

CHEMISTRY STUDY MATERIALS FOR CLASS 12

(NCERT BASED NOTES OF CHAPTER -02)

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SOLUBILITY

Solubility of a substance is its maximum amount that can be dissolved in a specified amount of solvent. It depends upon the nature of solute and solvent, temperature and pressure.

Solubility of a Solid in a Liquid

It is observed that polar solutes dissolve in polar solvents and non polar solutes in non polar solvents.

In general, a solute dissolves in a solvent if the intermolecular interactions are similar in the two or the general principle related to solubility is that “***like dissolves like***”.

Saturated and Unsaturated solutions

A solution in which no more solute can be dissolved at the same temperature and pressure is called a saturated solution. Here there is a dynamic equilibrium between the dissolved solute and the undissolved solute. A solution in which more solute can be dissolved at the same temperature is called an unsaturated solution.

Effect of temperature

The solubility of a solid in a liquid mainly depends on temperature. Since the dissolution of a solid in a liquid is an equilibrium process, it should follow Le Chateliers principle. In general, *if in a nearly saturated solution, the dissolution process is **endothermic** ($\Delta_{sol}H > 0$), the solubility should **increase** with rise in temperature and if it is **exothermic** ($\Delta_{sol}H < 0$) the solubility should **decrease** with temperature.*

Effect of pressure

Since solids and liquids are highly incompressible, pressure does not have any significant effect on solubility of solids in liquids.

Solubility of a Gas in a Liquid

Solubility of gases in liquids is greatly affected by pressure and temperature. The solubility of a gas increases with increase of pressure.

A quantitative relation between pressure and solubility of a gas in a liquid was first given by Henry, which is known as **Henry's law**. "*The law states that at A CONSTANT TEMPERATURE, THE SOLUBILITY OF A GAS IN A LIQUID IS DIRECTLY PROPORTIONAL TO THE PRESSURE OF THE GAS*".

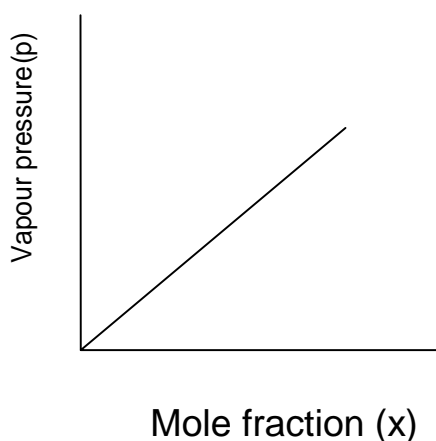
Or, "*the partial pressure of the gas in vapour phase (**p**) is proportional to the mole fraction of the gas*

(**x**) in the solution" and is expressed as:

$$p = K_H x$$

Here K_H is the **Henry's law constant**. The value of K_H depends on the nature of the gas and temperature. As the value of K_H increases, the solubility of the gas in the liquid decreases

A graph of partial pressure (p) of the gas against mole fraction (x) of the gas in solution is a straight line as follows. The slope of the graph gives the value of K_H .



As the temperature increases solubility of a gas in a liquid decreases. It is due to this reason that aquatic species are more comfortable in cold waters rather than in warm waters.

Applications of Henry's law

1. To increase the solubility of CO_2 in soft drinks and soda water, the bottle is sealed under high pressure.
2. *Scuba divers* carry oxygen cylinders to breath under deep sea. At high pressure under water, the solubility of atmospheric gases in blood increases. When the divers come towards surface, the pressure gradually decreases. This releases the dissolved gases and leads to the formation of bubbles of nitrogen in the blood. This blocks capillaries and creates a medical condition known as *bends*. To avoid

bends the cylinders used by scuba divers are filled with air diluted with helium (11.7% helium, 56.2% nitrogen and 32.1% oxygen).

3. At high altitudes the partial pressure of oxygen is less than that at the ground level. This leads to low concentrations of oxygen in the blood and tissues of people living at high altitudes or climbers. Low blood oxygen causes climbers to become weak and unable to think clearly. This condition is known as *anoxia*.

Effect of Temperature

Solubility of gases in liquids decreases with rise in temperature. When dissolved, the gas molecules

are present in liquid phase and the process of dissolution can be considered similar to condensation

and heat is evolved during this process. The dissolution process involves a dynamic equilibrium

and thus follows Le-Chateliers Principle. As dissolution is an exothermic process, the solubility should

decrease with increase of temperature.

Vapour Pressure of Liquid Solutions

In liquid solutions, the solvent is always a liquid. The solute can be a gas, a liquid or a solid. Generally, the liquid solvent is volatile. The solute may or may not be volatile. Based on the volatility of solute, the vapour pressure of the solution is greater or less than that of the solvent.

Vapour Pressure of Liquid-Liquid Solutions – Raoult's Law

A quantitative relationship between the vapour pressure and mole fraction of solute in a solution was first given by a French chemist F.M Raoult and it is known as Raoult's Law. It states that **for A SOLUTION OF VOLATILE LIQUIDS, THE PARTIAL VAPOUR PRESSURE OF EACH COMPONENT IN THE SOLUTION IS DIRECTLY PROPORTIONAL TO ITS MOLE FRACTION.**

Consider a binary solution of two volatile liquids 1 and 2. Let p_1 and p_2 be the partial vapour pressures of the two components 1 and 2 respectively and p_{total} be the total vapour pressure. Let x_1 and x_2 be the mole fractions of the two components 1 and 2 respectively.

Then according to Raoult's law, for component 1, $p_1 \propto x_1$ or, $p_1 = p_1^0 x_1$

and for component 2, $p_2 \propto x_2$ or, $p_2 = p_2^0 x_2$

Where p_1^0 and p_2^0 are the vapour pressures of the pure components 1 & 2 respectively.

According to Dalton's law of partial pressures, the total pressure (p_{total}) will be the sum of the partial pressures of the components of the solution.

So, $p_{\text{total}} = p_1 + p_2$

Substituting the values of p_1 and

p_2 , we get $p_{\text{total}} = x_1 p_1^0 + x_2 p_2^0$

$$= (1 - x_2) p_1^0 + x_2 p_2^0$$

Or, $p_{\text{total}} = p_1^0 + (p_2^0 - p_1^0) x_2$

Plots of p_1 or p_2 against the mole fractions x_1 and x_2 give straight lines (I and II). Similarly the plot of p_{total}

Versus X_2 (line III) is also linear

The composition of vapour phase in equilibrium with the solution is determined from the partial pressures of

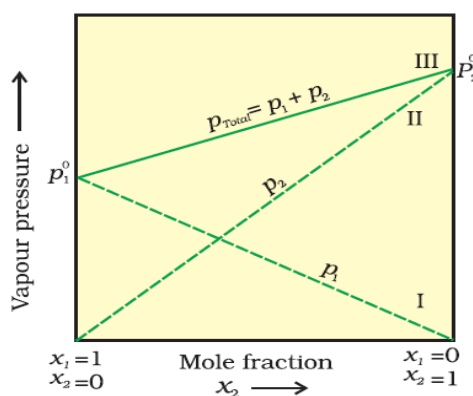
the components. If y_1 and y_2 are the mole fractions of the components 1 and 2 respectively in the vapour phase

then, using Dalton's law of partial pressures:

$$p_1 = y_1 p_{\text{total}} \text{ and } p_2$$

$$= y_2 p_{\text{total}} \text{ In general,}$$

$$p_i = y_i p_{\text{total}}$$



Raoult's Law as a special case of Henry's Law

According to Raoult's law, the vapour pressure of a volatile component in a solution is given by $p_i = x_i p_i^0$. According to Henry's law, solubility of a gas in a liquid is given by $p = K_H x$.

If we compare the equations for Raoult's law and Henry's law, we can see that the partial pressure of the volatile component or gas is directly proportional to its mole fraction in solution. Only the proportionality constant K_H differs from p_1^0 .

Thus, Raoult's law becomes a special case of Henry's law in which K_H becomes equal to p^0 .

Vapour Pressure of Solutions of Solids in Liquids

The vapour pressure of a liquid is the pressure exerted by the vapour in equilibrium with its own liquid. *If a non-volatile solute is added to a pure solvent, the vapour pressure of the resulting solution is always lower than that of the pure solvent.* This is because in a pure solvent, there are only solvent molecules, which can vapourise. But when a non-volatile solute is added to the solvent, a fraction of the surface is occupied by solute molecules. So the number of solvent molecules passing to the vapour phase decreases and hence the vapour pressure also decreases. The decrease in the vapour pressure of solvent depends on the quantity of non-volatile solute present in the solution and not on its nature.

For such a solution the Raoult's law can be stated as, **for any solution, the partial vapour pressure of each volatile component in the solution is directly proportional to its mole fraction.**

Consider a binary solution containing a solvent 1 and solute 2. Since the solute is non-volatile, only the solvent molecules are present in vapour phase and contribute to vapour pressure.

Let p_1 be the vapour pressure of the solvent, x_1 be its mole fraction, p^0 be its vapour pressure in the pure state. Then according to

Raoult's law, $p_1 \propto x_1$

$$\text{or, } p_1 = p_1^0 x_1$$

A graph between the vapour pressure and the mole fraction of the solvent is linear as follows:

