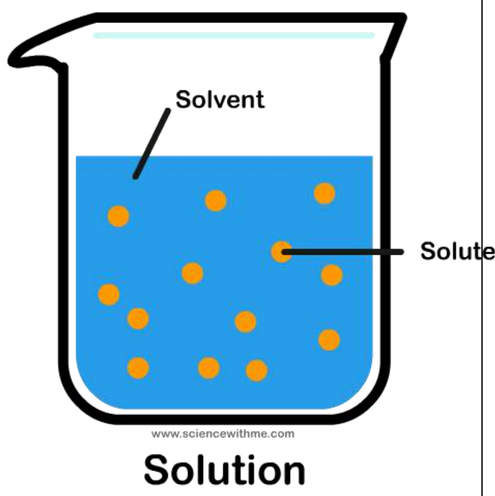
Chapter 9

Part 1

General properties of Solution

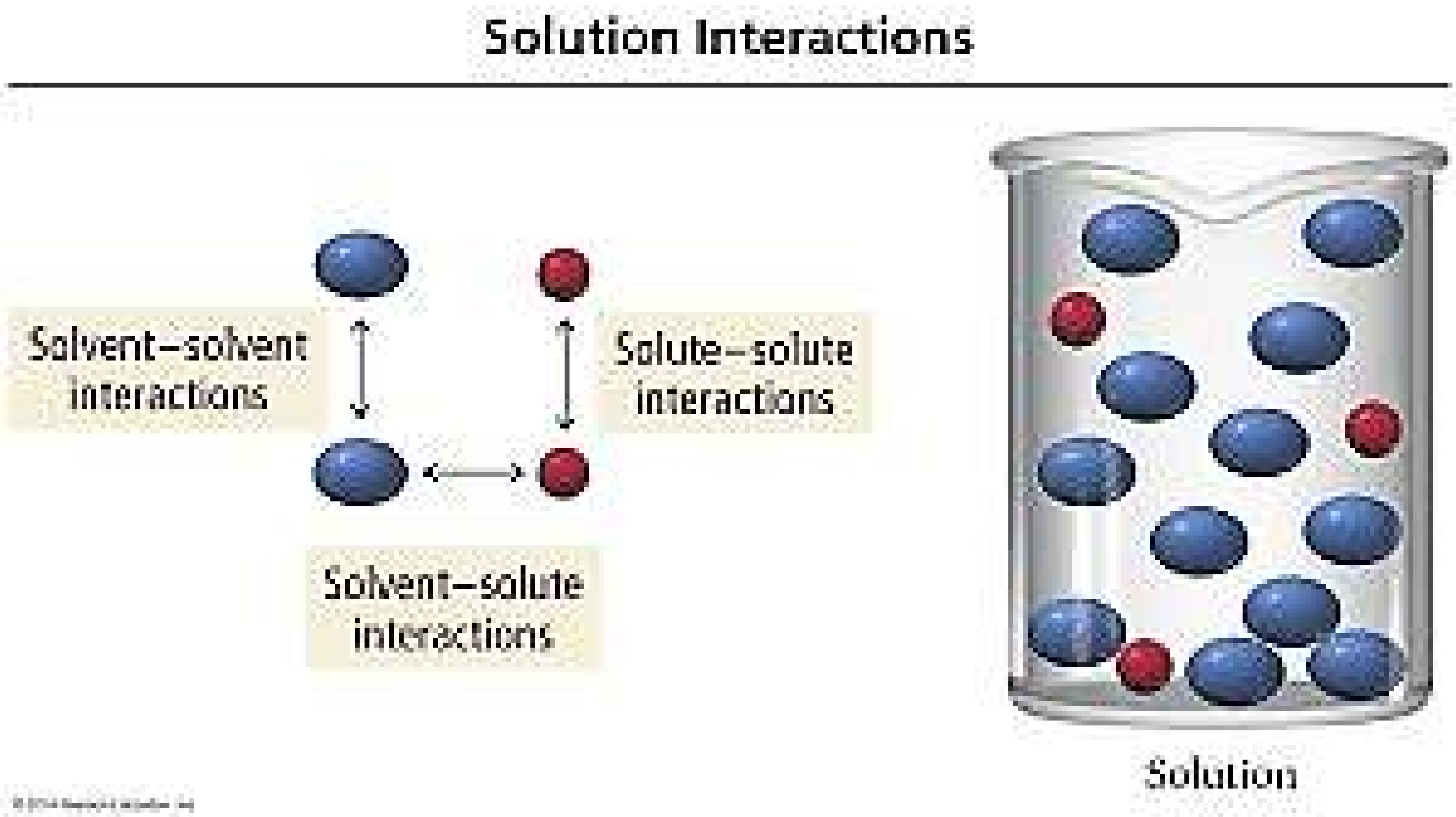
Solution

- **A solution** is a homogeneous mixture of two or more substances.
- The substance present in a smaller amount is called the **solute**, whereas the substance present in a larger amount is called the **solvent.**



- **Dissolution** is the process of dissolving or forming a solution. When dissolution happens, the solute separates into ions or molecules, and each ion or molecule is surrounded by molecules of solvent.

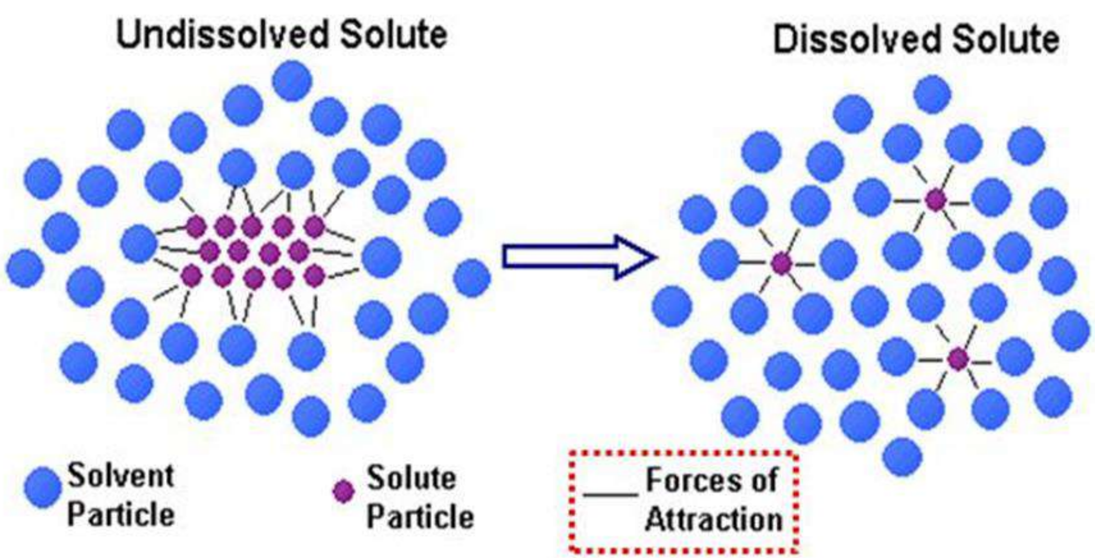
Dissolution



Solvation

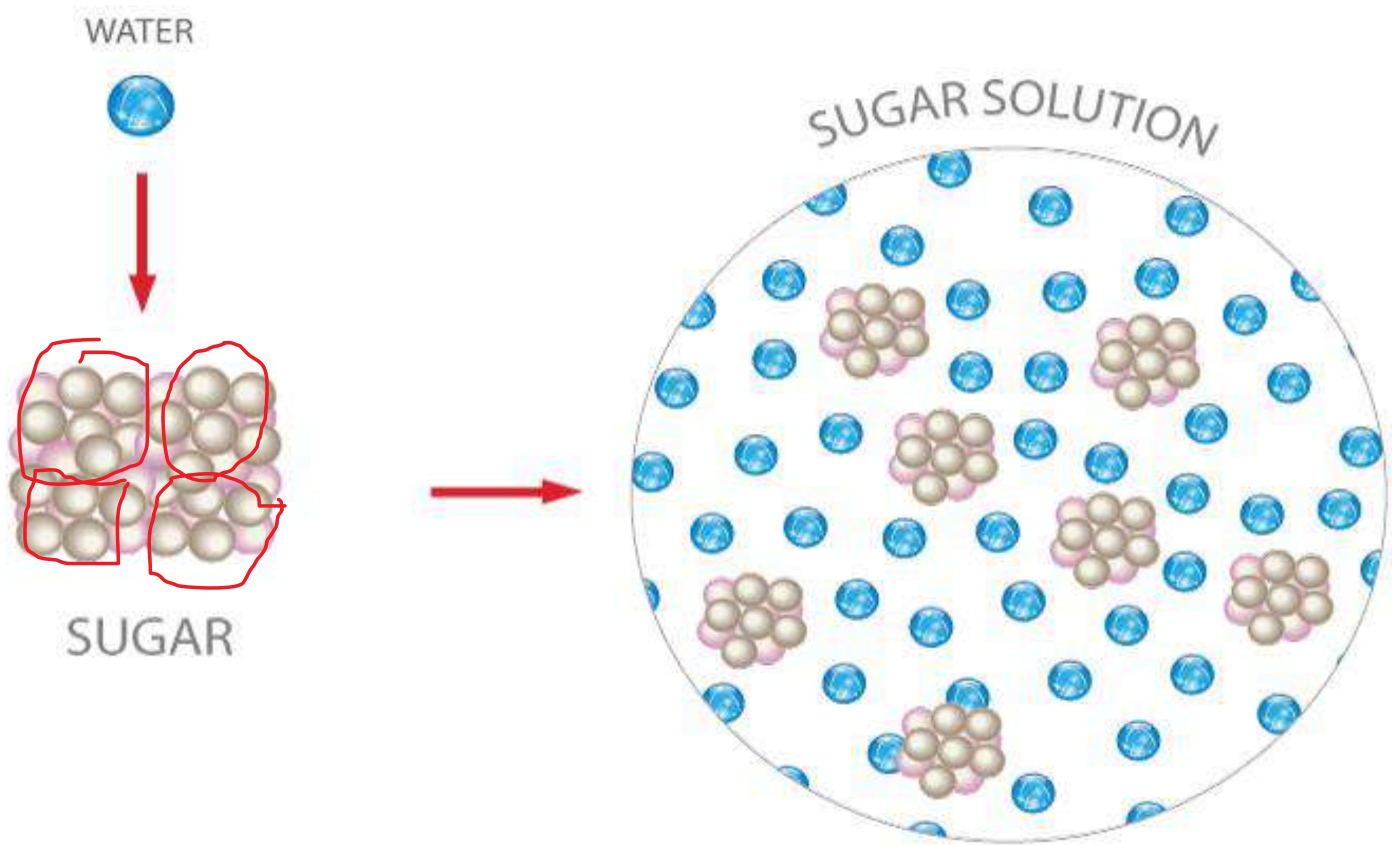
- The interactions between the solute particles and the solvent molecules is called solvation or hydration when the solvent is water).

Particles of **solute** will dissolve **IF** it is ***more attracted*** to the **solvent** particles than ***to itself***

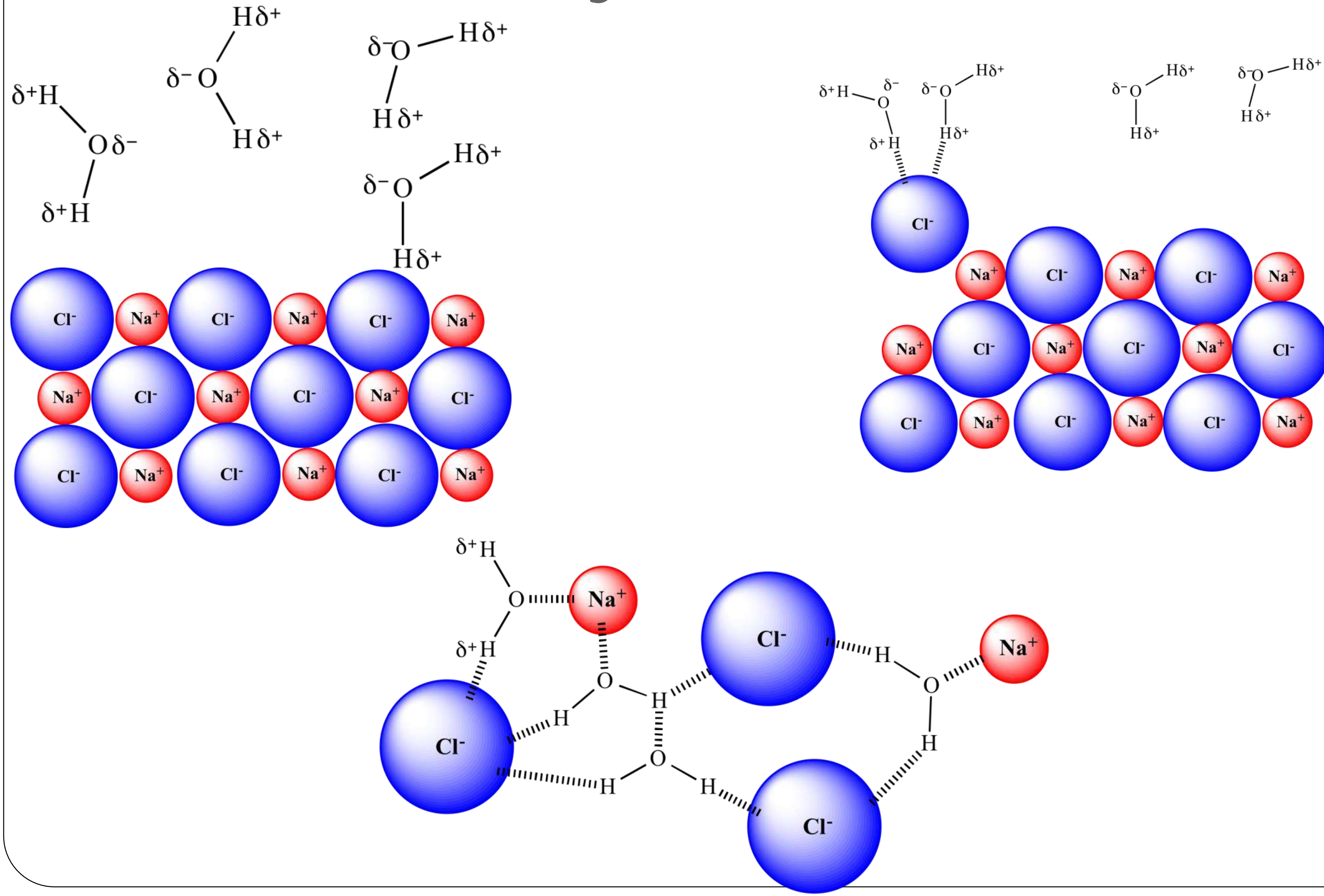


Hydration

$$C_6H_{12}O_6(s) \xrightarrow{H_2O} C_6H_{12}O_6\ (aq)$$



Hydration



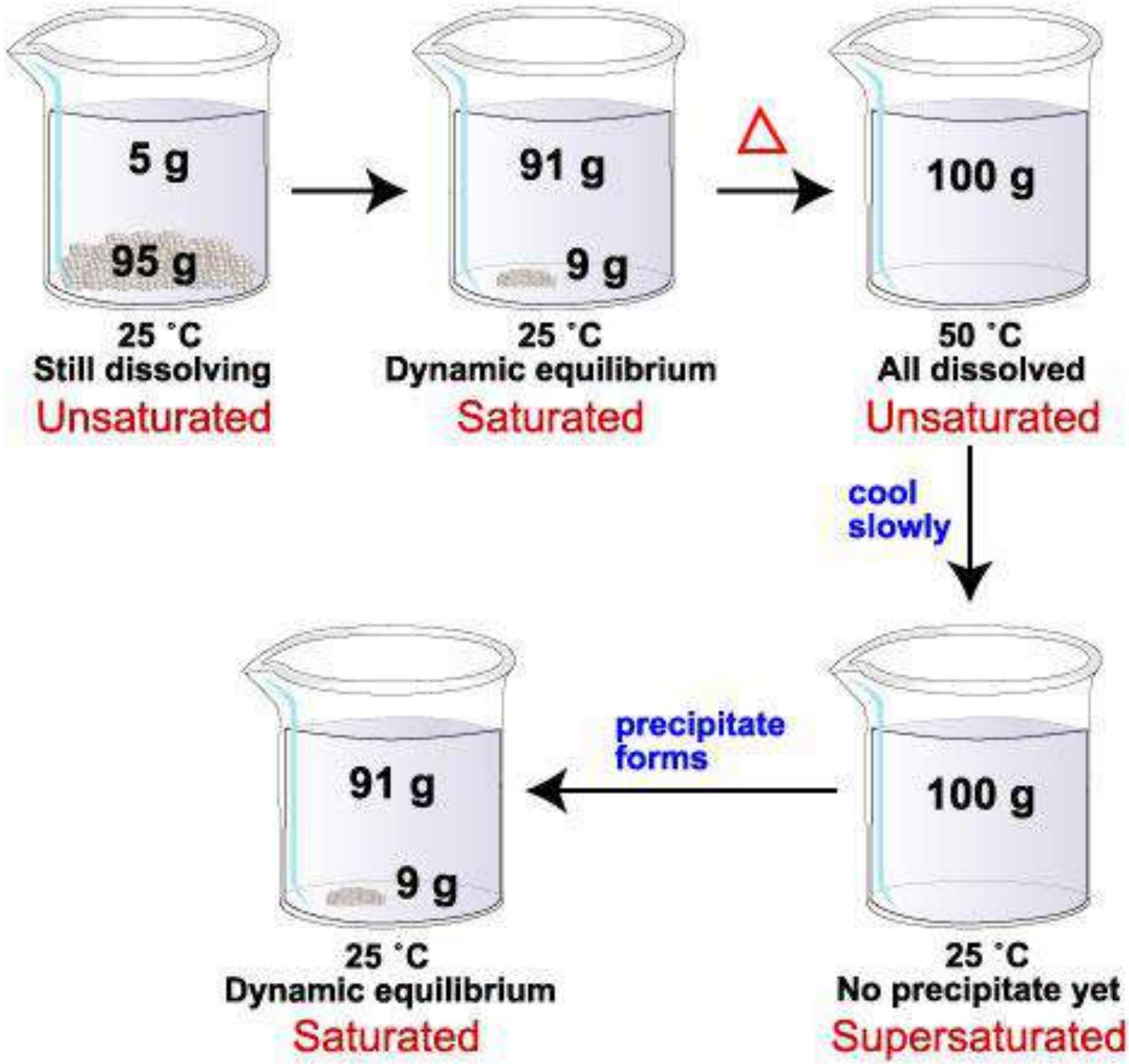
Types of solution according state of matter

TABLE 13.1 Types of Solutions

Solute	Solvent	State of Resulting Solution	Examples
Gas	Gas	Gas	Air
Gas	Liquid	Liquid	Soda water (CO_2 in water)
Gas	Solid	Solid	H_2 gas in palladium
Liquid	Liquid	Liquid	Ethanol in water
Solid	Liquid	Liquid	NaCl in water
Solid	Solid	Solid	Brass (Cu/Zn), solder (Sn/Pb)

Types of Solutions according their capacity

- Chemists also characterize solutions by their capacity to dissolve a solute.
- *A solution that contains the maximum amount of a solute in a given solvent, at a specific temperature,* is called a ***saturated solution.***
- Before the saturation point is reached, the solution is said to be ***unsaturated;*** it *contains less solute than it has the capacity to dissolve.*
- A third type, a ***supersaturated solution,*** *contains more solute than is present in a saturated solution.*
- Supersaturated solutions are not very stable. In time, some of the solute will come out of a supersaturated solution as crystals. *The process in which dissolved solute comes out of solution and forms crystals* is called ***crystallization*** (the opposite process of dissolution).

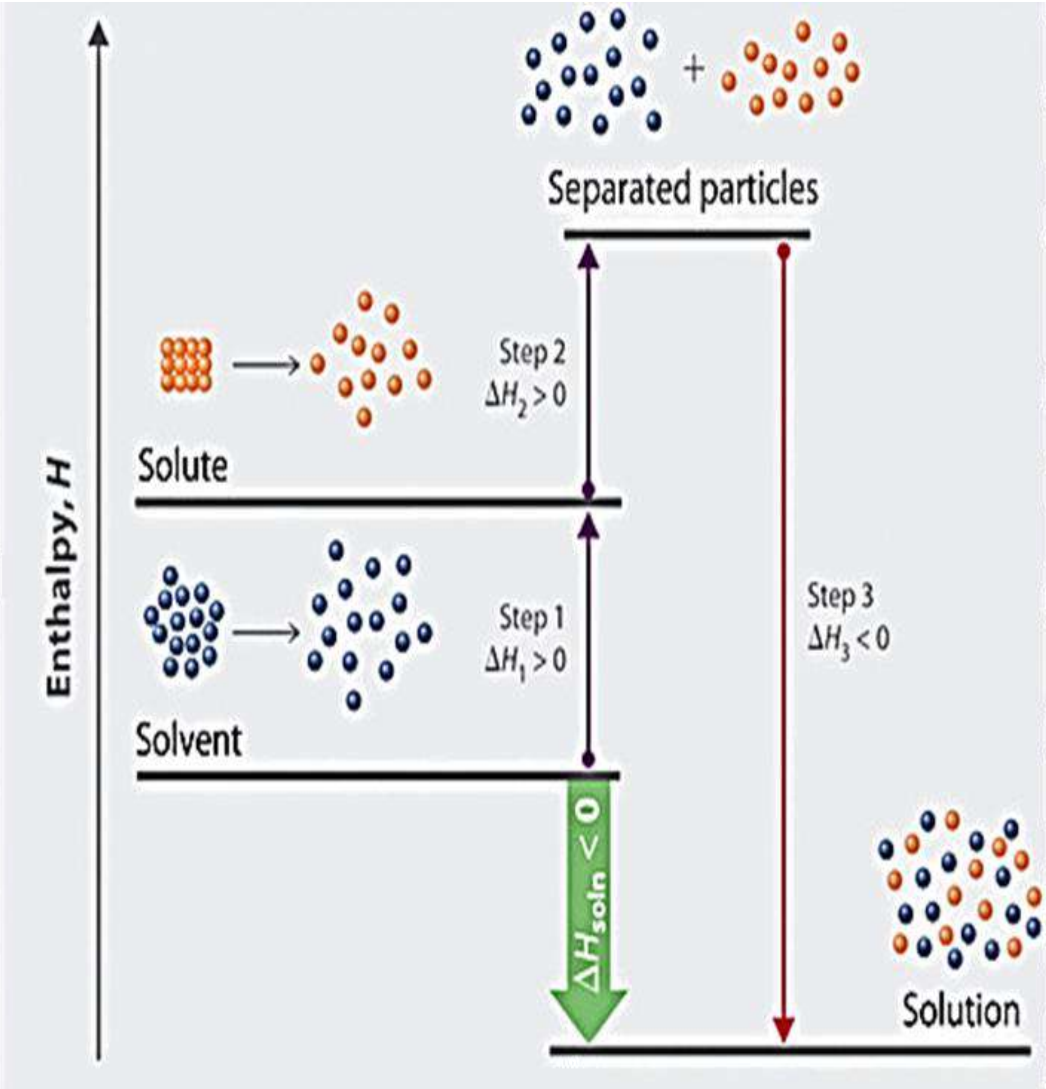

5 g
95 g
25 °C
Still dissolving
Unsaturated
91 g
9 g
25 °C
Dynamic equilibrium
Saturated
△
100 g
50 °C
All dissolved
Unsaturated
cool
slowly
100 g
25 °C
No precipitate yet
Supersaturated
precipitate
forms
91 g
9 g
25 °C
Dynamic equilibrium
Saturated

A Molecular View of the Solution Process with enthalpy changes

- In liquids and solids, molecules are held together by intermolecular attractions. These forces also play a central role in the formation of solutions.
- In the formation of solutions, three types of interactions:
  - solvent-solvent interaction
  - solute-solute interaction
  - solvent-solute interaction
- When a solvent is added to a solution, steps 1 and 2 are both endothermic because energy is required to overcome the intermolecular interactions in the solvent ($\Delta H_1 > 0$) and the solute ($\Delta H_2 > 0$). In contrast, energy is released in step 3, solute-solvent interaction ($\Delta H_3 < 0$).
- The overall enthalpy change in the formation of the solution (ΔH_{soln}) is the sum of the enthalpy changes in the three steps:

$$\Delta H_{soln} = \Delta H_1 + \Delta H_2 + \Delta H_3$$

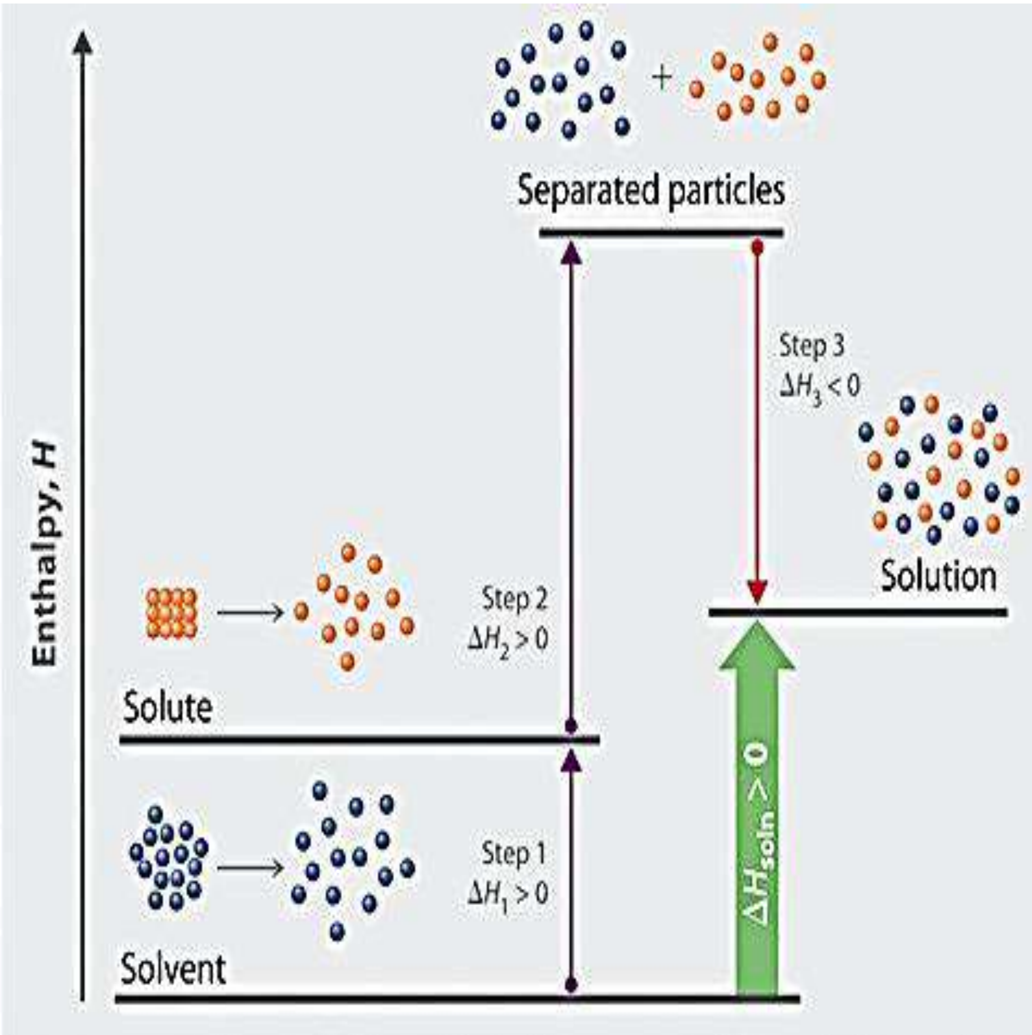
Exothermic solution formation



(a) Exothermic solution formation

When ΔH_3 is larger in magnitude than the sum of ΔH_1 and ΔH_2, the overall process is exothermic ($\Delta H_{soln} < 0$).

Endothermic solution formation



(b) Endothermic solution formation

When ΔH_3 is lesser in magnitude than the sum of ΔH_1 and ΔH_2, the overall process is endothermic ($\Delta H_{soln} > 0$).

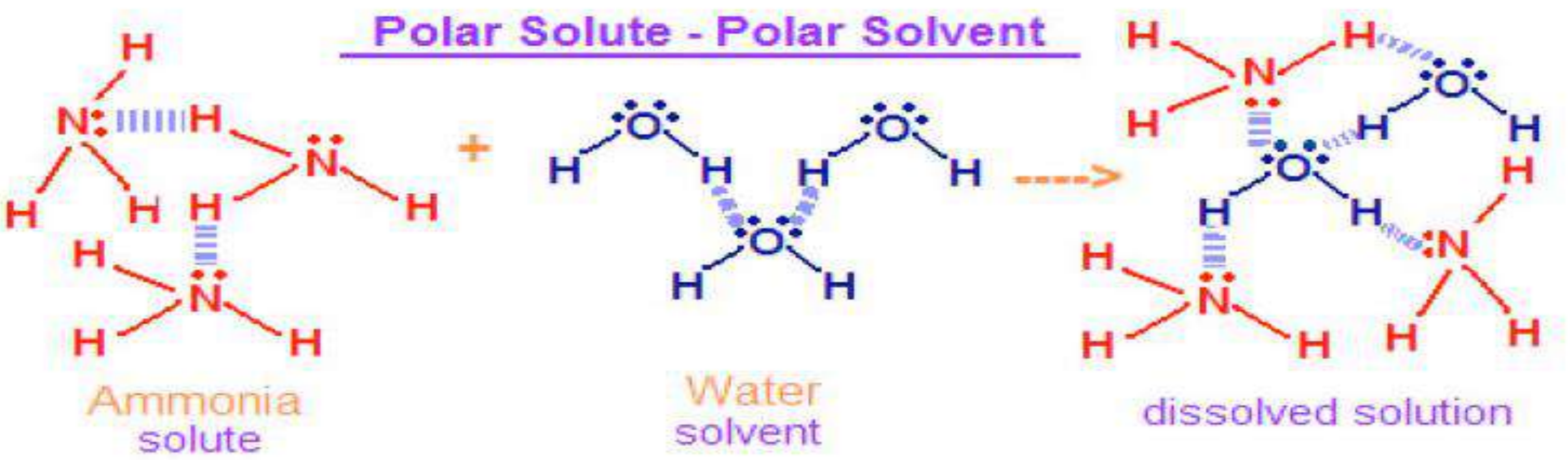
Solubility

- Solubility of the solute (g/L), is defined as the maximum amount of solute that will dissolve in a given quantity of solvent at a specific temperature.
- Chemists refer to substances as soluble, slightly soluble, sparingly, or insoluble in a qualitative sense.
- The saying **"like dissolves like"** helps in predicting the solubility of a substance in a solvent. What this expression means is that two substances with intermolecular forces of similar type and magnitude are likely to be soluble in each other.

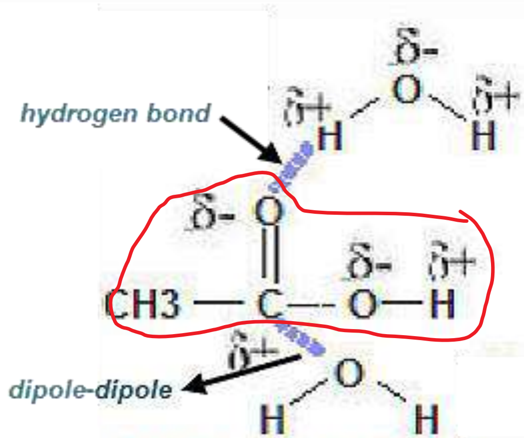
Like dissolves like

In non-polar compounds, the major intermolecular forces are the very weak induced dipoles. The weak bonds in the solution replace the weak bonds in the pure non-polar substances.

Like dissolves like

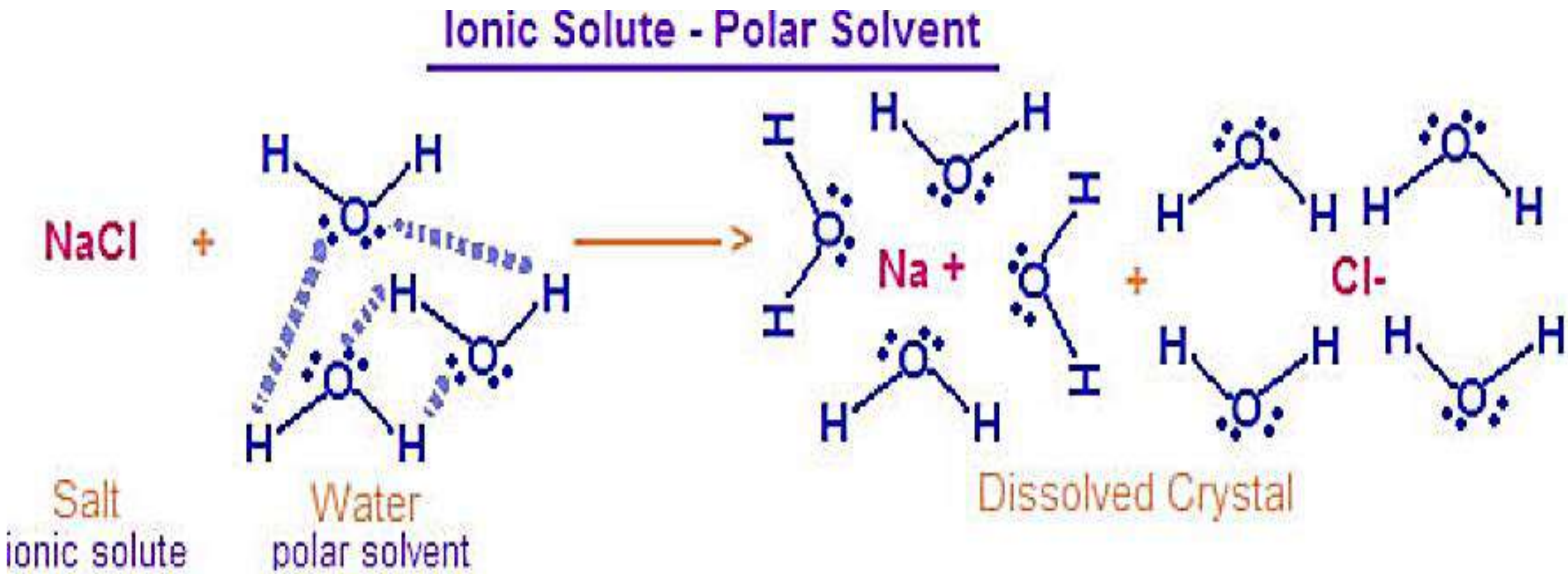


Polar ammonia molecules dissolve in polar water molecules because both types of molecules engage in H-bonding. Their intermolecular forces are relatively the same so they are able to break away from each other and form new bonds.



Acetic acid in water

Like dissolves like



Dissociation in aqueous solution

- Solutions in which water is the dissolving medium are called **aqueous solutions.**
- **Dissociation:** is the process by which certain solutes release ions to the aqueous solution.
- These solutes are called **electrolytes** because they can conduct electricity.

Classification of compounds according dissociation

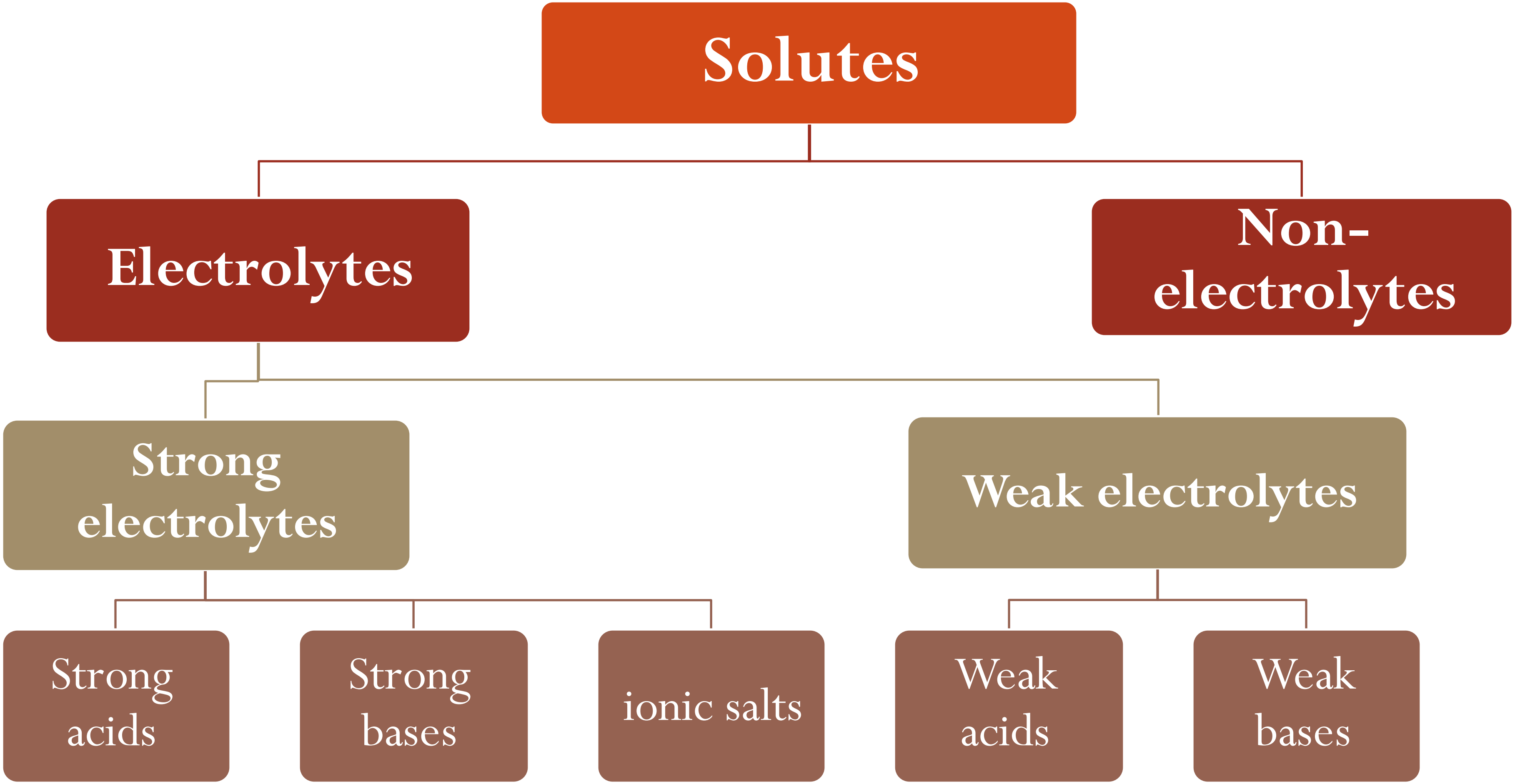
A- An electrolyte is a compound that releases ions and thus conducts an electric current when it is in an aqueous solution or melted. It has two types:

1. **Strong electrolyte** exist in solution completely (or nearly completely) as ions.
2. **Weak electrolyte** produce small concentrations of ions when they dissolve.

- Do not confuse the extent to which an electrolyte dissolves with whether it is a strong or weak electrolyte. (Weak electrolytes still fully dissolve).

B- Nonelectrolyte – a substance that does **not** form ions when it dissolves in water, and so aqueous solutions of nonelectrolytes *do not conduct electricity*.

Classification of compounds according dissociation



Even insoluble ionic compounds such as CaCO3 are electrolytes because they can conduct a current in the molten (melted) state.

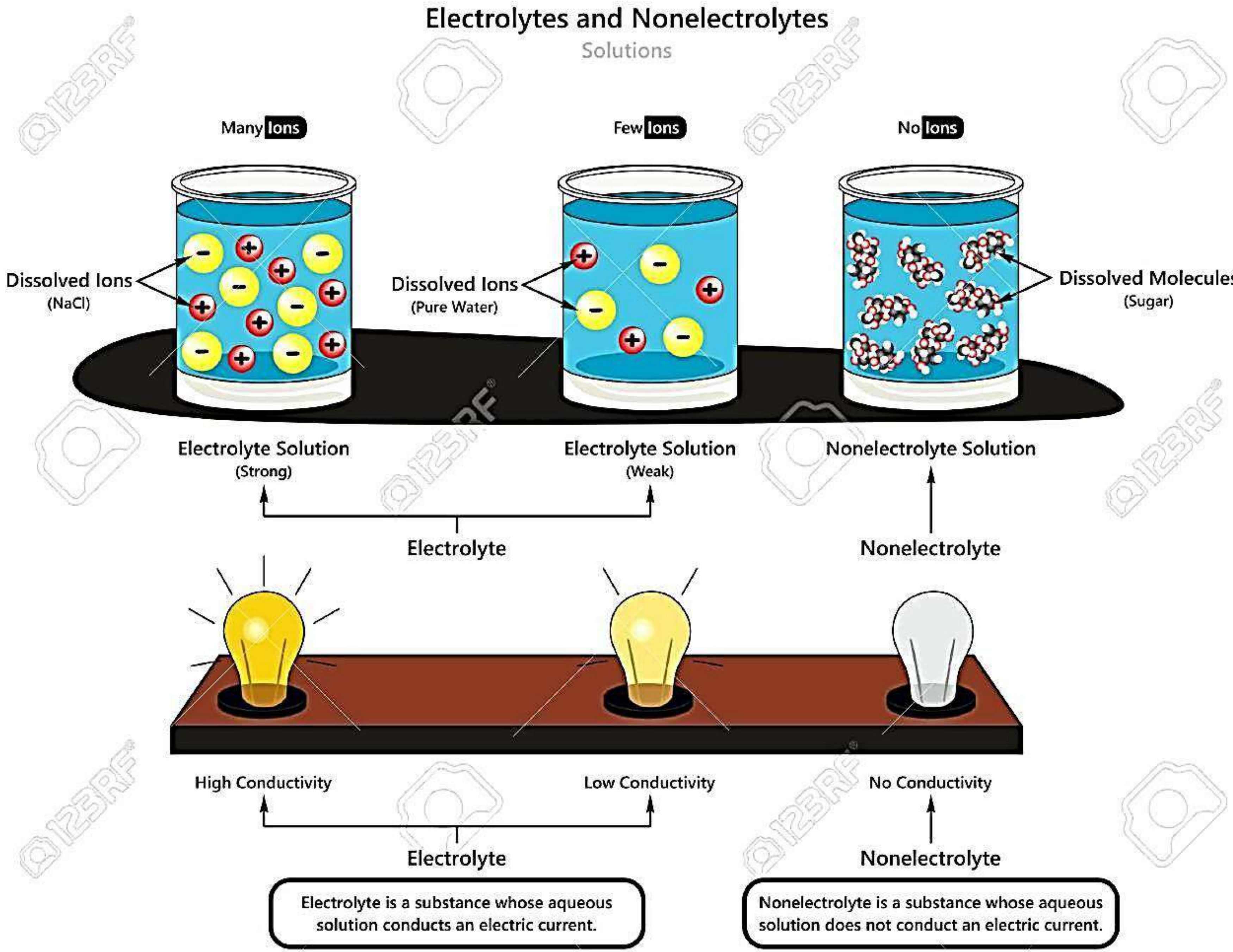

Electrolytes and Nonelectrolytes
Solutions
Many Ions
Few Ions
No Ions
Dissolved Ions
(NaCl)
Dissolved Ions
(Pure Water)
Dissolved Molecules
(Sugar)
Electrolyte Solution
(Strong)
Electrolyte Solution
(Weak)
Nonelectrolyte Solution
Electrolyte
Nonelectrolyte
High Conductivity
Low Conductivity
No Conductivity
Electrolyte
Nonelectrolyte
Electrolyte is a substance whose aqueous solution conducts an electric current.
Nonelectrolyte is a substance whose aqueous solution does not conduct an electric current.

TABLE 4.1 Classification of Solutes in Aqueous Solution

Strong Electrolyte	Weak Electrolyte	Nonelectrolyte
HCl	CH_3COOH	$(NH_2)_2CO$ (urea)
HNO_3	HF	CH_3OH (methanol)
$HClO_4$	HNO_2	C_2H_5OH (ethanol)
H_2SO_4*	NH_3	$C_6H_{12}O_6$ (glucose)
$NaOH$	H_2O†	$C_{12}H_{22}O_{11}$ (sucrose)
$Ba(OH)_2$		
Ionic compounds		

*H_2SO_4 has two ionizable H^+ ions.

†Pure water is an extremely weak electrolyte.

Chapter 9
part 2

Solution stoichiometry

Concentration Units

- Concentration is the amount of solute present in a given amount of solution.

1- The percent by mass (also called the percent by weight or the weight percent) is defined as

$$\text{percent by mass of solute} = \frac{\text{mass of solute}}{\text{mass of solute} + \text{mass of solvent}} \times 100\%$$

$$= \frac{\text{mass of solute}}{\text{mass of soln}} \times 100\%$$

(

2- The percent by volume

$$\text{Volume Percent}\left(\frac{V}{V}\right) = \frac{\text{Volume Solute}}{\text{Volume Solution}} \times 100\%$$

3- Weight by Volume percent

$$\text{Weight /Volume Percent}\left(\frac{W}{V}\right) = \frac{\text{Weight Solute, g}}{\text{Volume Soln,}\ \mathbf{ml}} \times 100\%$$

4- Molality (m)

Molality has the units of mole per Kg (mol/Kg).

$$\text{molality} = \frac{\text{moles of solute}}{\text{mass of solvent (kg)}}$$

5- Molarity (M)

Molarity has the units of mole per liter (mol/L).

$$\text{molarity} = \frac{\text{moles of solute}}{\text{liters of soln}}$$

- **Molarity of dilution:** $M_1V_{1\ \text{Before dilution}} = M_2V_{2\ \text{After dilution}}$

$M_{(\text{solution})} \times V_{(\text{solution})} = \text{mass}_{(\text{solute})} / \text{molar mass}_{(\text{solute})}$

6-

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$$X_{\text{Solute}} = \frac{\text{Moles of solute}}{\text{Total moles of solution}}$$

$$X_{\text{Solvent}} = \frac{\text{Moles of solvent}}{\text{Total moles of solution}}$$

Where:

$$X_{\text{solute}} + X_{\text{Solvent}} = 1$$

$$X_1 = \frac{n_1}{n_1 + n_2} = \text{mole fraction of species 1}$$

$$X_2 = \frac{n_2}{n_1 + n_2} = \text{mole fraction of species 2}$$

$$X_1 + X_2 = 1$$

7- Mass fraction (W)

$$\text{Mass Fraction} = \frac{\text{Mass of a component}}{\text{Total Mass of the Mixture}}$$

8- Parts per million (ppm)

$$\text{Ppm}(m/m) = \frac{1 \text{ mg solute}}{1 \text{ kg solution}}$$

$$\text{Ppm}(m/v) = \frac{\text{mass of solute (mg)}}{\text{volume of solution (L)}}$$

9- Normality

N = Molarity × Valency

N= M.a

a (Valency or no. of equivalents) =Number of H^+ or OH^- in acid-base reactions or electron transfer in redox reaction.

- **Calculate the molarity of each of the following solution: 6.57 g of methanol (CH3OH) in 1.50 x 10^2 mL of solution**

$$\text{molarity} = \frac{\text{moles of solute}}{\text{liters of soln}}$$

1

Solution:

n (for methanol)= mass/molar mass

= 6.57/32= 0.205mol

Molarity = 0.205/(1.5 x 10^2 x 10^{-3}) = 1.36875 mol/litre

- **How many grams of potassium dichromate ($K_2Cr_2O_7$) are present in a 250-mL solution whose concentration is 2.16 *M*?**

$$\text{molarity} = \frac{\text{moles of solute}}{\text{liters of soln}}$$

2

M (Molarity not molar mass) = n (solute)/V

$$2.16 = n/0.25$$

n= 2.16 x 0.25= 0.54 moles

Mass(solute) = n x molar mass   Mass = 0.54 x 294.2 = 159 g

- **How many grams of NaOH are needed to prepare 5oo ml of 0.2M aqueous solution?**

$n_{(NaOH)} = M_{(solution)} x V_{(solution)} = mass_{(NaOH)} / molar\ mass_{(NaOH)}$

$$0.2 \times 500 \times 10^{-3} = mass_{(NaOH)}/40$$

$Mass_{(NaOH)} = 0.2 \times 500 \times 10^{-3} \times 40 = 4g$

So, take 4 g of NaOH and complete to 500 ml with water.

- **Describe how you would prepare 5.00 x 10^2 mL of a 1.75 *M* H_2SO_4 solution, starting with an 8.61 *M* stock solution of H_2SO_4.**

This is dilution

$$M_1 x V_1 (\text{Before dilution}) = M_2 x V_2 (\text{After dilution})$$

3

$$(8.61\ M)(V_i) = (1.75\ M)(5.00 \times 10^2\ \text{mL})$$

$$V_i = \frac{(1.75\ M)(5.00 \times 10^2\ \text{mL})}{8.61\ M}$$

$$= 102\ \text{mL}$$

So, take 102 ml of the stock solution and complete to 500 ml with water.

- **A 46.2-mL, 0.568 *M* calcium nitrate [$Ca(NO_3)_2$]solution is mixed with 80.5 mL of 1.396 *M* calcium nitrate solution. Calculate the concentration of the final solution. Assume the volumes are additive.**

n1 = 0.568 x 0.0462 = 0.026 mol

4

n2 = 1.396 x 0.0805 = 0.112 mol

n total = n1 + n2 = 0.112+0.026= 0.138 mol

V total = 0.0462 + 0.0805 = 0.127 L

Molarity (final) = n total/V (total) = 0.138/0.127= 1.087 M.

- **Water is added to 7.85 g of methanol to give a 100 ml solution whose density is 0.976 g/mL. (Or An aqueous solution of methanol is prepared with a concentration of 7.85% w/v). The molar mass of methanol is 32.04 g. Calculate:**

5

Molarity, Molality ,W/W % ,W/V%, Mole fractions, Mass fractions

- **1)Molarity**

$$\text{molarity} = \frac{\text{moles of solute}}{\text{liters of soln}}$$

n (methanol)= mass/molar mass= 7.85/32.04= 0.245 mol

Molarity =0.245/100x10^{-3} = 2.45 M

- **2) Molality**

$$\text{molality} = \frac{\text{moles of solute}}{\text{mass of solvent (kg)}}$$

n (methanol)= mass/molar mass= 7.85/32.04= 0.245 mol

mass(solution) = Volume (solution)x density (solution)

= 100 x 0.976= 97.6 g

mass(solution) = mass solvent + mass of methanol

Mass(solvent) = 97.6-7.85= 89.75 g

Molality = 0.245/89.75 x10^{-3} = 2.73 m

- **3)W/W%(percent by mass)**

mass(solution) = Volume(solution) x density(solution)

= 100 x 0.976= 97.6 g

W/W% = (**7.85 g/** 97.6 g) x 100% = 8.04%

$$\text{percent by mass of solute} = \frac{\text{mass of solute}}{\text{mass of solute} + \text{mass of solvent}} \times 100\%$$

$$= \frac{\text{mass of solute}}{\text{mass of soln}} \times 100\%$$

- **4)W/V% (Weight by Volume percent)**

$$\text{Weight /Volume Percent} \left(\frac{W}{V}\right) = \frac{\text{Weight Solute, g}}{\text{Volume Soln, ml}} \times 100\%$$

W/V% = (**7.85 g/** 100 ml) x 100% = 7.85%

- **5)Mole fractions**

n (methanol)= mass/molar mass= 7.85/32.04= 0.245 mol

mass(solution) = Volume (solution)x density (solution)

= 100 x 0.976= 97.6 g

Mass(water) = 97.6-7.85= 89.75 g

n (water)= mass/molar mass= 89.75/18= 4.986 mol

X (methanol)= n (methanol)/ n (methanol) + n (water)

= 0.245/(4.986+ 0.245)

=0.0468

X(water)=1- X(methanol) = 1- 0.0468= 0.953

$$X_{Solute} = \frac{\text{Moles of solute}}{\text{Total moles of solution}}$$

$$X_{Solvent} = \frac{\text{Moles of solvent}}{\text{Total moles of solution}}$$

Where:

$$X_{solute} + X_{Solvent} = 1$$

- 6) mass fractions

$$\text{Mass Fraction} = \frac{\text{Mass of a component}}{\text{Total Mass of the Mixture}}$$

mass(solution) = Volume (solution)x density (solution)

= 100 x 0.976= 97.6 g

Mass(water) = 97.6-7.85= 89.75 g

X_m(methanol)= m (methanol)/ mass of solution

= 7.85/97.6 =0.08

X_m(water)=1- X_m(methanol) 1-0.08=0.92

- **You have 2.45 *M* aqueous solution of methanol (CH_3OH). What is the w/v% of the solution? The molar mass of methanol is 32.04 g.**

6

$$\text{molarity} = \frac{\text{moles of solute}}{\text{liters of soln}}$$

2.45 M means 2.45 moles of methanol in 1 liter of solution

Mass of methanol = n x molar mass = 2.45 x 32.04 = 78.498 g

$$\text{Weight /Volume Percent} \left(\frac{W}{V}\right) = \frac{\text{Weight Solute, g}}{\text{Volume Soln, ml}} \times 100\%$$

- **w/v of the solution**= (78.498/1000)X100%=7.85%

- **A solution of 28.0 g of NH3 in 72.0 g of water. The density of the solution is 0.898 g/mL. Calculate:** 7

Molarity, Molality , W/W % , W/V%, Mole fractions, Mass fractions

- **1- Molality**

$$\text{molality} = \frac{\text{moles of solute}}{\text{mass of solvent (kg)}}$$

n NH_3= mass/ molar mass= 28/17 =1.647 mol

Molality = 1.647/72 x10^{-3} =22.875 m

- **2- Molarity**

$$\text{molarity} = \frac{\text{moles of solute}}{\text{liters of soln}}$$

n NH_3= mass/ molar mass= 28/17 =1.647 mol

Mass of solution= 28+72= 100g

Volume of solution= $(\text{mass/density})_{\text{solution}}$ = 100/0.898 = 111.36 ml

Molarity = 1.647/111.356 x10^{-3} = 14.8 M

- **3)W/W% (percent by mass)**

(28/28+72) x 100%= 28%

$$\text{percent by mass of solute} = \frac{\text{mass of solute}}{\text{mass of solute} + \text{mass of solvent}} \times 100\%$$

$$= \frac{\text{mass of solute}}{\text{mass of soln}} \times 100\%$$

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- **4)W/V% (Weight by Volume percent)**

$$\text{Weight /Volume Percent} \left(\frac{W}{V}\right) = \frac{\text{Weight Solute, g}}{\text{Volume Soln, } \mathbf{ml}} \times 100\%$$

W/V% = (**28/** 111.36 ml) x 100%

=25.14 %

- 5) **mole fractions**

n_{H2O}= 72/18=4 mol

n NH_3= 28/17 =1.647 mol

X_{NH3} = 1.647/(1.647+ 4) = 0.291

X_{H2O} = 1-0.291=0.709

$$X_1 = \frac{n_1}{n_1 + n_2} = \text{mole fraction of species 1}$$

$$X_2 = \frac{n_2}{n_1 + n_2} = \text{mole fraction of species 2}$$

$$X_1 + X_2 = 1$$

- 6) mass fractions

$$\text{Mass Fraction} = \frac{\text{Mass of a component}}{\text{Total Mass of the Mixture}}$$

X_m (NH3)= 28/(28+72)= 0.28

X_m (H2O)= 72/(28+72)= 0.72

OR

X_m (H2O)= 1-0.28= 0.72

- **The concentrated sulfuric acid we use in the laboratory is 98.0% H_2SO_4 by mass. The density of the solution is 1.83 g/mL. Calculate: A) the molarity of the acid solution. B) how can you prepare 500 ml of 2M from the concentrated solution**

8

100 g of solution contains 98g H_2SO_4 solute

$$\text{molarity} = \frac{\text{moles of solute}}{\text{liters of soln}}$$

$$\text{molality} = \frac{\text{moles of solute}}{\text{mass of solvent (kg)}}$$

n H_2SO_4 = mass/ molar mass = 98/98 = 1mole

Density of solution = (mass/volume) for solution

V solution = 100/1.83 = 54.64 ml

A) Molarity = $1/(54.64 \times 10^{-3}) = 18.3$ M

All other concentrations also could be calculated as the previous examples(Try)

Also, it can be used in preparation of diluted solutions

B) M1 x V1 = M2 x V2

18.3 x V1 = 2 x 500

V1= 54.64 ml Take this volume and complete to 500 ml with water

What is the concentration of a solution, in parts per million, if 0.02 gram of NaCl is dissolved in 1000.grams of solution? 9

$$Ppm(m/m) = \frac{1\ mg\ solute}{1\ kg\ solution}$$

$$= 0.02x1000/1=20\ ppm$$

- **Calculate the conc. of 0.2 M Na^+ in ppm.**

0.2 M means 0.2 mol in 1 liter solution.

Mass(Na^+) = 0.2 x 23 =4.6 g

$$Ppm\ (m/v) = \frac{mass\ of\ solute\ (mg)}{volume\ of\ solution\ (L)}$$

$$Ppm = 4.6\ x1000/1 = 4.6x10^3\ ppm$$

9- Normality

N = Molarity × Valency

$N = M.a$ a (Valency or no. of equivalents) =Number of H^+ or OH^- in acid- base reactions or electron transfer in redox reaction.

Formula	No. of equivalents (a)
HCl	1
H_2SO_4	1----HSO_4^{-1} 2-----SO_4^{-2}
H_3PO_4	1-----$H_2PO_4^-$ 2----HPO_4^{-2} 3-------PO_4^{-3}
NaOH	1
$Ca(OH)_2$	2

$$H_2SO_4 + NaOH = NaHSO_4 + H_2O$$

$$H_2SO_4 + 2NaOH = Na_2SO_4 + 2H_2O$$

$$H_3PO_4 + NaOH = NaH_2PO_4 + H_2O$$

$$H_3PO_4 + 2NaOH = Na_2HPO_4 + 2H_2O$$

$$H_3PO_4 + 3NaOH = Na_3PO_4 + 3H_2O$$

- **What is the normality of 1.4 M H_2SO_4 for complete reaction?**

$N = M. a$ $N = 1.4 \times 2 = 2.8$ N

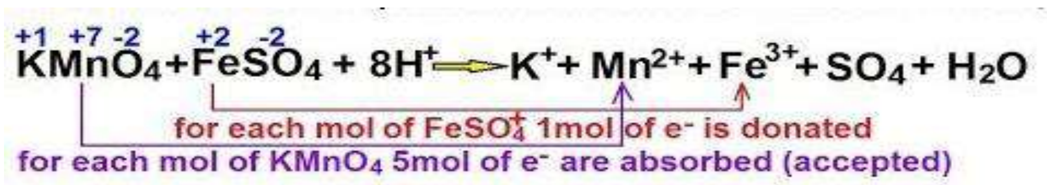
- **What is the normality of 6M H_3PO_4 for complete reaction?**

$N = 6 \times 3 = 18$ N

- **What is the molarity of 6N H_2SO_4 for complete reaction?**

$M=N/ a$ $M = 6/2= 3M$

- **What is the normality of 0.02 M KMnO4 in the following reaction?**



N= M.a

- **N=0.02 x 5=0.1 N**