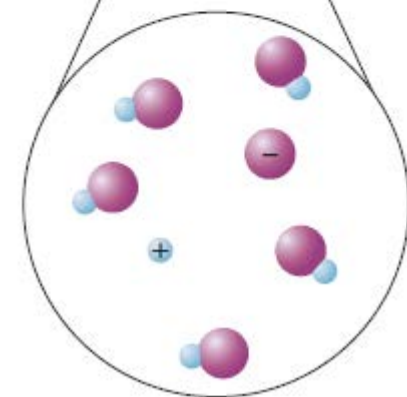
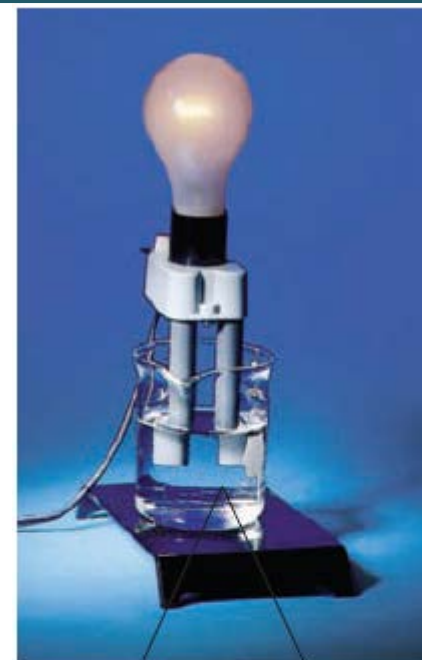
Strong Electrolyte

Substances that are completely ionized (i.e., **conduct electricity efficiently**) when they are dissolved in water. Examples include soluble salts, strong acids, and strong bases.



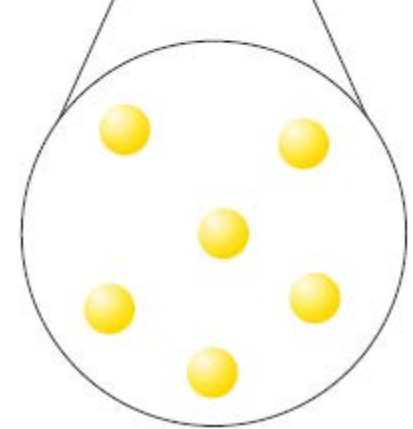
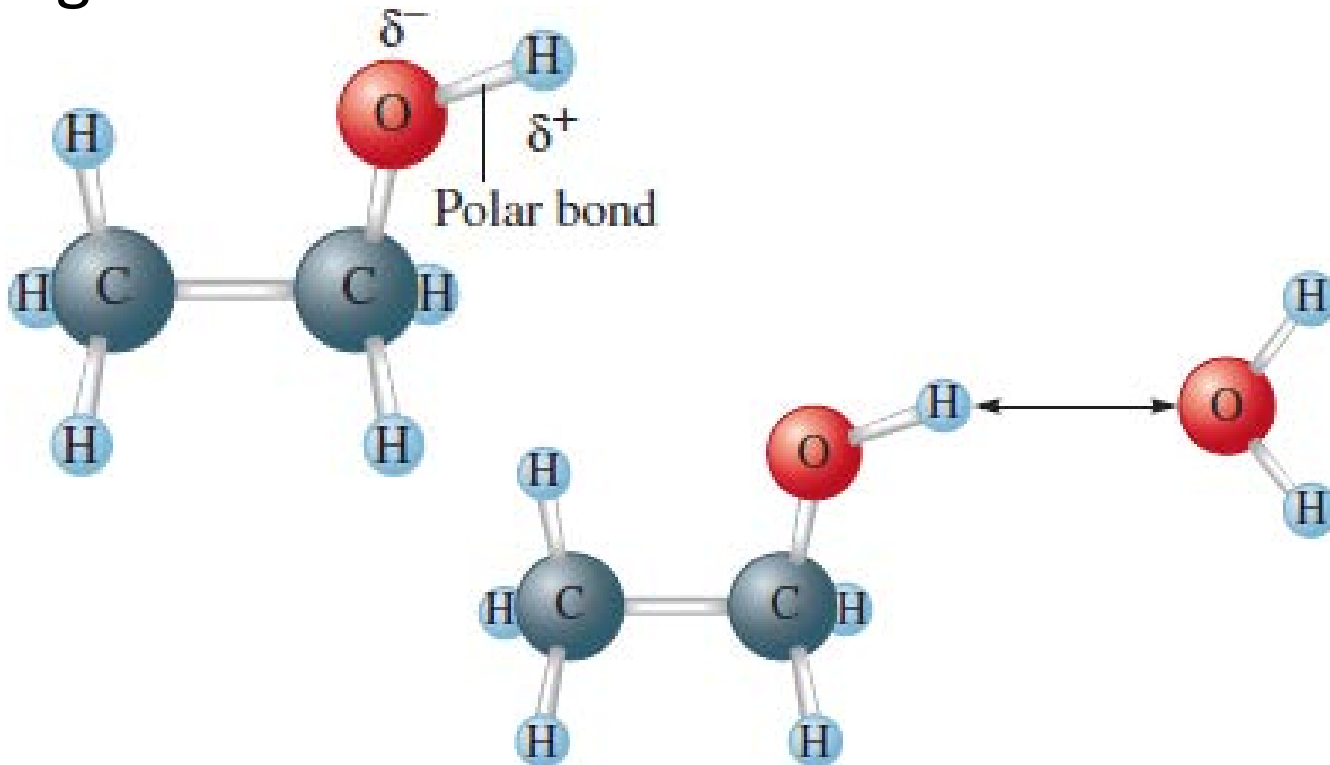
Weak Electrolyte

- ✚ Substances that exhibit a small degree of ionization in water (i.e., **conduct only a small current**).
- ✚ They produce relatively few ions when dissolved in water.
- ✚ Examples include **weak acids (acetic acid)** and **weak bases (ammonia)**.



Nonelectrolyte

- ✚ Substances that dissolve in water but do not produce any ions (i.e., **non conductors for electricity**).
- ✚ Examples include ethanol and glucose



Why do solutions form?

Tendency to Randomness or Disordering

This the only reason operating for gaseous solutions

Solute/Solvent Attractions Like Dissolves Like

- ✚ **Polar solvents** dissolve polar substances.
 - ✚ Ethanol (**not ionic** but **polar**) dissolves in H₂O
- ✚ **Non polar solvents** dissolve non polar substances

Heat of Solution



The amount of heat evolved or absorbed when one mole of a solute dissolves in a solvent at constant pressure to make a dilute solution.

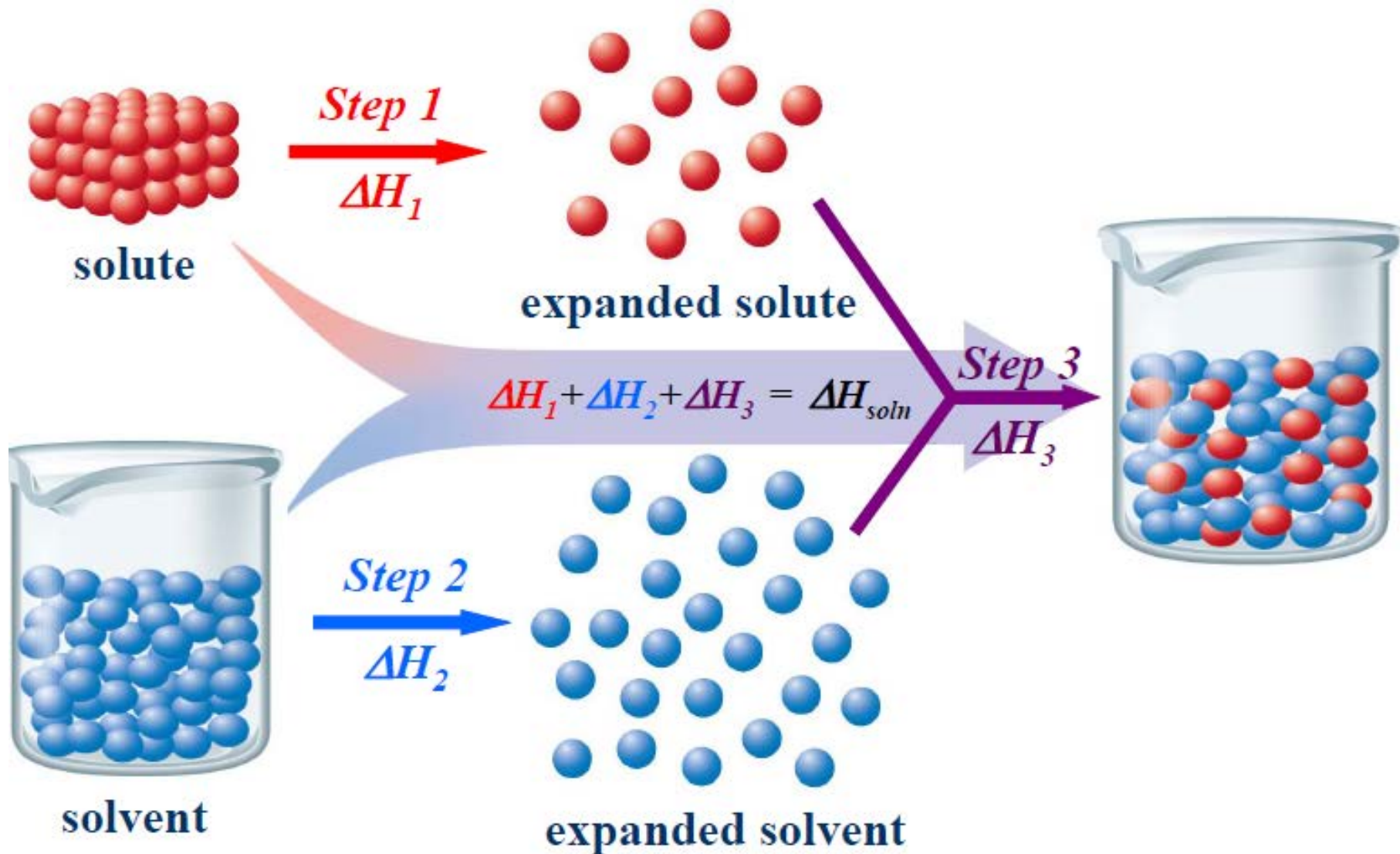
Steps involved in forming a solution

- Separation of solute (ΔH_1) and solvent (ΔH_2) particles
 - This needs energy (**+ve ΔH**), i.e., **Endothermic**
- Attraction of solute and solvents particles
 - This releases energy (**-ve ΔH_3**), i.e., **Exothermic**

$$\Delta H_{\text{sol}} = \Delta H_1 + \Delta H_2 + \Delta H_3$$

- If $\Delta H_1 + \Delta H_2 = \Delta H_3$ (in value but opposite signs), $\Delta H_{\text{sol}} = 0 \rightarrow$ ideal solution
 - almost equal attraction forces between solute/solute, solvent/solvent, and solute/solvent)
- If $\Delta H_1 + \Delta H_2 \neq \Delta H_3$, $\Delta H_{\text{sol}} \neq 0 \rightarrow$ Non ideal solution

Energy (heat) of solution



$$\Delta H_{\text{sol}} = \Delta H_1 + \Delta H_2 + \Delta H_3$$

When do solutions form?

$$\Delta H_{\text{sol}} = \Delta H_1 + \Delta H_2 + \Delta H_3$$

large
+Ve or -Ve

Small
+Ve or -Ve

**Solutions
does not
form**

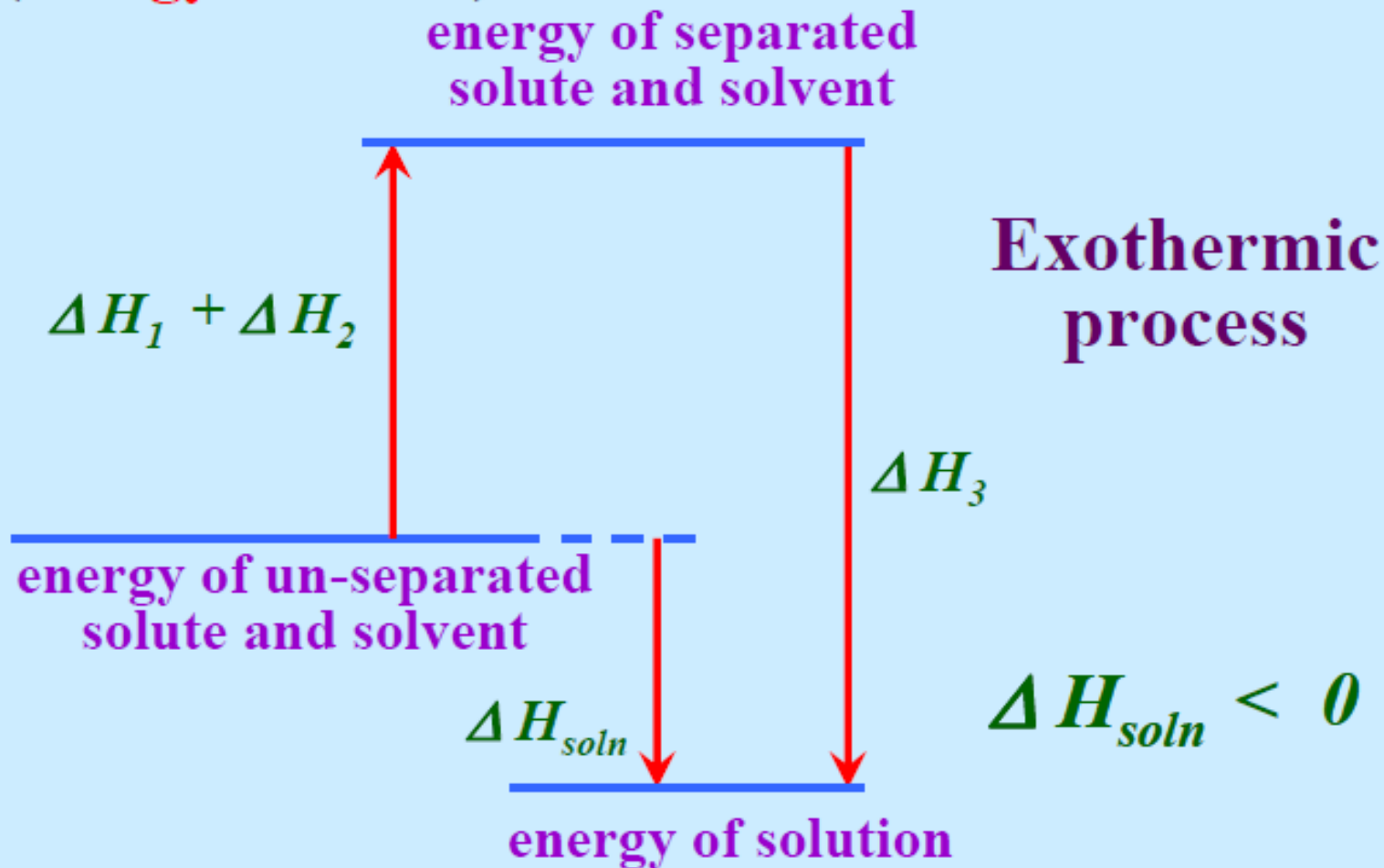
Dissolution of a solute in a solvent to form a solution does not involve a chemical transformation.

**Solutions
form**

Exothermic Process

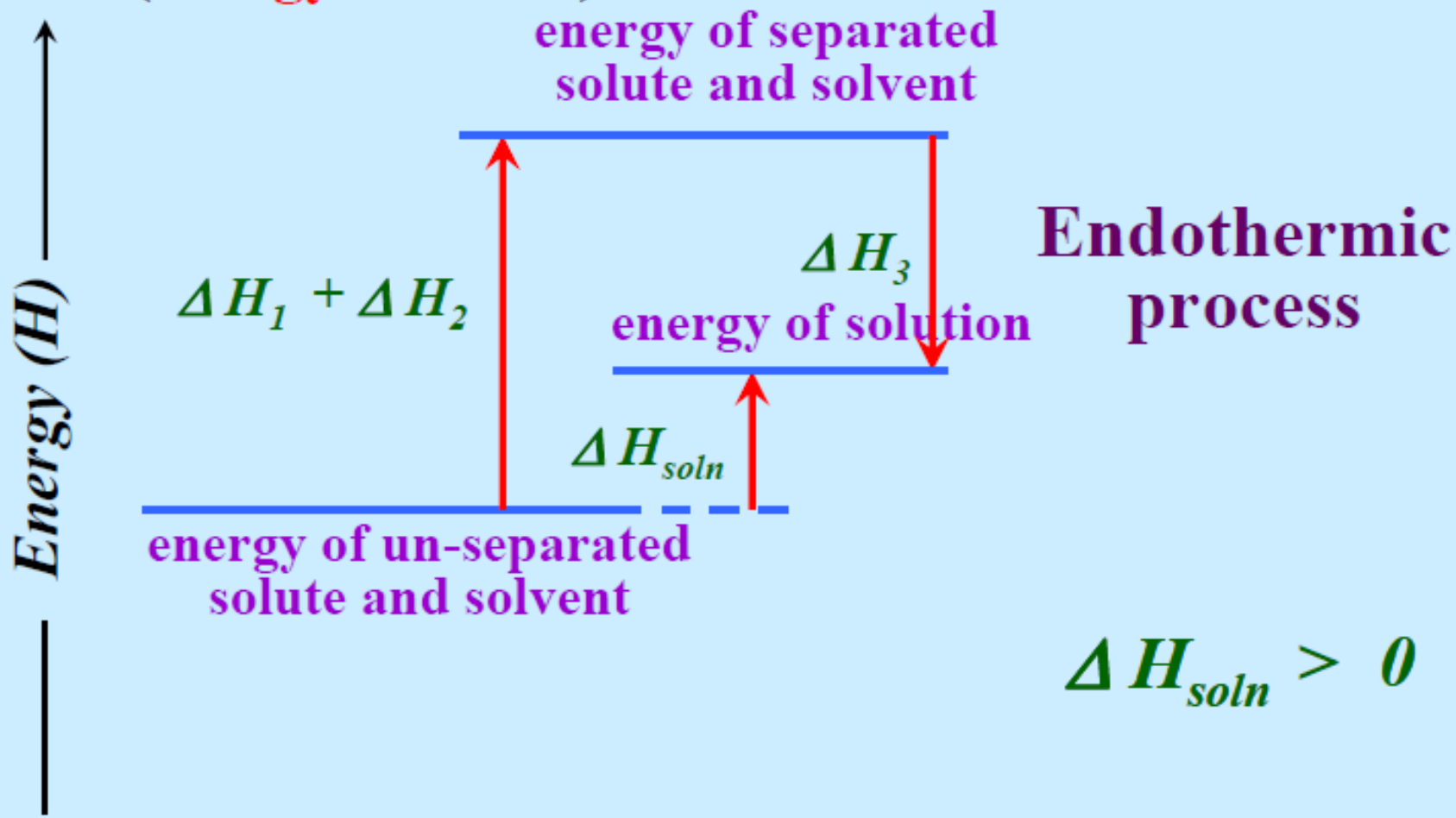
ΔH_{soln} could be positive (**energy absorbed**) or negative (**energy released**)

Energy (H) ↑

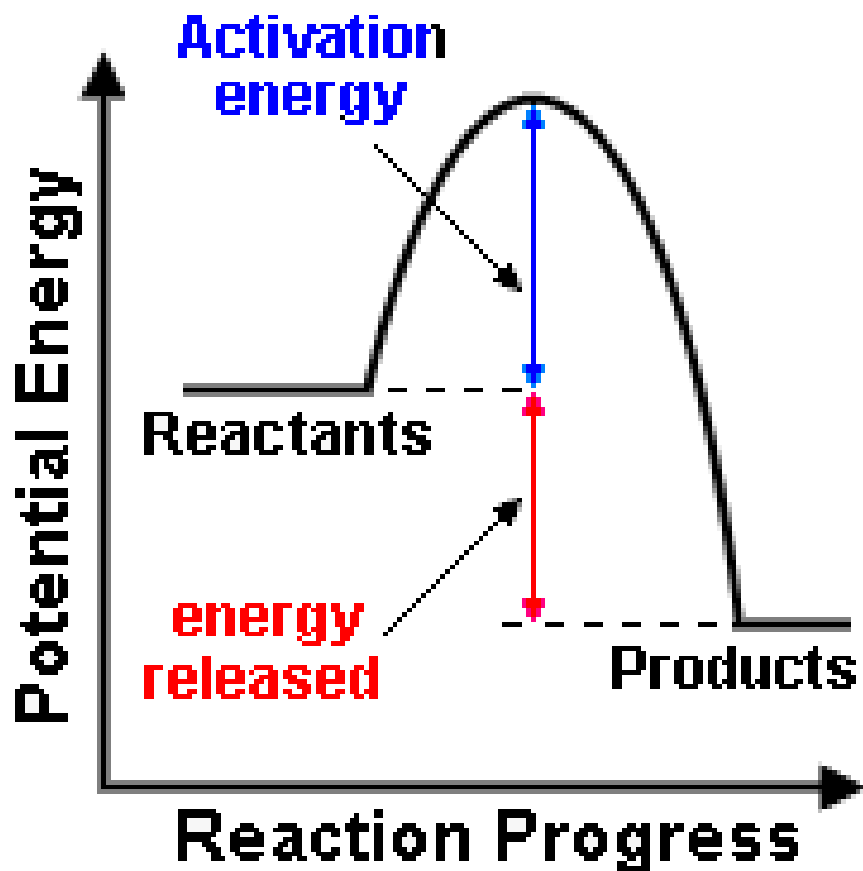


Endothermic Process

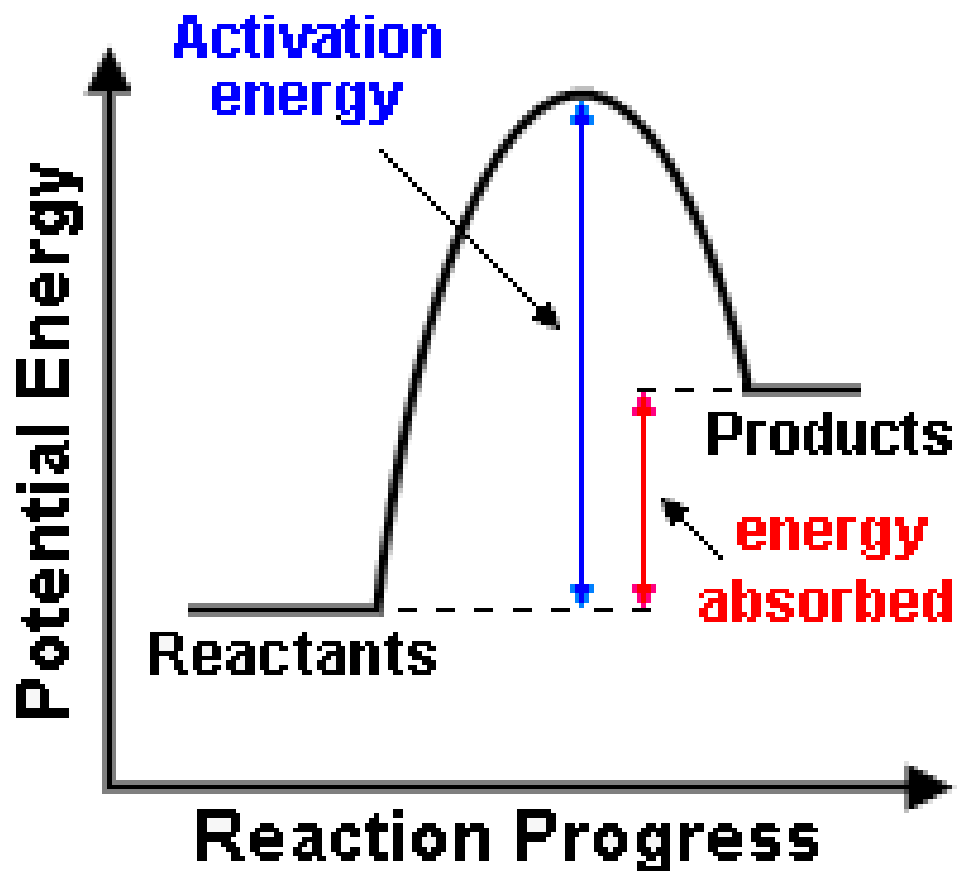
ΔH_{soln} could be positive (**energy absorbed**) or negative (**energy released**)



Potential Energy Diagrams



**Exothermic
reaction**



**Endothermic
reaction**

Nature of solutes and Solvents

Why oil is insoluble in water?

- ✚ **Oil:** a mixture of non polar molecules having only the weak London dispersion forces, i.e., ΔH_1 is small +Ve
- ✚ **Water:** is a polar solvent having the relatively strong H-bonding, i.e., ΔH_2 is large +Ve
- ✚ **Oil–Water interaction:** is almost negligible, i.e., ΔH_3 is small –Ve

$$\Delta H_{\text{sol}} = \Delta H_1 + \Delta H_2 + \Delta H_3 = \text{large +Ve}$$

↪ Solution does not form

Nature of solutes and Solvents

Why NaCl is soluble in water?

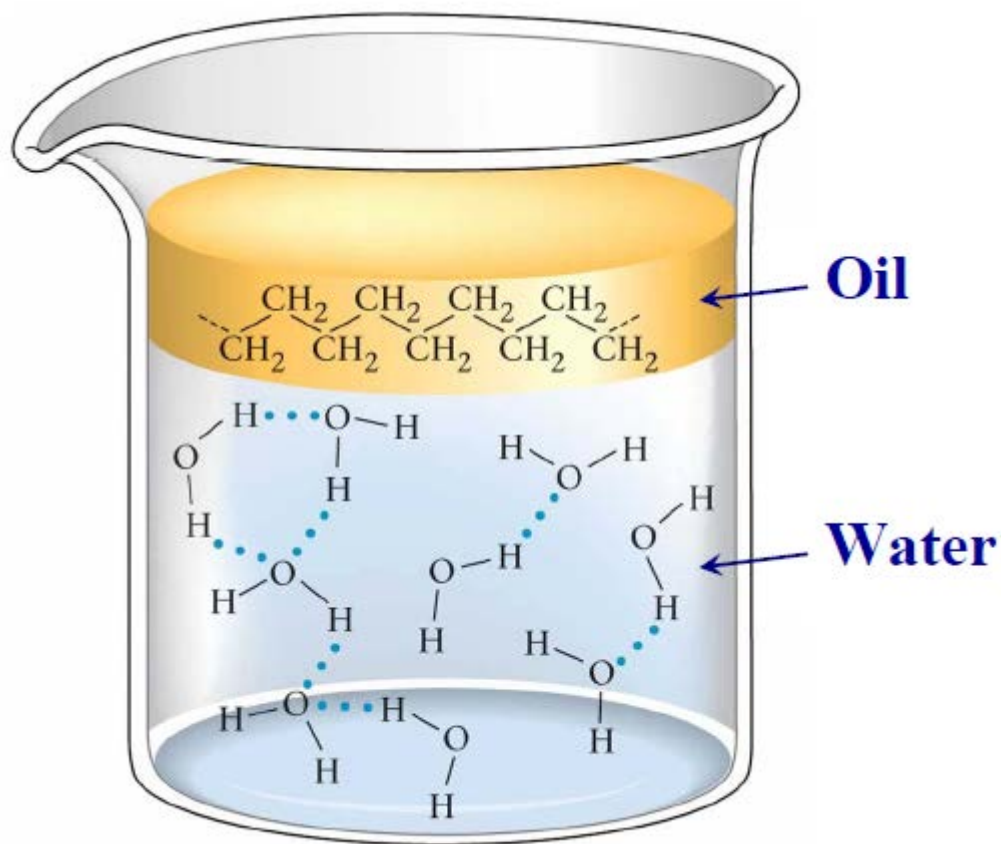
- ✚ **NaCl:** is an ionic solid having the strong ionic bond, i.e., ΔH_1 is large +Ve
- ✚ **Water:** is a polar solvent having the relatively strong H-bonding, i.e., ΔH_2 is large +Ve
- ✚ **NaCl–Water interaction:** is strong, i.e., ΔH_3 is large –Ve

$$\Delta H_{\text{sol}} = \Delta H_1 + \Delta H_2 + \Delta H_3 = \text{small +Ve} = +3.9 \text{ kJ mol}^{-1}$$

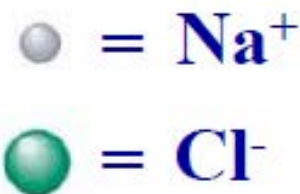
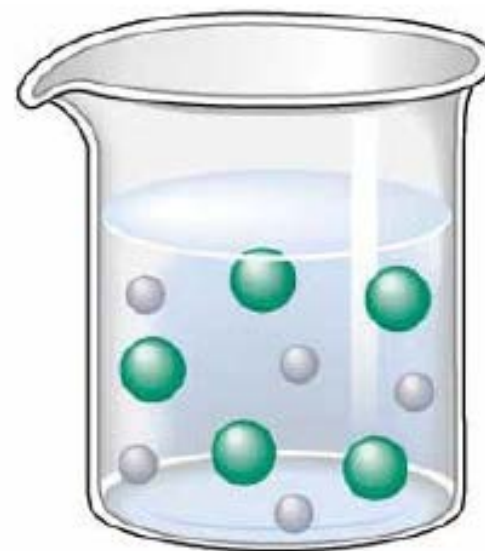


A solution forms

Nature of solutes and Solvents



Polar solvents don't dissolve non-polar solutes



Polar solvents dissolve polar solutes

Nature of solutes and Solvents

	ΔH_1	ΔH_2	ΔH_3	ΔH_{soln}	Outcome
Polar solvent Polar solute	Large +	Large +	Large -	Small \pm	Solution forms
Polar solvent Non-polar solute	Small +	Large +	Small -	Large +	No solution forms
Non-polar solvent Non-polar solute	Small +	Small +	Small -	Small \pm	Solution forms
Non-polar solvent Polar solute	Large +	Small +	Small -	Large +	No solution forms

Solubility

The mass of solute necessary to form a saturated solution with a given mass of solvent at a specific temperature.

- Its unit is usually expressed in $\text{g solute}/100 \text{ g solvent}$ or in $\text{mole solute}/\text{g solvent}$.
- A saturated solution: is a solution containing the maximum amount of solute soluble in a definite amount of solvent at a given temperature (**equilibrium concentration**)

Supersaturated solution

- is a solution containing more solutes than the equilibrium amount.
- It is unstable and tends to move toward saturation under proper conditions



Unsaturated
solution




Saturated
solution







Supersaturated
solution

Solubility (S) and equilibrium

 In saturated solutions, a dynamic equilibrium exists between the undissolved solute and the soluble solute in solution



Factors affecting solubility


-  Temperature
-  Pressure
-  Concentration
-  Nature of solutes and solvents

Effect of T on S of a gas in a liquid

- ❖ At constant pressure, the solubility of gases in liquids always **decreases** with T.
- ❖ The reasons are complicated where a very close competition exists between the two parameters responsible for solution formation (**randomness and attractions**)

Effect of T on S of solids & liquids in liquids



 If equilibrium is distorted by any factor, the equilibrium will shift toward the direction restoring equilibrium (Le Chatelier Principle)


Endothermic Reactions



 Increasing T shifts the reaction to right increasing S

Exothermic Reactions



 Increasing temperature shifts the reaction to left
lowering the solubility of the solute

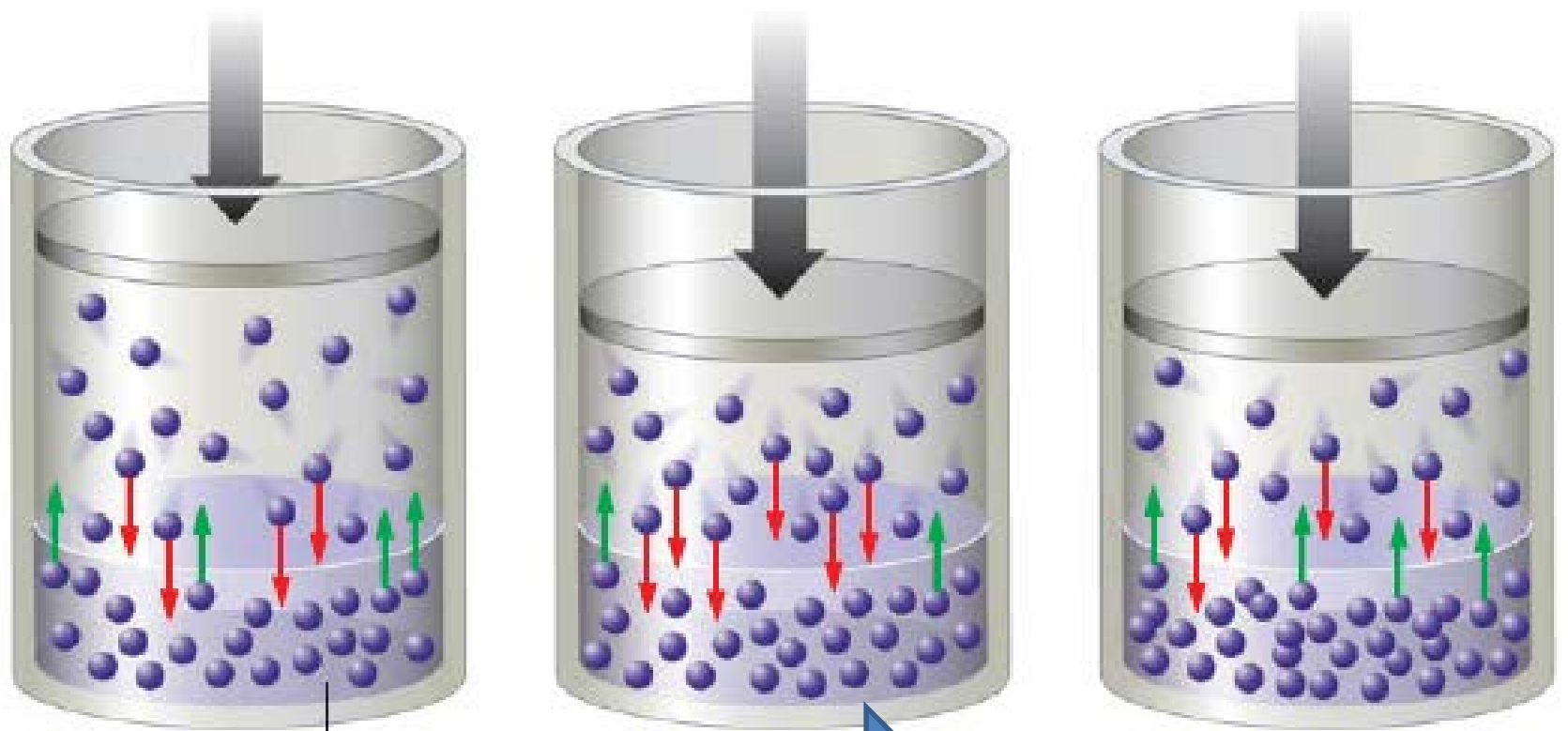
Effect of Pressure on S of gases

- ❖ **Pressure** has a significant effect in case of gaseous solutes **since liquids and solids are incompressible**
- ❖ Carbonated beverages, for example, are always bottled at **high pressures** of carbon dioxide to ensure a high concentration of carbon dioxide in the liquid.
- ❖ The **fizzing** that occurs when you open a **can of soda** results from the escape of gaseous carbon dioxide, **because** under these conditions the pressure of CO_2 above the solution is much lower than that used in the bottling process.

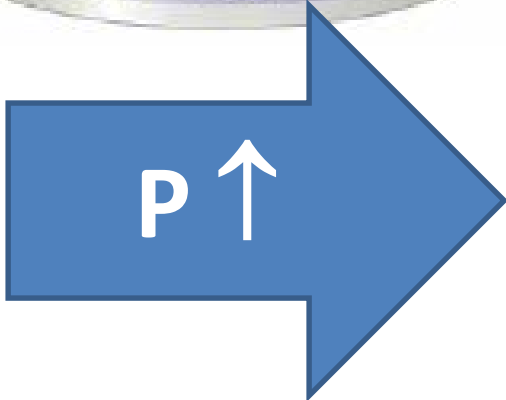
- Consider a closed container that is partially filled with a solution (gas in liquid)

Gas + Solvent \leftrightarrow Solution

- The gas molecules are entering and leaving the solution at the same rate.
- If P is suddenly increased, the number of gas molecules per unit volume increases, and the gas enters the solution at a higher rate than it leaves.
- As the concentration of dissolved gas increases, the rate of the escape of the gas also increases until a new equilibrium is reached, where the solution contains more dissolved gas than before.



solution



🍷 new equilibrium with a higher solubility

Henry's law

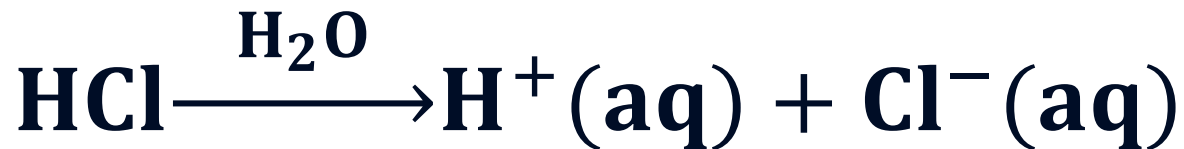
✚ The **amount** of a gas dissolved in a solution is **directly proportional** to the **pressure** of the gas above the solution.

$$C = kP$$

- ✚ C: concentration of the dissolved gas (**S**),
- ✚ k: a **constant** characteristic of a particular solution,
- ✚ P: the **partial pressure** of the gaseous solute above the solution.

Henry's law

- Henry's law is obeyed most accurately for dilute solutions of gases that do not dissociate in or react with the solvent.
- For example, Henry's law is obeyed by oxygen gas in water, but it does not correctly represent the behavior of gaseous hydrogen chloride in water because of the dissociation reaction



Exercise

A certain soft drink is bottled so that a bottle at 25°C contains CO₂ gas at a pressure of 5.0 atm over the liquid. Assuming that the partial pressure of CO₂ in the atmosphere is 4.0×10^{-4} atm, calculate the equilibrium concentrations of CO₂ in the soda both before and after the bottle is opened. The Henry's law constant for CO₂ in aqueous solution is 3.1×10^{-2} mol/L atm . atm at 25°C.

Solution

Before opening

$$\begin{aligned} C &= kP = \left(\frac{3.1 \times 10^{-2} \text{ mol}}{\text{L} \cdot \text{atm}} \right) \times (5.0 \text{ atm}) \\ &= 0.16 \text{ mol/L} \end{aligned}$$

After opening

$$\begin{aligned} C &= kP = \left(\frac{3.1 \times 10^{-2} \text{ mol}}{\text{L} \cdot \text{atm}} \right) \times (4.0 \times 10^{-4} \text{ atm}) \\ &= 1.2 \times 10^{-5} \text{ mol/L} \end{aligned}$$

- Note the **large change** from **0.16** to **1.2** $\times 10^{-5}$ mol/L in concentration of CO₂.
- This is why soda **disappears** after being open for a while.

Effect of structure on S

- ✿ **Solubility** is favored if the solute and solvent have similar polarities.
- ✿ Since it is the molecular structure that determines polarity, there should be a definite connection between **structure** and **solubility**.

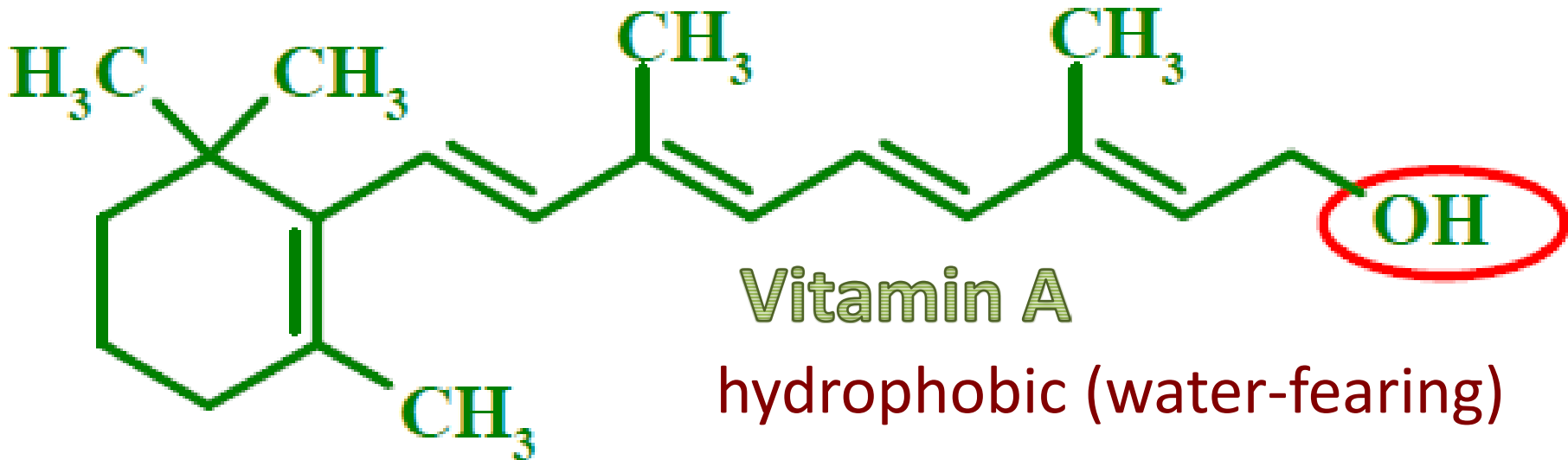
Vitamins can be divided into two classes:

Fat-soluble

**Vitamins A, D, E
and K**

Water-soluble

Vitamins B and C



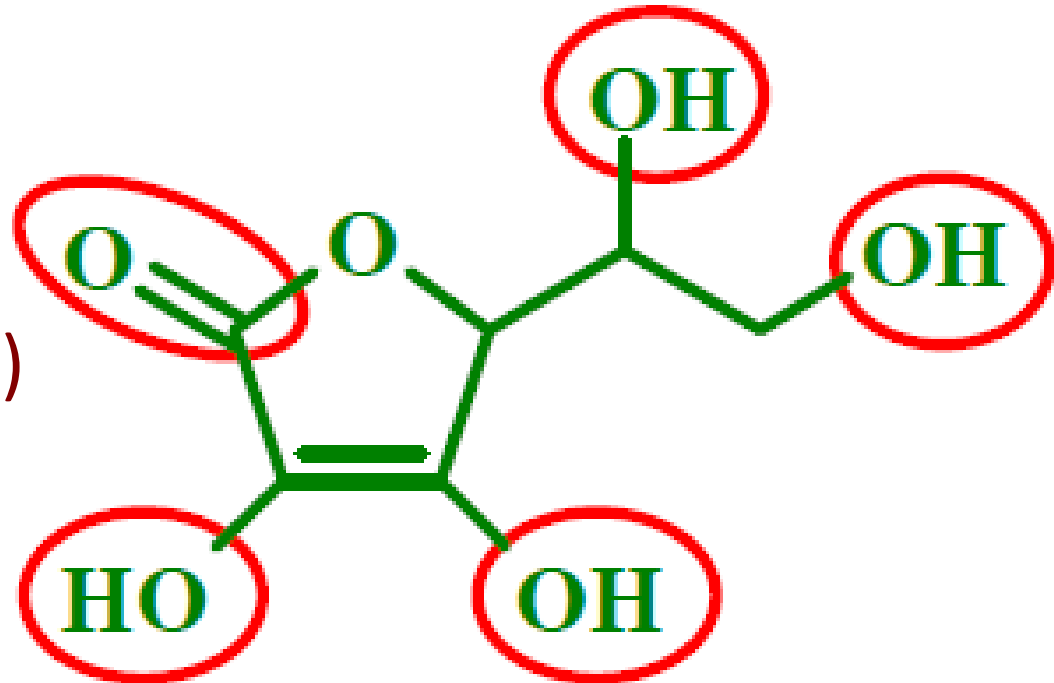
hydrophobic (water-fearing)

soluble in nonpolar materials such as body fat

Vitamin C

water-soluble

hydrophilic (water-loving)



Concentrations

Composition of Solutions



Mass of a solute per mass of solvent or solution


- ▶ Mole fraction and Mole percent,
- ▶ Mass fraction and Mass percent,
- ▶ Molality



Mass of a solute per Volume of solution

- ▶ Molarity
- ▶ Normality

Mole fraction, X

 The ratio of the no. of moles of a given component in a solution to the total no. of moles of all components

$$X_A = \frac{n_A}{n_A + n_B + n_C + \dots + n_Z}$$


Unitless

$$\sum X_i = 1$$

Mole Percent

is the mole fraction multiplied by 100

Mass fraction

 The ratio of the mass of a given component in a solution to the total mass of all components

$$(\text{mass fraction})_A = \frac{m_A}{m_A + m_B + m_C + \dots + m_Z}$$

Unitless

$$\sum (\text{mass fraction})_i = 1$$

Mass Percent is the mass fraction multiplied by 100

A solution labeled “0.9 % NaCl” means 0.9 g NaCl is dissolved in 99.1 g H₂O or 100 g of solution

Molality (Molal concentration)

The no. of **moles** of **solute** dissolved in **1 kg** of **solvent**

$$m = \frac{n_{\text{solute}}}{\text{mass of solvent (kg)}}$$

$$m = \frac{W_{\text{solute}}}{Mwt_{\text{solute}}} \times \frac{1000}{W_{\text{solvent (g)}}$$

n_{solute} : moles of solute

Mwt_{solute} : molar mass of solute

W_{solute} : mass of solute

W_{solvent} : mass of solvent

Molarity (Molar concentration)

 The no. of moles of solute dissolved in 1 liter of solution

$$M = \frac{n_{\text{solute}}}{\text{Volume of solution (L)}} = \frac{W_{\text{solute}}}{\text{Mwt}_{\text{solute}} \times V \text{ (L)}}$$

n_{solute} : no. of moles of solute


$\text{Mwt}_{\text{solute}}$: molar mass of solute

W_{solute} : mass of solute

V : Volume of solution in liter

$$W_{\text{solute}}(\text{g}) = M(\text{mol/L}) \times \text{Mwt}_{\text{solute}}(\text{g/mol}) \times V \text{ (L)}$$

Normality

 The number of equivalents of solute per liter of solution

$$\begin{aligned}\text{No. Equivalent} &= \frac{\text{mass}_{\text{solute}}(\text{g})}{\text{Equivalent mass}_{\text{solute}}(\text{g/equivalent})} \\ &= \frac{W_{\text{solute}}}{\text{Eq. wt}_{\text{solute}}}\end{aligned}$$

The **definition** of the “**equivalent mass**” and “**equivalent**” depends on the reaction taking place in the solution.

Equivalent mass

Acid-Base Rxs

$$\text{Eq.wt} = \frac{\text{molar mass}}{\text{No of replacable H}^+ \text{ or OH}^-}$$

An “**equivalent**” is the mass of acid or base that can furnish or accept exactly 1 mole of protons (H⁺ ions).

Acid/Base	Mwt, g/mol	Equivalent mass	M/N relationship
HCl	36.5	36.5	1M = 1N
H ₂ SO ₄	98	98/2 = 49	1M = 2N
NaOH	40	40	1M = 1N
Ca(OH) ₂	74	74/2 = 37	1M = 2N

Equivalent mass

Oxidation-Reduction Rxs

The “**equivalent**” is defined as the quantity of oxidizing or reducing agent that can accept or furnish 1 mole of electrons.



$$\begin{aligned} \text{Equivalent mass of KMnO}_4 &= \frac{\text{molar mass}}{5} \\ &= \frac{158 \text{ g}}{5} = 31.6 \text{ g} \end{aligned}$$

Equivalent mass

Salt-formation Rxs

$$\text{Equivalent mass of a salt} = \frac{\text{molar mass}}{\text{no. of ions} \times \text{its valency}}$$

$$\text{NaCl: Eq. wt} = \text{MWt}/1$$

$$\text{Na}_3\text{PO}_4: \text{Eq.Wt} = \text{Mwt} / 3$$

Normality

$$N = \frac{\text{no. equivalents}_{\text{solute}}}{\text{Volume of solution (L)}} = \frac{W_{\text{solute}}}{\text{Eq. wt}_{\text{solute}} \times V \text{ (L)}}$$

n_{solute} : no. of moles of solute

$\text{Eq. wt}_{\text{solute}}$: Equivalent mass of solute

W_{solute} : mass of solute

V : Volume of solution in liter

$W_{\text{solute}}(\text{g})$

$= N \text{ (equivalents/L)} \times \text{Eq. wt}_{\text{solute}}(\text{g/equivalents}) \times V \text{ (L)}$

Exercise

A solution is prepared by mixing 1.00 g ethanol (C_2H_5OH) with 100.0 g water to give a final volume of 101 mL. Calculate the molarity, mass percent, mole fraction, and molality of ethanol in this solution.

Solution

molar mass of ethanol = 46.07 g/mol

$$\begin{aligned} M &= \frac{W_{solute}}{Mwt_{solute} \times V (L)} \\ &= \frac{1.0 \text{ g}}{46.07 \text{ g mol}^{-1} \times 101 \text{ mL}} \times \frac{1000 \text{ mL}}{1 \text{ L}} \\ &= 0.215 \text{ mol/L} \\ &= 0.215 \text{ M} \end{aligned}$$

mass percent of ethanol

$$\begin{aligned} &= \frac{m_{\text{ethanol}}}{m_{\text{ethanol}} + m_{\text{water}}} \times 100 \\ &= \frac{1.0}{1.0 + 100.0} \times 100 = 0.990 \% \end{aligned}$$

$$\begin{aligned} X_{\text{ethanol}} &= \frac{n_{\text{ethanol}}}{n_{\text{ethanol}} + n_{\text{water}}} = \\ &= \frac{1.0 \text{ g} / 46.07 \text{ g mol}^{-1}}{1.0 \text{ g} / 46.07 \text{ g mol}^{-1} + 100.0 \text{ g} / 18.0 \text{ g mol}^{-1}} \\ &= 0.00389 \end{aligned}$$

$$m = \frac{w_{\text{ethanol}}}{M_{\text{wt ethanol}}} \times \frac{1000}{w_{\text{water}} (\text{g})}$$

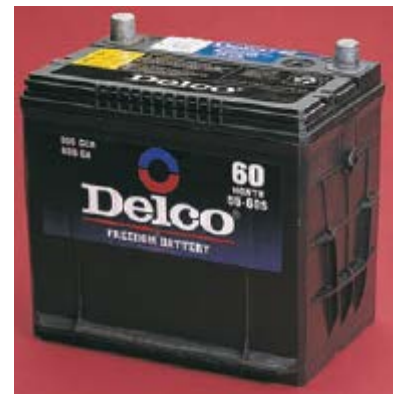
$$= \frac{1.0 \text{ g}}{46.07 \text{ g mol}^{-1}} \times \frac{1000}{100.0 (\text{g})}$$

$$= 0.217 \text{ mol kg}^{-1} = 0.217 \text{ m}$$

Exercise

molar mass of sulfuric acid = 98 g/mol

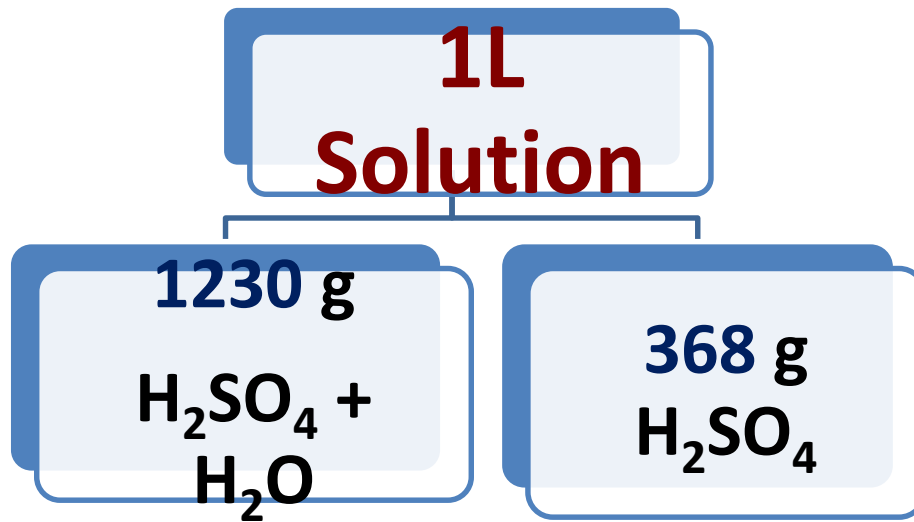
The electrolyte in automobile lead storage batteries is a 3.75 M sulfuric acid solution that has a density of 1.230 g/mL. Calculate the mass percent, molality, and normality of the sulfuric acid?



Solution

+ $d = 1.230 \text{ g/mL} = 1230 \text{ g/L} \rightarrow 1230 \text{ g solution (H}_2\text{SO}_4 + \text{H}_2\text{O)}$ in every liter of solution (H₂SO₄ + H₂O)

+ **Molarity** of H₂SO₄ = 3.75 M \rightarrow means we have 3.75 mole (368 g) of H₂SO₄ in every liter of solution (H₂SO₄ + H₂O)



mass of water in 1L solution = $1230 - 368 = 862 \text{ g}$

$$\begin{aligned} \text{mass percent of ethanol} &= \\ &= \frac{m_{\text{sulfuric acid}}}{m_{\text{sulfuric acid}} + m_{\text{water}}} \times 100 \\ &= \frac{368}{368 + 862} \times 100 = 29.9 \% \end{aligned}$$

$$\begin{aligned} m &= \frac{W_{\text{sulfuric acid}}}{M_{\text{wt}}_{\text{sulfuric acid}}} \times \frac{1000}{W_{\text{water}} \text{ (g)}} \\ &= \frac{368 \text{ g}}{98 \text{ g mol}^{-1}} \times \frac{1000}{862 \text{ (g)}} = 4.35 \text{ m} \end{aligned}$$

$$N = M \times 2 = 3.75 \times 2$$

$$= 7.5 \text{ equivalents per liter (N)}$$