Solubility of Solids and Gases in Liquids

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Solubility of solids: Solubility of a substance expresses the maximum amount of it which can be dissolved in a specific amount of solvent.

Solubility of solids in liquids: When a solid (solute) is added to the solvent, the solute dissolves because its particles go into the liquid and its concentration in the solution increases. This process is known as dissolution. Some solute particle in solution collides with solid solute particles and get precipitated out. This process is called crystallization. The process of dissolution continues until the solution attains a certain maximum concentration. Such a solution in which no more solute can be dissolved at a given condition of temperature and pressure is called saturated solution. A solution in which more solute can be dissolved at the same temperature is called unsaturated solution. At the saturated solution stage, an equilibrium gets established between the process of dissolution and crystallization. Under such conditions, the number of solute particles going into the solution will be equal to the number of solute particles separating out and a state of dynamic equilibrium is reached.

$$\text{solute} + \text{solvent} \underset{\text{crystallization}}{\overset{\text{dissolution}}{\leftrightarrow}} \text{solution}$$

Therefore, in saturated solution, the concentration of the solute in the solution will remain constant under the given condition i.e., temperature and pressure. Thus, solubility of substance at a given temperature is defined as the amount of the solid that dissolves in 100 grams of the solvent at a given temperature to form a saturated solution.

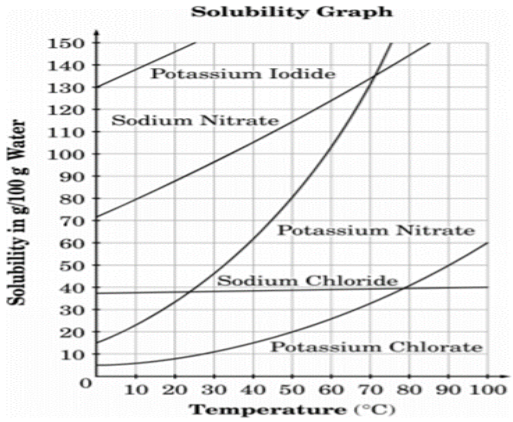
The solubility is also expressed as molar solubility which gives the molar concentration of a substance in a saturated solution. For example, if the concentration of glucose in its saturated solution at 20ºC is 6 mol/ litre, so its molar solubility is reported at 6 mol/ litre thus, concentration of the solute has highest value in saturated solution. The solubility of a solid in a liquid depends upon the following factors:

Nature of the solute and the solvent: - Every solid does not dissolve in a given liquid. In general, a solid dissolve in a liquid if the intermolecular interaction is similar in solute and the solvent. This is in accordance with basic rules "like dissolve like". This means that ionic (polar) compounds dissolve more readily in polar solvents like water and are very little soluble or almost insoluble in non-polar solvents like benzene, ether and carbon tetrachloride. Similarly, non-polar (covalent or organic) compounds are soluble in nonpolar solvents like benzene, ether and CCl_4, but are very little soluble in water.

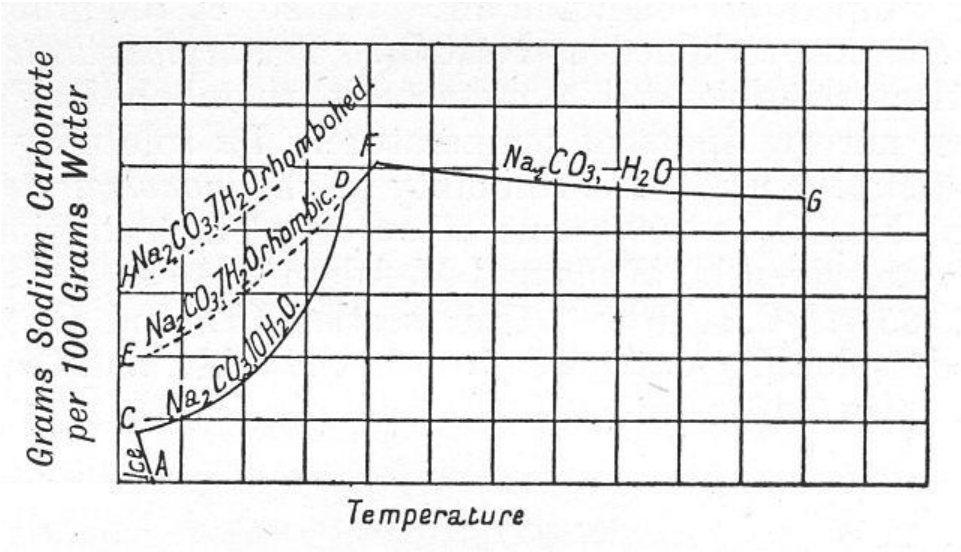
For example, common salt and sugar are soluble in water. Their solubility in water are 5.3 mol/ litre and 3.8 mol/ litre. Naphthalene and anthracene (non-polar compounds) dissolve readily in benzene but sodium chloride and sugar do not. Naphthalene and anthracene are not dissolved in water.

Effect of temperature: - The solubility may increase or decreases with increase in temperature. It is observed that most ionic and molecular solids become more soluble at higher temperature. The variation of solubility of a solid with temperature depends upon the enthalpy of solution. We observe three types of trends in the behavior of different solute.

(a**) The solubility of solute increase with increase in temperature: -** The solubility of most of the substances such as sodium nitrate, ammonium chloride, Potassium Chloride, silver nitrate, potassium iodide, etc. increase with rise in temperature. This is because the dissolution process for these substances is endothermic (Δsol H>0) solute + solvent + heat ↔solution Δsol H = +ve

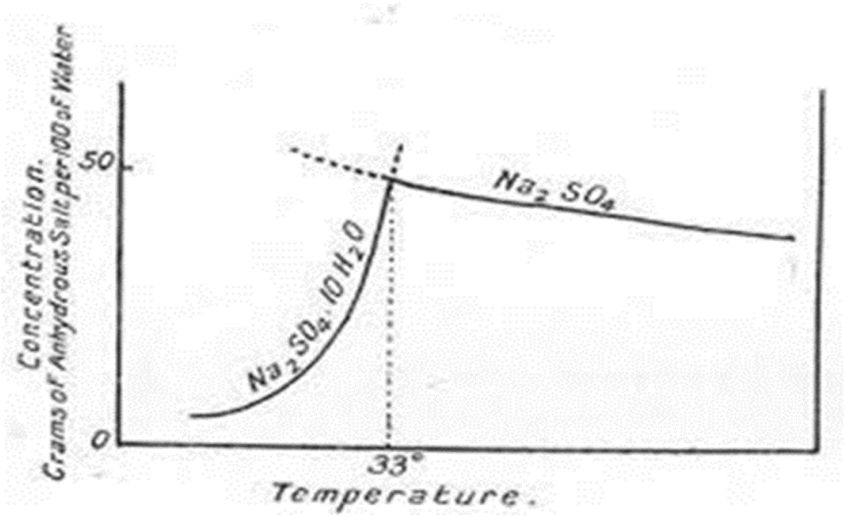


(b) The solubility of solids decreases with increase in temperature: The solubility of some substance like Lithium sulphate (Li_2SO_4), cerium sulphate [Ce_2SO_4), some calcium salt of organic acids, sodium carbonate monohydrate ($Na_2CO_3.H_2O$), decreases with rise in temperature. This is because their dissolution process is exothermic (Δsol H< 0). These dissolve with evolution of heat, a decrease of solubility with the temperature is expected in accordance with Le- Ch atelier's principle.



Solubility shows irregular behavior with increase in temperature: - For some substances the solubility behavior is not regular. For example, solubility of sodium sulphate increases up to a certain temperature and then decrease as the temperature is further raised. The solubility curve of sodium sulphate shows a sharp break at 32.8ºC. This temperature is called transition temperature. This is due to change in one solid form into another solid form. Sodium sulphate at 32.8ºC, there is an equilibrium between solid decahydrate ($Na_2SO_4.10H_2O$) and anhydrous sodium sulphate.

$$Na_2SO_4.10H_2O \underset{\text{below } 32.8}{\overset{\text{above } 32.8}{\leftrightarrow}} Na_2SO_4$$



Below this temperature only sodium sulphate exists while above this temperature anhydrous sodium sulphate exists.

If the solute dissolved with absorption of heat (endothermic process), the solubility increases with rise in temperature. If the solute dissolves with evolution of heat (exothermic process), the solubility decreases with rise in temperature

Effect of pressure: The effect of pressure on the solubility of solid in liquid is generally very small or insignificant. This is because solids and liquids are highly incompressible and practically unaffected by changes in pressure. For example: - A change of 500 atm. in pressure increases the solubility of sodium chloride in water only by 2.3%.

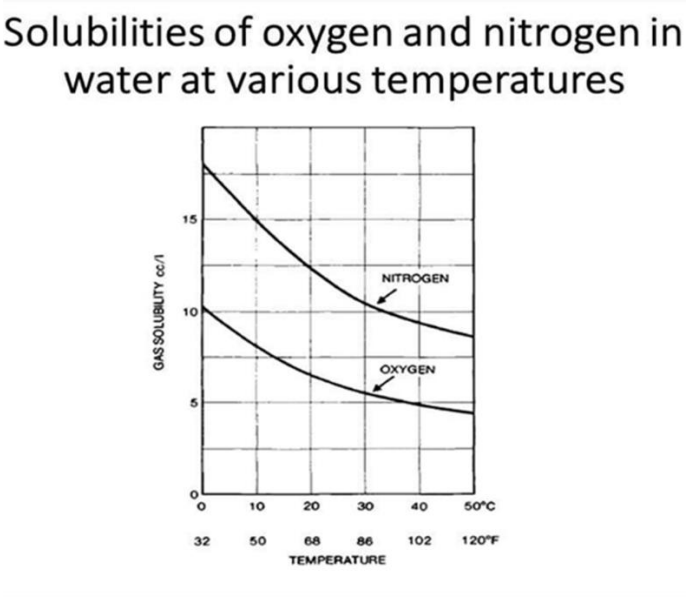
Solubility of gases in liquids: Gases dissolve in liquids to form homogeneous solutions. The solubility of a gas in a liquid depends upon:

- 1. the nature of the substance
- 2. the nature of the solvent
- 3.temperature of the solution
- 4. pressure

The solubility of different gases in the same solvent varies considerably. For example: - gases like N_2, H_2, O_2 and He etc. dissolve in water only to a small extent. Gases like Ammonia, Sulphur dioxide, and HCl are highly soluble in water due to the chemical reactions of these gases with water to form NH_4OH, H_2SO_3 and HCl acid. Therefore, the most soluble gases are those with chemically react with liquid solvent.

(a) Effect of temperature: The solubility of a gas decrease with increase of temperature. This is because, gases dissolve in a liquid with the evolution of heat i.e, exothermic process. Therefore, accordance with Le-chatelier's principle, the increase in temperature will result in decrease in the solubility of the gas. It is for this reason that most of gases which dissolve without ionizing are readily expelled from solution by boiling.

It may be noted that there are certain gases such as hydrogen and inert gases whose solubility increases slightly with increase of temperature especially in the non-aqueous solvent such as alcohols, acetone and hydrocarbon



(b) Effect of pressure: The solubility of gases increases with increase of pressure. Consider a gas in dynamic equilibrium with a solution at pressure p and temperature. Number of gas molecules entering the solution is equal to the number of dissolved molecules leaving solution phase.

Now increase the pressure over the solution phase by compressing the gas to a smaller volume. This will increase the number of gaseous particles per unit volume over the solution. As a result, the more molecules will be striking the surface of the liquid and hence more molecules will dissolve and the solubility of gas will increase until a new equilibrium reached.