Chapter 12

Solutions

Sections: 12.1 – 12.8

• Types of Solution

Solution: a homogenous mixture of two or more substances.

المحلول: خليط متجانس من مادتين أو أكثر.

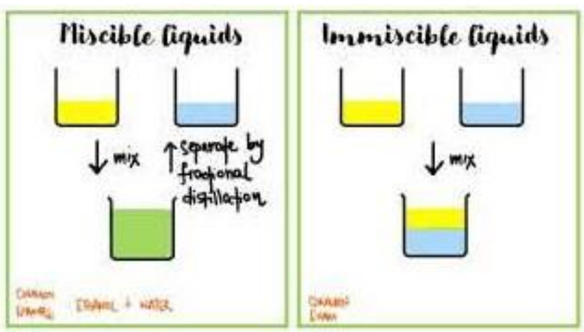
Solute: is(are) the substance(s) present in the smaller amount(s).

المذاب: هو المادة أو المواد الموجودة بكمية أو كميات أصغر.

Solvent: is the substance present in a larger amount.

المذيب: هو المادة الموجودة بكمية أكبر.

Fluids that mix with or dissolve in each other in all proportions are said to be **miscible**.



Fluids that do not dissolve in each other are said to be **immiscible**.

Example 1:

Identify the solute(s) and solvent(s) in the following solutions.

a. 70 g of Cr and 12 g of Mo

b. 5 g of $MgCl_2$ dissolved in 1500 g of H_2O

c. 39% N_2, 41% Air, and the rest O_2

Answer:

a. The 12 g of Mo is the solute; the 70 g of Cr is the solvent.

b. $MgCl_2$ is the solute; H_2O is the solvent.

c. O_2 and N_2 are the solutes; Ar is the solvent.

• Solubility and the Solution Process

- **saturated solution:** contains the maximum amount of a solute that will. dissolve in a given solvent at a specific temperature.
- **المحلول المشبع:** يحتوي على أكبر كمية من المادة المذابة التي تذوب في مذيب معين عند درجة حرارة معينة.

- **unsaturated solution:** contains less solute than the solvent can dissolve at a specific temperature.
- **المحلول غير المشبع:** يحتوي على كمية من المذاب أقل مما يمكن للمذيب أن يذوب عند درجة حرارة معينة.

- **supersaturated solution:** contains more solute than is present in a saturated solution at a specific temperature.
- **المحلول فوق المشبع:** يحتوي على نسبة مذابة أكبر من الموجودة في المحلول المشبع عند درجة حرارة معينة.

- **Solubility:** the amount of solute that dissolves in a given quantity of solvent at a given temperature.
- **الذائبية:** كمية المذاب التي تذوب في كمية معينة من المذيب عند درجة حرارة معينة.

For example, The **solubility** of sodium chloride in water is **36.0 g/100 mL at 20°C**.

Three types of interactions in the solution process:

- **solvent-solvent** interaction
- **solute-solute** interaction
- **solvent-solute** interaction

$\Delta H\ solution = \Delta H_1 + \Delta H_2 + \Delta H_3$

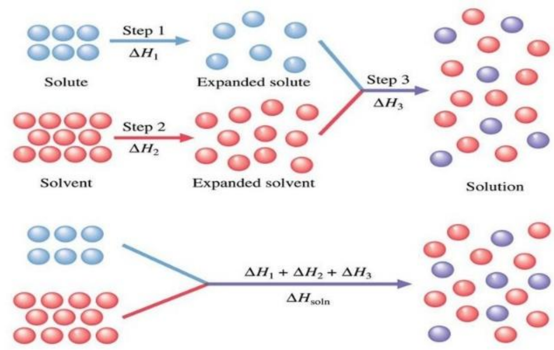
$If\ \Delta H\ solution > 0$ لا يحدث التفاعل ولا يتكون محلول

$If\ \Delta H\ solution < 0$ يحدث التفاعل ويتكون محلول

$If\ \Delta H\ solution = 0$ محلول مثالي

$If\ \Delta H\ solution$ small and positive يحدث التفاعل ويتكون محلول

$If\ \Delta H\ solution\ big\ and\ positive$ لا يحدث التفاعل ولا يتكون محلول



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like dissolves like:

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

- **non-polar** molecules are soluble in **non-polar** solvents, ex: CCl_4 in C_6H_6
- **polar** molecules are soluble in **polar** solvents, ex: C_2H_5OH in H_2O
- **ionic** compounds are more soluble in **polar** solvents, ex: NaCl in H_2O or NH_3

Miscible liquids; Similar polarity ex: $CH_3CH_2OH\ and\ water\ (H_2O)$

Immiscible Liquids;

- Two insoluble liquids; Do not mix; Get two separate phases.
- Different polarity

ex: $C_3H_8\ and\ H_2O$

Ch 12

Example 2:

Which of the following molecules is most soluble in hexane, C_6H_{14}?

A. NH_3

B. CH_3NH_2

C. CH_3OH

D. <u>CH_3CH_3</u>

E. H_2O

Example 3:

Which of the following compounds is likely to be **more soluble** in water?

A. $C_5H_{11}SH$

B. CH_3I

C. <u>C_4H_9OH</u>

D. CS_2

E. $CH_3CH_2CH_3$

Example 4:

Which of the following compounds is likely to be more soluble in KCl ?

A. <u>NH_3</u>

B. CS_2

C. CH_3I

D. CCl_4

E. C_6H_6

Example 5:

Which of the following compounds is likely to be **soluble** in Br_2?

A. C_5H_{10}

B. CS_2

C. CH_3Cl

D. $CH_3CH_2CH_3$

E. <u>A , B and D</u>

F. B and D

• Ways of Expressing Concentration

Concentration: the amount of solute present in a given quantity of solvent or solution.

$$number\ of\ moles\ (mol) = \frac{mass\ (Kg)}{molar\ mass\ \left(\frac{Kg}{mol}\right)} = n = \frac{m}{Mw}$$

$$Density = \frac{mass}{volume} = \frac{m}{V}$$

$$solution = solute + solvent$$

$$Mass\ fraction = \frac{mass\ of\ solute}{mass\ of\ solution} = \frac{mass\ of\ solute}{mass\ of\ solute + mass\ of\ solvent}$$

$$Percentage\ by\ mass = \frac{mass\ of\ solute}{mass\ of\ solution} \times 100\%$$

$$Mole\ fraction = \frac{mol\ of\ solute}{mol\ of\ solution} = \frac{mol\ of\ solute}{mol\ of\ solute + mol\ of\ solvent}$$

$$Mole\ percent = \frac{mol\ of\ solute}{mol\ of\ solution} \times 100\%$$

- **Molarity (concentration) (mol/L)**

$$Molrity\ (M) = \frac{moles\ of\ solute\ (mol)}{volume\ of\ solution\ (L)}$$

- **Molality (mol/Kg)**

$$Molality\ (m) = \frac{moles\ of\ solute}{mass\ of\ solvent}$$

Molarity	$M = \frac{\text{moles of solute}}{\text{liters of solution}}$
Percentage by mass	$\text{Percentage by mass} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$
Mass fraction	$\text{Mass fraction} = \frac{\text{mass of solute}}{\text{mass of solution}}$
Molality	$m = \frac{\text{mol of solute}}{\text{kg of solvent}}$
Mole fraction	$X_A = \frac{n_A}{n_A + n_B + n_C + n_D + \cdots + n_Z}$
Mole percent	$\text{mol percent } A = \frac{n_A}{n_A + n_B + n_C + n_D + \cdots + n_Z} \times 100 \text{ mol\%}$
Percentage by mass–volume	$\%(\text{w/v}) = \frac{\text{grams solute}}{\text{mL solution}} \times 100\%$

Example 6:

How many grams of hydrogen chloride (HCl) are required to prepare 4 liters of 5M HCl in water?

The molar mass of HCl is 36.5 g/mol.

Solution:

$$Molrity\ (M) = \frac{moles\ of\ solute\ (mol)}{volume\ of\ solution\ (L)}$$

$$n = M \times V = 5 \times 4 = 20\ mol$$

$$mass = n \times Mw = 20 \times 36.5 = \mathbf{730\ g}$$

Example 7:

The density of a solution prepared by dissolving 120 g of urea (Mw= 60 g/mol) in 1000 g of water is 1.15 g/mL. The molarity of urea is:

a) 2.05 M

b) 1.02 M

c) 0.50 M

d) 1.78 M

Solution:

$$Total\, mass = m_{solute} + m_{solvent} = 120 + 1000 = 1120\ g$$

$$V = \frac{m_{Total}}{density} = \frac{1120}{1.15} = 973.91\ ml = 0.97391\ L$$

$$n_{urea} = \frac{m}{Mw} = \frac{120}{60} = 2\ mol$$

$$Molrity = \frac{n}{V} = \frac{2}{0.97391} = \mathbf{2.05\ M}$$

Example 8:

Calculate the molality of a sulfuric acid solution containing 30.4 g of sulfuric acid in 193 g of water. The molar mass of sulfuric acid is 98.09 g/mol.

Solution:

$$Moles\ of\ H_2SO_4 = \frac{mass\ of\ H_2SO_4}{Mw\ of\ H_2SO_4} = \frac{30.4}{98.09} = 0.31\ mol$$

$$Molality\ (m) = \frac{moles\ of\ solute\ (H_2SO_4)}{mass\ of\ solvent\ (water)} = \frac{0.31\ mol}{0.193\ Kg}$$

$$= \mathbf{1.6\ m}$$

Example 9:

What is the molarity of the 42.6%(w/v) solution of sodium hydroxide (40g/mole) ?

A. 18 *M*
B. 11 *M*
C. 9.7 *M*
D. 1.065 *M*
E. *101.65 M*

Solution:

$$Let\ volume\ of\ solution = 100\ ml$$

$$mass\ of\ sodium\ hydroxide = \frac{42.6\ g}{100\ ml} \times 100\ ml = 42.6\ g$$

$$n = \frac{m}{Mw} = \frac{42.6}{40} = 1.065\ mol$$

$$Molrity = \frac{n}{V} = \frac{1.065}{0.1} = \mathbf{10.65M}$$

Example 10:

The density of a 2.45 *M* aqueous solution of methanol (CH_3OH) is 0.976 g/mL.

What is the molality of the solution?

The molar mass of methanol is 32.04 g/mol.

Solution:

$$Let\ volume\ of\ solution = 1\ L$$

$$mass\ of\ solution = density\ \times V_{solution} = 0.976\frac{g}{ml} \times 1000\frac{ml}{L} \times 1L = 976\ \text{g}$$

$$moles\ of\ solute\ (CH_3OH) = 2.45\ M \times 1\ L = 2.45\ \text{mol}$$

$$mass\ \text{of solvent}\ (\text{H}_2\text{O}) = \text{mass of solution} - \text{mass of solute}$$

$$= 976 - \left(2.45\ \text{mol} \times 32.04\frac{g}{mol}\right) = 976 - 78.5 = 897.5\ \text{g} = 0.8975\ \text{Kg}$$

$$Molality\ (m) = \frac{moles\ of\ solute\ (CH_3OH)}{mass\ of\ solvent\ (H_2O)} = \frac{2.45\ mol}{0.8975\ Kg} = \mathbf{2.73\ m}$$

Example 11:

Calculate the molality of a 40.4 percent (by mass) aqueous solution of phosphoric acid (H_3PO_4).

The molar mass of phosphoric acid is 97.99 g/mole.

Solution:

$$Molality\ (m) = \frac{moles\ of\ solute\ (H_3PO_4)}{mass\ of\ solvent\ (water)}$$

$$Let\ mass\ of\ solution = 100\ g$$

$$moles\ of\ H_3PO_4 = \frac{mass}{molar\ mass} = \frac{40.4\ g}{97.99\ g/mol} = 0.41\ mol$$

$$mass\ of\ solvent = 100 - 40.4 = 59.6\ g = 0.0596\ Kg$$

$$Molality = \frac{0.41}{0.0596} = 6.88\ m$$

Example 12:

What is the concentration of the $45\%(w/w)$ solution of sodium hydroxide $(40g/mole)$ if its density is $1.629\ g/mL$?

A. <u>$18\ M$</u>   C. $1.9\ M$

B. $1.25\ M$ D. $0.76\ M$

Solution:

$$Let\ mass\ of\ solution = 100\ g$$

$$n = \frac{m}{Mw} = \frac{45}{40} = 1.125\ mol$$

$$V = \frac{m}{dinsity} = \frac{100}{1.629} = 61.39\ ml = 0.06139\ L$$

$$Molrity = \frac{n}{V} = \frac{1.125}{0.0.6139} = \mathbf{18.3\ M}$$

Example 13:

What **mass fraction** and mass **percentage by mass** of NH_4Cl (53.49g/mole) must be dissolved in 100 mL of H_2O to make a 0.250 M solution?
The density of the solution of NH_4Cl is 55000 g/m^3.

Solution:

$$Molarity = \frac{moles\ of\ NH_4Cl}{volume\ of\ solution} \quad \rightarrow \quad n_{NH_4Cl} = V \times M = 0.1 \times 0.250 = 0.025\ mol$$

$$mass\ of\ NH_4Cl = n \times Mw = 0.025 \times 53.49 = 1.34\ g$$

$$mass\ of\ solution = density\ \times volume = 55000\frac{g}{m^3} \times \frac{1\ m^3}{1000\ L} \times 0.1\ L = 5.5\ g$$

$$mass\ fraction\ of\ NH_4Cl = \frac{mass\ of\ NH_4Cl}{mass\ of\ solution} = \frac{1.34}{5.5} = \mathbf{0.24}$$

$$percentage\ by\ mass\ of\ NH_4Cl = \frac{mass\ of\ NH_4Cl}{mass\ of\ solution} \times 100\% = \mathbf{24}\%$$

Example 14:

What **mole fraction** and mass **percentage by mole** of NH_4Cl (53.49g/mole) must be dissolved in 100 mL of H_2O to make a 0.250 M solution?
The density of the solution of NH_4Cl is 55000 g/m^3.

Solution:

$$Molarity = \frac{moles\ of\ NH_4Cl}{volume\ of\ solution} \quad \rightarrow \quad n_{NH_4Cl} = V \times M = 0.1 \times 0.250 = 0.025\ mol$$

$$mass\ of\ solution = density\ \times volume = 55000\frac{g}{m^3} \times \frac{1\ m^3}{1000\ L} \times 0.1\ L = 5.5\ g$$

$$mass\ of\ NH_4Cl = n \times Mw = 0.025 \times 53.49 = 1.34\ g$$

$$mass\ of\ H_2O = 5.5 - 1.34 = 4.16\ g \qquad , \qquad n_{H_2O} = \frac{4.16}{18} = 0.23\ mol$$

$$mole\ fraction\ of\ NH_4Cl = X_{NH_4Cl} = \frac{moles\ of\ NH_4Cl}{moles\ of\ solution} = \frac{0.025}{0.025 + 0.23} = \mathbf{0.098}$$

$$mole\ percent\ of\ NH_4Cl = \frac{moles\ of\ NH_4Cl}{moles\ of\ solution} \times 100\% = \mathbf{9.8}\%$$

- **the Stoichiometric Factors**

Example 15:

What are the concentrations of potassium and nitrate ions in a 0.025 M solution of KNO_3? The dissociation reaction for potassium nitrate (KNO_3) is:

$KNO_3 \rightarrow K^+ + NO_3^-$

Solution:

Concentration of K^+ : $1 \times 0.025\ M = 0.025\ M$

Concentration of NO_3^- : $1 \times 0.025\ M = 0.025\ M$

Example 16:

What are the concentrations of zinc and bromide ions in a 0.030 M solution of $ZnBr_2$?

The dissociation reaction for zinc bromide ($ZnBr_2$) is:

$ZnBr_2 \rightarrow Zn^{+2} + 2Br^-$

Solution:

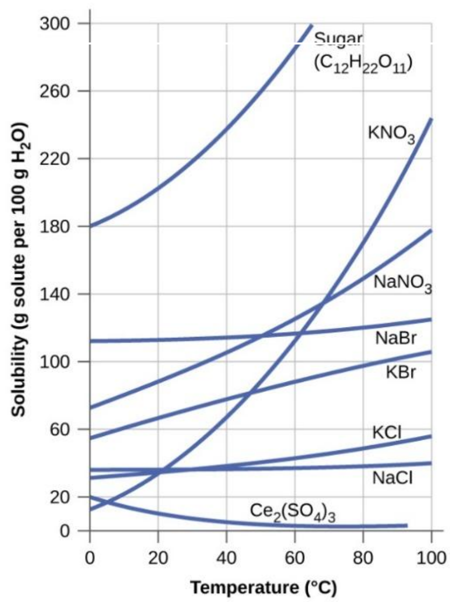
$$[Zn^{+2}] = 1 \times 0.030\ M = 0.030\ M$$

$$[Br^-] = 2 \times 0.030\ M = 0.060\ M$$

• Effects of Temperature and Pressure on Solubility

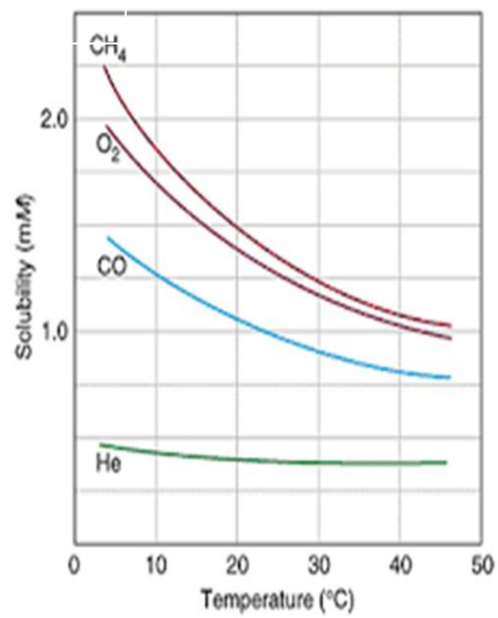
• Effect of temperature on Solubility of Gases and solids

• **Solid** solubility and temperature



The Solubility in <u>most</u> solids **increases** with temperature.

• **Gas** solubility and temperature



The Solubility in <u>most</u> gases **decreases** with temperature.

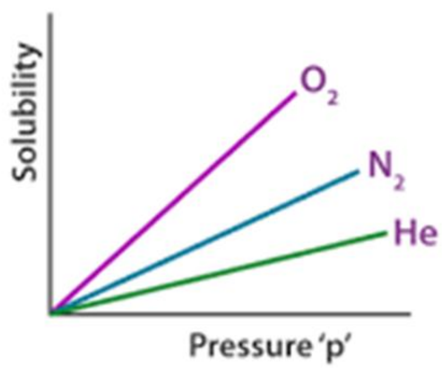
- **Effect of Pressure on Solubility of Gases**

Henry`s law: The solubility of a gas in a liquid is proportional to the pressure of the gas over the solution

$$C = KP$$

, or $\frac{C_1}{C_2} = \frac{P_1}{P_2}$

- $C\ (S)$: is the concentration (M) of the dissolved gas.
- P: is the pressure of the gas over the solution
- K: is a constant for each gas $(mol/L \bullet atm)$ that depends only on temperature.



The Solubility in gases **increases** with pressure.

Example 17:

At $25°C$ $24\ grams$ of CH_4 $(16\ g/mol)$ are dissolved in 37.5 L water at a partial pressure of 2.0 atm. Calculate the solubility of methane in water when the partial pressure is decreased to 0.5 atm at the same temperature.

Solution:

$$Moles\ of\ CH_4 = \frac{mass}{molar\ mass} = \frac{24}{16} = 1.5\ mol$$

$$[CH_4](\text{solubility}) = \frac{1.5\ mol}{37.5\ L} = 0.04\ M\ (mol/L)$$

$$S_1 = KP_1 \ \rightarrow K = \frac{S}{P_1} = \frac{0.04}{2} = 0.02\frac{mol}{L} \cdot atm$$

$$S_2 = KP_2 = 0.02 \times 0.5 = \mathbf{0.01\ mol/L}$$

Example 18:

The solubility of nitrogen gas (N_2) in water at 25°C is found to be 3.2×10^{-4} mol/L when the partial pressure of nitrogen gas above the water is 1.5 atm. Calculate the solubility of nitrogen gas in water when the partial pressure is increased to 3.0 atm at the same temperature.

A. $640\ M$
B. $6.4 \times 10^{-4}\ L/mol$
C. $\underline{6.4 \times 10^{-4}\ M}$
D. $6.9 \times 10^{-4}\ M$

Solution:

$$\frac{S_1}{S_2} = \frac{P_1}{P_2}\ \ or\ S = kP \qquad \longrightarrow \qquad S_2 = S_1\frac{P_2}{P_1} = 3.2 \times 10^{-4} \times \frac{3}{1.5} = \mathbf{6.4 \times 10^{-4}\ mol/L}$$

• Colligative Properties

Colligative properties: are properties that depend only on the number of solute particles in solution and not on the nature of the solute particles**.**

الخواص التي تعتمد فقط على عدد جزيئات المذاب في المحلول وليس على طبيعة جزيئات المذاب.

$Amount\ of\ solute \uparrow \ \ \rightarrow Vapor\ pressure \downarrow$

- Vapor-Pressure Lowering
- Boiling-Point Elevation
- Freezing-Point Depression
- Osmotic Pressure (π)

- **Vapor-Pressure Lowering**

1. When a **non-volatile**, insoluble solid dissolves in a given solution, then we use **Raoult`s law**.

عند اذابة مادة صلبة غير متطايرة وغير قابلة للتفكك لمحلول معين.

Raoult's law:

$$\boldsymbol{P = X_1 P^\circ}$$

$$\boldsymbol{\Delta P = P^\circ - P}$$

Example 19:

Calculate the **vapor pressure** of a solution formed by dissolving 25.6 g of sucrose (molar mass = 342.3 g/mol) in 200 mL of ethanol (molar mass = 46 g/mol) at 40°C. What is the **vapor-pressure lowering**?

The vapor pressure of pure ethanol at 40°C is 100 mmHg. Assume the density of ethanol is $0.789\ g/mL$.

Solution:

$$n_2\ (sucrose) = \frac{25.6}{342.3} = 0.075\ mol$$

$$n_1\ (ethanol) = 0.789\frac{g}{ml} \times 200ml\ \times \frac{1}{46\frac{g}{mol}} = 3.43\ mol$$

$$X_1 = \frac{n_1}{n_1 + n_2} = \frac{3.34}{3.34 + 0.075} = 0.978$$

$$P = X_1 * P° = 0.978 * 100 = \mathbf{97.8\ mmHg}$$

$$\Delta P = P° - P = 100 - 97.8 = \mathbf{2.2\ mmHg}$$

- Vapor-Pressure Lowering

For nonvolatile solute: - $P < P°$

2. If there are two liquids (A and B) **completely miscible** and both are **volatile.**

2. في حال وجود سائلين (A , B) ذائبين ببعضهما البعض وكلاهما متطاير.

$P_A = X_A * P_A°$, $P_B = X_B * P_B°$

$P_T = P_A + P_B$

$\boldsymbol{P_T = X_A * P_A° + X_B * P_B°}$ $\boldsymbol{X_A + X_B = 1}$

$\boldsymbol{so\ we\ can\ use\ also}$: $\boldsymbol{P_T = (1 - X_B) * P_A° + X_B * P_B°}$

Example 20:

At 40°C, the vapor pressure of pure acetone (molar mass = 58.08 g/mol) is 365.5 torr, while the vapor pressure of pure ethanol (molar mass = 46.07 g/mol) is 92.4 torr. If a solution is prepared by mixing 50.0 g of acetone and 30.0 g of ethanol at this temperature, what would be the total vapor pressure of the mixture?

Solution:

$n_1\ (acetone) = \frac{50\ g}{58.08\ g/mol} = 0.86\ mol$, $n_2\ (ethanol) = \frac{30\ g}{46.07\ g/mol} = 0.65\ mol$

$$X_1 = \frac{n_1}{n_1 + n_2} = \frac{0.86}{0.86 + 0.65} = 0.57$$

$$X_2 = \frac{n_2}{n_1 + n_2} = \frac{0.65}{0.86 + 0.65} = 0.43$$

$P_1 = X_1 * P_1° = 0.57 * 365.5 = 208.3\ torr$, $P_2 = X_2 * P_2° = 0.43 * 92.5 = 39.8\ torr$

$P_T = P_1 + P_2 = 208.3 + 39.8 = \boldsymbol{248.1\ torr}$

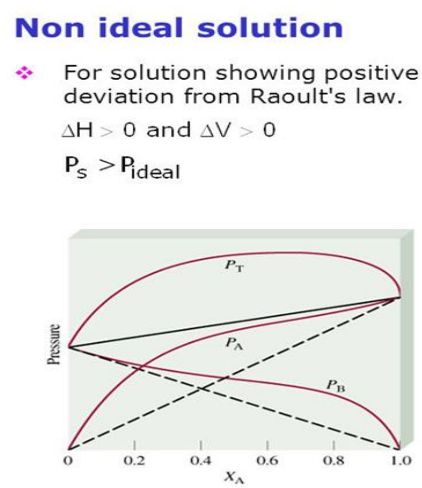
Or, $P_T = X_A * P_A° + X_B * P_B° = 0.57 * 365.5 + 0.43 * 92.5 = \mathbf{248.1\ torr}$

• Vapor Pressure of a Solution

- Vapor pressure for a **nonideal** solution.

❖ تعمل معادلة **(Raoult’s law)** بشكل جيد مع المحلول المثالي **(ideal)**: المذيب والمذاب متساويان تمامًا نفس التفاعلات بين الجزيئات**(Intermolecular interaction)**

❖ Real solutions are not ideal, deviation from this equation is **expected.**



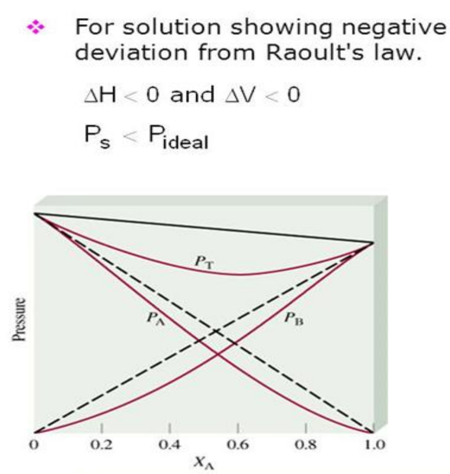
1. Solution showing positive deviation from Raoult`s law:

a) $P_{solution} > P_{ideal}$

b) $V_{solution} > V_{solute} + V_{solvent}$

c)

Ex: London + H-bonding → London



2. Solution showing negative deviation from Raoult`s law:

a) $P_{solution} < P_{ideal}$

b) $V_{solution} < V_{solute} + V_{solvent}$

c)

Ex: Dipole-Dipole + Dipole-Dipole → H-bonding

• Boiling-Point Elevation and Freezing-Point Depression

- **Boiling point elevation (الارتفاع في درجة الغليان)**

❖ $Amount\ of\ solute \uparrow \quad \rightarrow boling\ point \uparrow$

❖ كل ما زادت كمية المذاب زادت درجة الغليان

$$\Delta T_b = K_b * m$$

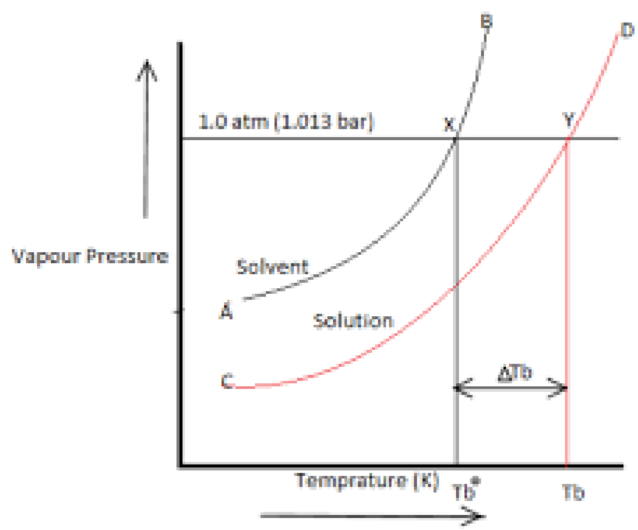
$$\Delta T_b = T_b - T_b{}^{\circ} \quad , \quad T_b > T_b{}^{\circ}$$

T_b : boiling point of solution

$T_b{}^{\circ}$: boiling point of pure solvent

m : molality of the solution (mol/Kg)

K_b: molal boiling-point elevation constant for a given solvent ($^{\circ}C/m$)



- **Freezing point depression (الانخفاض في درجة التجمد)**
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❖ $Amount\ of\ solute \uparrow \ \rightarrow freezing\ point \downarrow$

❖ كل ما زادت كمية المذاب تقل درجة التجمد

$$\Delta \boldsymbol{T_f} = \boldsymbol{K_f} * \boldsymbol{m}$$

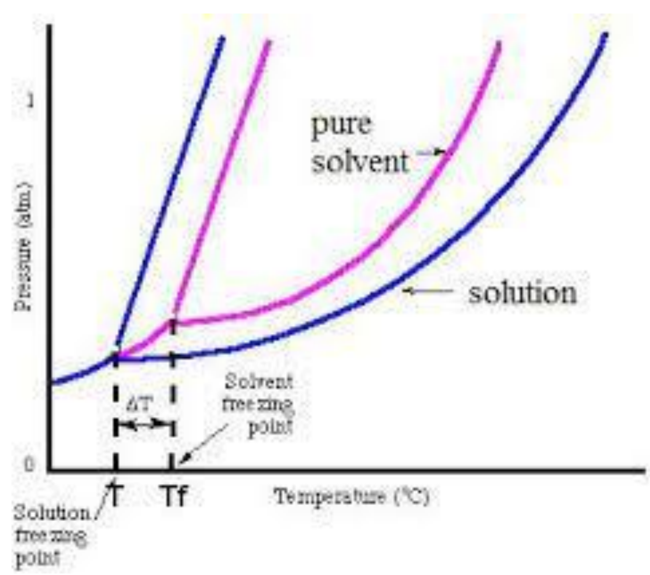
$$\Delta \boldsymbol{T_f} = \boldsymbol{T_f}^{\circ} - \boldsymbol{T_f} \quad , \quad T_f < T_f^{\circ}$$

T_f : freezing point of solution

T_f° : freezing point of pure solvent

m : molality of the solution (mol/Kg)

K_f: molal freezing point depression constant for a given solvent (°C/m)



Example 21:

Propylene glycol ($C_3H_8O_2$) ($Mw = 76.09\ g/mol$) is another common antifreeze used in automobile cooling systems. It is also water-soluble and has a boiling point of 188.2°C. Calculate the freezing point and boiling point of a solution containing 800 g of propylene glycol in 1500 g of water.

$K_b = 3.55\ ℃/m$, $K_f = 1.86\ ℃/m$

Solution:

$$n_{C_3H_8O_2} = \frac{800\ g}{\frac{76.09\ g}{mol}} = 10.5\ mol$$

$$molality\ (m) = \frac{mole\ of\ solute}{mass\ of\ solvent\ (Kg)} = \frac{10.5\ mol}{1.5\ Kg} = 7$$

$$\Delta T_b = K_b * m = 3.55 * 7 = 24.85\ ℃$$

$$\Delta T_b = T_b - T_b° \ \rightarrow\ T_b = \Delta T_b + T_b° = 24.85 + 100 = \mathbf{124.85}\ ℃$$

$$\Delta T_f = K_f * m = 1.86 * 7 = 13\ ℃$$

$$\Delta T_f = T_f° - T_f \ \rightarrow\ T_f = T_f° - \Delta T_f = 0 - 13 = \mathbf{-13}\ ℃$$

Example 22:

A 6.25 g sample of a compound with the empirical formula C_3H_3 is dissolved in 250 g of toluene. The freezing point of the solution is found to be 2.3°C below that of pure toluene. Calculate the **molar mass** of the compound.

$K_f = 3.6\ ℃/m$

Solution:

$$\boldsymbol{freezing\ point\ depression\ \rightarrow molality\ \rightarrow number\ of\ moles\ \rightarrow\ molar\ mass}$$

$$\Delta T_f = K_f * m \ \rightarrow\ m = \frac{\Delta T_f}{K_f} = \frac{2.3}{3.6} = 0.64\ m$$

$$m = \frac{mole\ of\ solute}{mass\ of\ solvent\ (Kg)} \ \rightarrow\ n_{C_3H_3} = 0.64 \times \frac{mol}{Kg} 0.250\ Kg = 0.16\ mol$$

$$molar\ mass = \frac{mass}{n} = \frac{6.25}{0.16} = \mathbf{39.06\ g/mol}$$

Or, $\boldsymbol{M_w\ (solute) = \frac{mass\ of\ solute \times K_f}{mass\ of\ solvent \times 10^{-3} \times \Delta T_f} = \frac{6.25\ g \times 3.6\ ℃/m}{250 \times 10^{-3} \times 2.3\ ℃} = 39.06\ g/mol}$

• Osmosis

• Osmotic pressure (π) (الضغط الاسموزي)

❖ الماء ينتقل من المحلول الذي يمتلك تركيز أقل إلى المحلول الذي يمتلك تركيز أعلى.

Osmotic pressure (π): the pressure required to stop osmosis.

Osmotic pressure:

الضغط اللازم لتوقف انتقال الماء بين المحلولين.

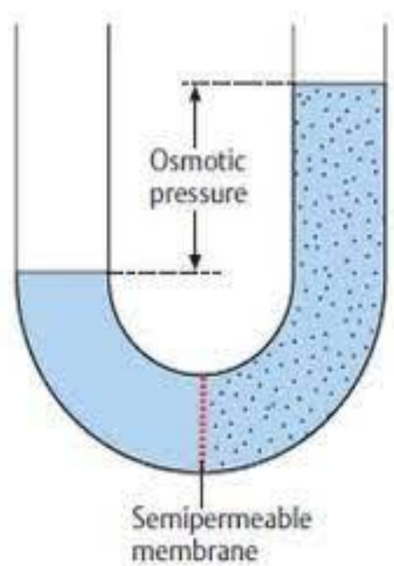
$$\pi = MRT$$

M : the molarity of the solution

T : the temperature (in K)

R : gas constant (0.0821 L . atm/K . mol)

π : osmatic pressure (atm , mmHg , … ,)



Example 23:

A solution is prepared by dissolving 18.5 g of glucose in enough water to make up 500 mL in volume. If the osmotic pressure of the solution is found to be 8.2mmHg at 25°C, calculate the **molar mass** of glucose.

Solution:

$$Osmotic\ pressure \rightarrow \boldsymbol{molarity} \rightarrow \boldsymbol{number\ of\ moles} \rightarrow \boldsymbol{molar\ mass}$$

$$\boxed{1\ atm = 760\ mmHg}$$

$$\pi = MRT \rightarrow M = \frac{\pi}{RT} = \frac{8.2\ mmHg \times \frac{1\ atm}{760\ mmHg}}{0.0821\ \left(L \cdot \frac{atm}{K} \cdot mol\right) \times (25 + 273)\ K°} = \frac{0.01}{0.0821 \times 298} = 0.00041\ M$$

$$n = M * V = 0.00041 * 0.5 = 0.000205\ mol$$

$$Mw = \frac{mass}{n} = \frac{18.5}{0.000205} = \boldsymbol{9.02 \times 10^4\ g/mol}$$

• Osmosis

$$\text{van't Hoff factor (i)} = \frac{\text{actual number of particles in soln after dissociation}}{\text{number of formula units initially dissolved in solution}}$$

$NaCl \rightarrow \ Na^{+} + Cl^{-}$

$\downarrow \quad \downarrow$

$1 \quad 1 \quad \rightarrow \ i = 1 + 1 = 2$

$Na_2SO_4 \ \rightarrow \ 2Na^{+} + SO_4^{-2}$

$\downarrow \quad \downarrow$

$2 \quad 1 \quad \rightarrow \ i = 2 + 1 = 3$

$FeCl_3 \ \rightarrow \ Fe^{+3} + 3Cl^{-}$

$\downarrow \quad \downarrow$

$1 \quad 3 \quad \rightarrow \ i = 1 + 3 = 4$

Colligative Properties of Electrolyte Solutions

Boiling-Point Elevation	$\Delta T_b = i K_b m$
Freezing-Point Depression	$\Delta T_f = i K_f m$
Osmotic Pressure (π)	$\pi = i MRT$

Example 24:

The osmotic pressure of a 0.020 M solution of sucrose at 39° C is found to be 1.23 atm. Calculate the **van't Hoff factor** for sucrose at this concentration.

A. 1.4
B. 2.5
C. 2.4
D. 3
E. 2

Solution:

$$\pi = iMRT \;\rightarrow\; i = \frac{\pi}{MRT} = \frac{1.23\ atm}{0.020\ M \times 0.0821\ (L \cdot atm/K \cdot mol) \times (39 + 273)\ K°} = \frac{1.23}{0.51} = \mathbf{2.4}$$

Example 25:

A $8.75\ g$ sample of a compound with the empirical formula NH_4Cl $(53.49\ g/mol)$ is dissolved in $350\ g$ of water. The boiling point elevation of the solution is found to be $1.2°C$ above that of pure water. Calculate the **molar mass** of the compound

K_b = 0.512 °C/m

Solution:

$$NH_4Cl \rightarrow NH_4^+ + Cl^-$$

$$\boldsymbol{Boiling\ point\ elevation \rightarrow molality \rightarrow number\ of\ moles \rightarrow molar\ mass}$$

$$\Delta T_b = i * K_b * m \;\rightarrow\; m = \frac{\Delta T_b}{i * K_b} = \frac{1.2}{2 * 0.512} = 1.17\ m$$

$$m = \frac{mole\ of\ solute}{mass\ of\ solvent\ (Kg)} \;\rightarrow\; n = 1.17 \frac{mol}{Kg} \times 0.350\ Kg = 0.41\ mol$$

$$molar\ mass = \frac{mass}{n} = \frac{8.75}{0.41} = \mathbf{21.3\ g/mol}$$

Or, $M_w\ (solute) = \frac{mass\ of\ solute \times i \times K_b}{mass\ of\ solvent \times 10^{-3} \times \Delta T_b} = \frac{8.75\ g \times 2 \times 0.512 ℃/m}{350\ g \times 10^{-3} \times 1.2\ ℃} = \mathbf{21.3\ g/mol}$

Example 26:

A mole fraction of 0.097 of a compound with the empirical formula $FeCl_3$ $(162.2\ g/mol)$ is dissolved in $450\ g$ of water.

Calculate **the freezing point** of the compound.

$K_f = 1.86\ °\mathrm{C/m}$

Solution:

$$\boldsymbol{FeCl_3 \rightarrow Fe^{+3} + 3Cl^-}$$

$$n_{water} = \frac{450}{18} = 25\ mol$$

$$X_{FeCl_3} = \frac{mole\ of\ FeCl_3}{mole\ of\ solution} \rightarrow X = \frac{n_{FeCl_3}}{n_{FeCl_3} + n_{water}} \rightarrow 0.097 = \frac{n}{n+25}$$

$$\rightarrow 0.097(n+25) = n \rightarrow n = 2.69\ mol$$

$$m = \frac{mole\ of\ solute}{mass\ of\ solvent\ (Kg)} = \frac{2.69}{0.450} = 5.98\ m$$

$$\Delta T_f = i * K_f * m = 4 * 1.86 * 5.98 = 44.5\ °\mathrm{C}$$

$$\Delta T_f = T_f° - T_f \rightarrow T_f = \Delta T_f + T_f° = 44.5 + 0 = \mathbf{44.5}\ °\mathrm{C}$$

Ch 12

Problems:

1) The mole fraction of copper (II) nitrate in an aqueous copper (II) nitrate solution is 0.135. What is the molality of the copper (II) nitrate solution?

a) $7.49\ m$
b) $8.01\ m$
c) $8.66\ m$
d) $9.34\ m$
e) $8.06\ m$

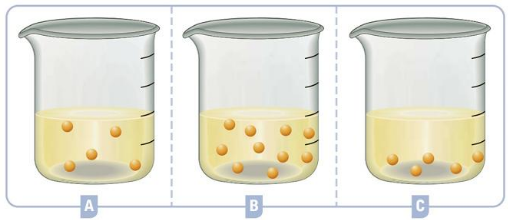
2) A $5.1\ g$ sample of $CaCl_2$ is dissolved in a beaker of water. Which of the following statements is true of this solution?

a) The solution will freeze at a lower temperature than pure water.
b) The solution has a higher vapor pressure than pure water.
c) The solution will boil at a lower temperature than pure water
d) Water is the solute in this solution.
e) None of the other statements (a–d) are true.

3) All of the following are colligative properties except:

a) vapor pressure lowering
b) freezing point depression
c) osmotic pressure
d) density elevation
e) boiling point elevation

4) Consider the following three beakers that contain water and a non-volatile solute. The solute is represented by the orange spheres.



a) Which solution would have the highest vapor pressure?
b) Which solution would have the lowest boiling point?
c) What could you do in the laboratory to make each solution have the same freezing point?

5) Arrange the following substances in order of increasing solubility in hexane, C_6H_{14}: CH_2OHCH_2OH, $C_{10}H_{22}$, H_2O.

a) $CH_2OHCH_2OH < C_{10}H_{22} < H_2O$
b) $C_{10}H_{22} < CH_2OHCH_2OH < H_2O$
c) $H_2O < CH_2OHCH_2OH < C_{10}H_{22}$
d) $H_2O < C_{10}H_{22} < CH_2OHCH_2OH$
e) None of these

6) The solubility of carbon dioxide in water is $0.161\ g\ CO_2$ in 100 mL of water at $20\ ℃$ and $1.00\ atm$. A soft drink is carbonated with carbon dioxide gas at $5.50\ atm$ pressure. What is the solubility of carbon dioxide in water at this pressure?

a) $0.886\ g/100ml$
b) $0.55\ g/100ml$
c) $1.886\ g/100ml$
d) $0.75\ g/100ml$
e) $0.04\ g/100ml$

7) What mass of solution containing 6.50% sodium sulfate, Na_2SO_4, by mass contains $1.75\ g\ Na_2SO_4$?

a) $34\ g$
b) $27\ g$
c) $33\ g$
d) $30.1\ g$
e) $0.75\ g$

8) An automobile antifreeze solution contains $2.50\ kg$ of ethylene glycol, $CH_2OHCH_2OH\ (Mw = 62.07\ g/mol),\ and\ 2.25\ kg$ of water. Find the mole fraction of ethylene glycol in this solution. What is the mole fraction of water?

a) $0.0078\ ,\ 0.9922$
b) $0.5\ ,\ 0.5$
c) $0.6\ ,\ 0.4$
d) $0.04\ ,\ 0.96$
e) $0.24\ ,\ 0.76$

9) An antiseptic solution contains hydrogen peroxide, H_2O_2, in water. The solution is $0.610\ m\ H_2O_2$. What is the mole fraction of hydrogen peroxide?

a) 0.9×10^{-2}
b) 1.1×10^{-3}
c) 2.1×10^{-2}
d) 1.1×10^{-2}
e) 1.1×10^{-9}

10) A solution was prepared by dissolving $0.800\ g$ of sulfur S_8 $(Mw = 256.56\ g/mol)$, in 100.0 g of acetic acid, $HC_2H_3O_2$.If the freezing point of pure acetic acid is $16.6\ °C$ and the boiling point of pure acetic acid is $118.1\ ℃$. Calculate the freezing point and boiling point of the solution.

$K_f = 3.9\ C°/m$, $K_b = 3.07\ °C/m$

a) 17.9 ℃ , 88.1 ℃
b) 16.5 ℃ , 118.1 ℃
c) 17.9 ℃ , 848.1 ℃
d) 17.9 ℃ , 88.9 ℃
e) 55 ℃ , 118.2 ℃

11) Which aqueous solution has highest osmotic pressure?

a) $0.15\ molar\ Ba(NO_3)_2$ $(0.15 \times 3 particles = 0.45\ M)$
b) $0.1\ molar\ Al(NO_3)_3$ $(0.1 \times 4 particles = 0.4\ M)$
c) $0.1\ molar\ CaCl_2$ $(three\ particle)$
d) $0.15\ molar\ NaCl$ $(two\ particle)$
e) $0.2\ molar\ NH_3$ $(one\ particle)$

12) The osmotic pressure of blood at $37\ ℃\ is\ 7.7\ atm$. A solution that is given intravenously must have the same osmotic pressure as the blood. What should be the molarity of a glucose solution to give an osmotic pressure of $7.7\ atm\ at\ 37\ ℃$?

a) $0.6\ M$
b) $0.9\ M$
c) $0.3\ M$
d) $0.1\ M$
e) 0

Ch 12

Answers:

1) c ($8.66\ m$)

2) a (The solution will freeze at a lower temperature than pure water)

3) d (density elevation)

4) a) C b) C c) Make the amount of **solute** in the three solutions equal.

5) c ($H_2O < CH_2OHCH_2OH < C_{10}H_{22}$)

6) A ($0.886\ g/100ml$)

7) b ($27\ g$)

8) e (0.24 , 0.76)

9) d (1.1×10^{-2})

10) b (16.5 ℃ , 118.1 ℃)

11) a ($0.15\ molar\ Ba(NO_3)_2$

12) c ($0.3\ M$)