St. V.S PUBLIC SCHOOL
Chapter -1 (Solution)
CLASS- Xll
SUBJECT: CHEMISTRY

SOLUTION :- A Solution is a homogenous mixture of two or more components. It is defined by using the terms *solute* and *solvent*.

***Solvent*::-** The component that is present in largest quantity is called solvent. It determines the physical state of solution.
Solute::- One or more components present in solution other than solvent is called solute.
Binary solutions: Solution consisting of two components only.

Types of Solutions

According to the phase of solvent, a binary solution can be classified in following types:

Types of Solutions	Solute	Solvent	Examples
Gaseous solutions	Gas	Gas	Mixture of O_2 and N_2
	Liquid	Gas	Chloroform mixed with N_2 Gas
	Solid	Gas	Camphor in nitrogen gas
Liquid Solutions	Gas	Liquid	Oxygen dissolved in water
	Liquid	Liquid	Ethanol dissolved in water
	solid	Liquid	Glucose dissolved in water
Solid Solutions	Gas	solid	Solution of H_2 and Pd
	Liquid	solid	Amalgam of Hg with Na
	Solid	solid	Alloy

In this chapter we are mainly focusing on binary solutions (solution made up of two components) of liquid known as *liquid solutions*.

Different Methods of Expressing Concentration of Solutions

The composition of solution is defined in terms of concentration. There are several ways to define concentration of solution as follows:

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(A) **Mass percentage (w/w)**:

$$\text{Mass \% of component} = \frac{\text{Mass of the component in the solution}}{\text{Total mass of solution}} \times 100$$

(B) **Volume percentage (V/V)** =

$$\text{Volume \% of component} = \frac{\text{Volume of the component in the solution}}{\text{Total volume of solution}} \times 100$$

(C) **Mass by volume percentage (w/V)** = $\frac{\text{Mass of the component}}{\text{100 mL solution}}$

(D) **Part per million (ppm)**:

$$\text{ppm} = \frac{\text{Number of parts of compnent}}{\text{Total number of parts of all components of solution}} \times 10^6$$

(E) **Mole fraction**:

$$\text{Mole fraction of component} = \frac{\text{Moles of component}}{\text{Total number of moles of all the component}}$$

(F) **Molarity** = $\frac{\text{Moles of solute}}{\text{Volume of solution in Litre}}$

(G) **Molality** = $\frac{\text{Moles of solute}}{\text{Mass of solution in Kg}}$

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Question: A solution of glucose (molar mass = 180 g mol^{-1}) in water is labelled as 10% (by mass). What would be the molality and molarity of the solution? (Density of solution = 1.2 g mL^{-1}). [CBSE 2014,2013]

Sol: 10% by mass solution of glucose in water means that 10 g of glucose in present in 100 g of the solution.

Amount of water present = (100 − 10) g = 90 g of water.

Molar mass of glucose ($C_6H_{12}O_6$) = 180 g mol^{-1}

$$\textbf{Molality} = \frac{\text{Moles of solute}}{\text{Mass of solution in Kg}}$$

$$\text{Moles of solute} = \frac{\text{Mass of solute in solution}}{\text{Molar Mass of solute}}$$

Molality of given solution is:

$$\text{Molality} = \frac{\text{Mass of glucose}}{\text{Molar Mass of glucose}} \times \frac{1000\text{g kg}^{-1}}{\text{mass of solvent in g}}$$

$$= \frac{10\text{ g}}{180\text{ g mol}^{-1}} \times \frac{1000\text{g kg}^{-1}}{90\text{ g}}$$

$$= 0.62\text{ m}$$

For calculating the molarity we have to calculate the amount of solvent present in solution. This is calculated with the help of density. Given that density of the solution is 1.2 g mL^{-1}.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Volume} = \frac{\text{Mass}}{\text{density}}$$

$$= \frac{100\text{ g}}{1.2\text{ g mL}^{-1}}$$

$$= 83.33\text{ mL}$$

Now,

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Volume of solution in Litre}}$$

$$\text{Moles of solute} = \frac{\text{Mass of solute in solution}}{\text{Molar Mass of solute}}$$

Molarity of given solution is:

$$\text{Molarity} = \frac{\text{Mass of glucose}}{\text{Molar Mass of glucose}} \times \frac{1000\text{ mL L}^{-1}}{\text{mass of solvent in g}}$$

$$= \frac{10\text{ g}}{180\text{ g mol}^{-1}} \times \frac{1000\text{ mL L}^{-1}}{83.33\text{mL}}$$

$$= 0.67\text{ M}$$

By- Nitin Sir

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Question: Define the term mole fraction. [CBSE 2012]

Sol: The mole fraction of a component in a mixture is defined as the ratio of the number of moles of the component to the total number of moles of all the components in the mixture. Mathematically, it is represented as:

$$\text{Mole fraction of component} = \frac{\text{Moles of component}}{\text{Total number of moles of all the component}}$$

Let us assume there are two components in mixture. The number of moles of component 1 is n_1 and component 2 is n_2. Then mole fraction of each species is given as:

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

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

$$X_1 + X_2 = 1$$

Solubility

Solubility of a substance is the maximum amount that can be dissolved in given amount of solvent at specific temperature. Factors affecting the solubility:

- **Nature of solute**
- **Nature of solvent**
- **Temperature**
- **Pressure**

Solubility of Solid in a Liquid

Nature of solute and solvent:

According to the nature of solute and solvent the solubility of solid in a liquid follow the principle " *Like dissolves like"*

If the nature of solute and solvent is same, the intermolecular force of interaction would be same. That helps in solubility of solute in solvent.

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Polar solute dissolves in polar solvent. For example: NaCl and sugar dissolves in water. Non-polar solute dissolves in non-polar solvent. For example: Naphthalene and anthracene dissolves in benzene not in water.

***Saturated solution*:** If the concentration of solute in solution remain constant at given set of temperature and pressure is called saturated solution. If we add more solute in it, it would precipitate out.

Un-Saturated solution: If the concentration of solute in solution can increase at given set of temperature and pressure is called un-saturated solution. If we add more solute in it, it would get dissolve and increase the concentration of solution.

Effect of temperature:

The solubility of solute in solvent always follows the dynamic equilibrium.
Solute + Solvent Solution.
It follows the Le Chateliers principle for the change in temperature at dynamic equilibrium.
If the solution is formed by giving heat means dissolution is endothermic. By increasing the temperature, the reaction will proceed in forward direction and solubility of solute increases.
If the heat is released in formation of solute means dissolution is exothermic. By increasing the temperature, the reaction will proceed in backward direction and solubility of solute decreases.

Effect of pressure:

Pressure has no significant effect on solubility of solid in liquid.

Solubility of Gas in a Liquid

Nature of solute and solvent:

Solubility of gas in liquid is also somewhat affected by nature of solute and solvent. Oxygen dissolves only a small extent in water but HCl is highly soluble in water because of polar nature of solute and solvent.

Effect of pressure:

Solubility of gas in liquid is highly affected by temperature and pressure. As the pressure of the gas above the surface of the liquid increases, it increases the solubility of gas in liquid. The quantitative relation of this equation is given by Henry's Law.

Henry's Law:

It states that, "*At constant temperature, the solubility of gas in a liquid is directly proportional to the partial pressure of the gas present above the surface of the liquid or solution."*
If we consider mole fraction of gas in a solution to measure its solubility then it can be said that, "Mole *fraction of gas in a liquid is proportional to the partial pressure of gas above the liquid or solution*."

Now the Henry's Law can be stated as , " *The partial pressure of a gas in vapour phase (p) is proportional to the mole fraction of gas(x) in solution*."
Expression for Henry's Law:
p_x
$p = K_H . x$
K_H is Henry's Law constant
Important point regarding Henry's Law:

- Different gases have different K_H values at the same temperature. That is K_H depends on the nature of gas.
- Higher the value of K_H at given pressure, lower is the solubility of gas in given liquid.
- K_H value of particular gas increases with increasing temperature. It indicates that solubility of gas decreases with increasing temperature.

Effect of temperature:

Dissolution of gas in a liquid is an exothermic process. As dissolution process involves dynamic equilibrium, it follows Le Chaterlier's principle. Hence the solubility of gas in liquid, decreases with increase in temperature.

Vapour Pressure of a Liquid Solution

Liquid solution are formed when solvent is in liquid phase. Solute may be solid, liquid or gas. On the basis of solute, the liquid solution is classified in 3 types as:

(*i*) Solid in liquid
(*ii*) Liquid in liquid
(*iii*) Gas in liquid
We will discuss the various properties of liquid in liquid solution and solid in liquid solutions.

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Roult's Law:

It states that for the solutions of volatile liquid, the partial vapour pressure of each component of the solution is directly proportional to its mole fraction present in solution.

For component 1,

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$p_1 \propto x_1$
$p_1 = p_1^\circ x_1$...(1)
p_1 = Vapour pressure of component 1 in solution.
p_1° = Vapour pressure of pure liquid component 1at the same temperature
x_1 = Mole fraction of component 1 in solution.
Similarly for component 2 :

$P_2 = p_2^\circ x_2$ ...(2)
According to **Dalton's Law of partial pressure**, The total pressure (p_{total}) over the solution phase in the container will be the sum of partial pressure of the components in solution. If the solution is made up of two volatile liquids then total pressure above the solution is:
$p_{total} = p_1 + p_2$ ...(3)
p_{total} = Total pressure over the solution phase
p_1 = Vapour pressure of component 1 in solution
p_2 = Vapour pressure of component 1 in solution
Substituting the values of p_1 and p_2 in eq...(3) we get:
$p_{total} = p_1^\circ x_1 + p_2^\circ x_2$ ...(4)
As, total mole fraction of components in any solution is 1. Therefore,

$x_1 + x_2 = 1$
$x_1 = (1 - x_2)$...(5)
Putting the value of x_1 in eq (4) we get:
$p_{total} = p_1^\circ(1- x_2) + p_2^\circ x_2$
$p_{total} = p_1^\circ - p_1^\circ x_2 + p_2^\circ x_2$
$\boldsymbol{p_{total} = p_1^\circ + (p_2^\circ - p_1^\circ) x_2}$ **...(6)**
The equation ...(6) is known as the mathematical expression for Roult's Law for the solution made up of two volatile liquids.

From this equation ...(6) we can conclude the following points :

- p_{total} can be related to mole fraction of any of the one component.
- p_{total} varies linearly with x_2
- p_{total} increases or decreases with increase of x_1

This can be represents on graph as follows assuming $p_1^\circ < p_2^\circ$:

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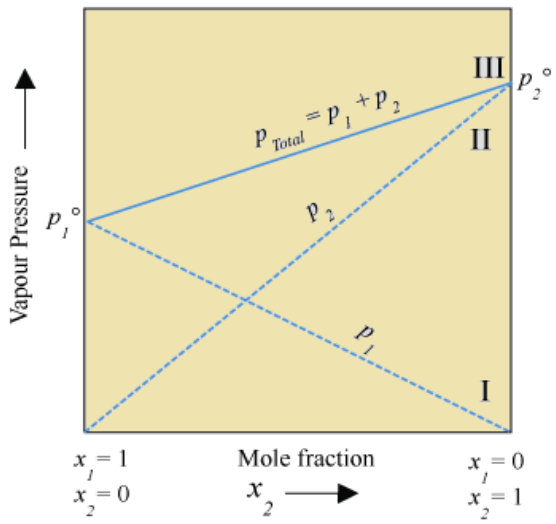

Conclusion from graph:

- Plot of p_1° vs x_1 is linear
- Plot of p_2° vs x_2 is linear
- Maximum value of $p_{total} = p_2^\circ$
- Minimum value of $p_{total} = p_1^\circ$

Composition of vapour phase at equilibrium is determined by using Dalton's Law. Let y_1 and y_2 be the mole fraction of liquid 1 and 2 in solution then partial vapour pressure of each component is written as:

$\boldsymbol{p_1 = y_1\, p_{total}}$**... (7)**

Equation ...(7) gives you the value of partial vapour pressure of each component in vapour phase.

Vapour Pressure of a Solid-Liquid Solution

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When a non-volatile solid is added to the solvent to form a solution, then the vapour pressure of solution is found lower than vapour pressure of the pure solvent at same temperature. The decrease in the vapour pressure of the solution is solely depends on the quantity of non-volatile solute present in solution.

The vapour pressure of such solution is given by using general equation of Roult's Law.

Assume that water is component 1 and non-volatile component is component 2, then vapour pressure of the solution will be equal to the vapour pressure of solvent in solution. Vapour pressure of solvent p_1 is proportional to its mole fraction in solution and given as :

$p_1 \propto x_1$

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p_1 = Vapour pressure of component 1 in solution.
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Ideal and Non Ideal Solutions

Liquid-liquid solutions can be classified as ideal and non-ideal on the basis of certain properties.

Ideal Solution

- Obeys the Roult's Law over the entire range of concentration.
- $\Delta H_{mixing} = 0$
- $\Delta V_{mixing} = 0$
- Example : solution of n-hexane and n-heptane, solution of bromoethane or chloroethane.

It can be summarised as: If a Solution formed by mixing the two components A and B, in which intermolecular force of attraction between A and B (A–B) is nearly equal to intermolecular force of attraction between pure components (A–A and B–B) then no heat would be evolved or absorbed in forming the solution. Also volume of the solution will be equal to the total volume of the individual component taken to form the solution.

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Vapour Pressure of a Liquid-Liquid Solution

Let us take a binary solution made up of two volatile liquids 1 and 2. As the liquid start evaporating; a stage will come when the vapour pressure of liquid will be in equilibrium with the corresponding liquid. As we know that vapour pressure of liquid is proportional to its mole

fraction. The quantitative relationship between the vapour pressure and mole fraction in binary solution is given by *Roult's Law*.

Roult's Law:

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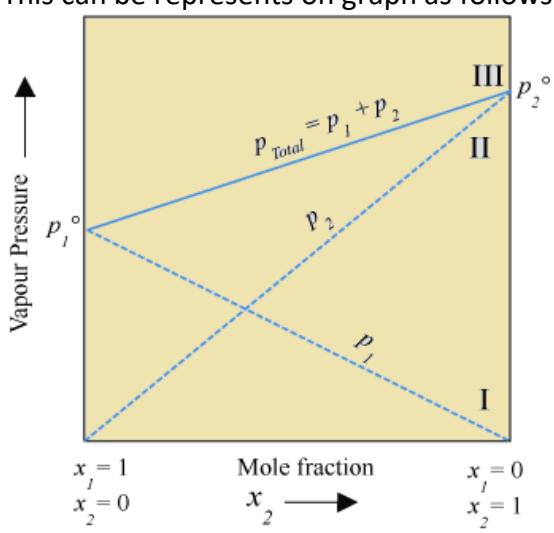

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Non-Ideal Solution

- Does not obey the Roult's Law over the entire range of concentration.
- $\Delta H_{mixing} \neq 0$
- $\Delta V_{mixing} \neq 0$
- Example: Solution of chloroform and acetone
  It can be summarised as: If a Solution formed by mixing the two components A and B , in which intermolecular force of attraction between A and B (A–B) is not equal to intermolecular force of attraction between pure components (A–A and B–B). This new interaction (A–B) is either less than or more than the interaction of the pure components (A–A and B–B). This leads to the positive or negative deviations from Roult's Law.

Positive Deviation from Roult's Law

- The vapour pressure of solution formed by mixing two components is **higher** than predicted from Roult's Law
- The new intermolecular interactions formed by mixing the component A and B (A–B) are **weaker** than the intermolecular interactions of pure component (A–A and A–B)
- Example: mixture of ethanol and acetone, solution of carbon disulphide and acetone.
  Graph representing the positive deviation:

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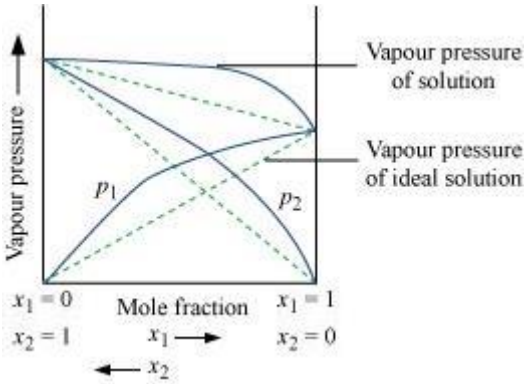
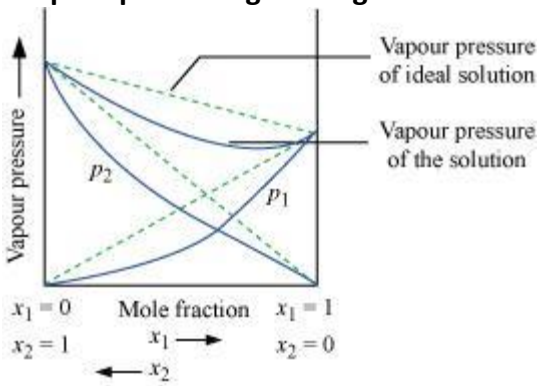


Negative Deviation from Roult's Law

- The vapour pressure of solution formed by mixing two components is lower than predicted from Roult's Law
- The new intermolecular interactions formed by mixing the component A and B (A-B) are stronger than the intermolecular interactions of pure component (A-A and A-B)
- Example: solution of phenol and aniline, chloroform and acetone.

Graph representing the negative deviation:



Azeotropes

These are mixture of two liquids having same composition in liquid as well as vapour phase and boil at the constant temperature. This liquid mixture cannot be separated into pure component even on fractional distillation.

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Types of Azeotropes

Minimum boiling azeotrope:

The solution which show large positive deviation from Raoult's Law. Example: solution of 95% ethanol in water.

Maximum boiling azeotropes:

The solution which show large negative deviation from Raoult's Law. Example: solution of 68% nitric acid and 32% water by mass.