chemical equilibrium and chemical solubility

chemical equilibrium:

Chemical equilibrium definition refers to the state of a system where the concentration of the reactant and the concentration of the products do not change with respect to time and the system does not display any further change in properties.

Chemical equilibrium is said to be achieved by the system when the rate of the forward reaction is equal to the rate of the reverse reaction. When there is no further change in the concentrations of the reactants and the products due to the equal rates of the forward and reverse reactions, at the time point of time the system is said to be in a dynamic state of equilibrium

Let's understand this with an example. Consider hydrogen and iodine gas. These gases react to form hydrogen iodide. Here the reaction is given below:

Reaction A: Forward reaction $H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$

Reaction B: Reverse reaction $2HI_{(g)} \rightleftharpoons H_{2(g)} + I_{2(g)}$

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Initially, only the forward reaction occurs because HI was not present. As soon as some HI is formed, it begins to decompose back into H2 and I2. After that, the rate of the forward reaction decreases while the rate of the reverse reaction keeps on increasing. In the long run, the rate of the combination of H2 and I2 to produce HI becomes equal to the rate of decomposition of HI into H2 and I2. When the rates of the forward and rate of reverse reactions become equal to one another, then the reaction has achieved its state of balance.

Types of Chemical Equilibrium

There are two types of chemical equilibrium:

- Homogeneous Equilibrium
- Heterogeneous Equilibrium

Homogeneous Chemical Equilibrium

In this type of reaction, the reactants and the products of chemical equilibrium are all in the same phase

It is also divided into two types: (i) Reactions having the number of molecules of the products is equal to the number of molecules of the reactants. For example,

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$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

$$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$$

(ii) Reactions having the number of molecules of the products is not equal to the total number of reactant molecules. For example,

$$2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$$

$$COCL_{2(g)} \rightleftharpoons CO_{(g)} + Cl_{2(g)}$$

Heterogeneous Chemical Equilibrium

In this type of reaction, the reactants, as well as the products of chemical equilibrium, are present in different phases. Examples are given below:

$$CO_{2(g)} + C_{(S)} \rightleftharpoons 2CO_{(g)}$$

$$CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$$

Conditions for Equilibrium

Chemical equilibrium is a dynamic process. The forward and reverse reactions continue to occur even after the equilibrium state has been achieved. However, the rates of the reactions are the same here, and there is no change in the relative concentrations of reactants and products for a

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reaction that is at equilibrium. Following are the conditions and properties of a system at equilibrium.

- The system must be closed, which means no substances can enter or leave the system.
- Equilibrium is a dynamic process. Even though we don't necessarily see the reactions, both forward and reverse reactions are taking place.
- The forward and reverse rates of reactions must be equal.
- The number of reactants and products need not be equal. However, after equilibrium is achieved, the amounts of reactants and products will always be constant.

Factors Affecting Chemical Equilibrium

- **Change in Pressure**

  Change in pressure occurs due to the change in the volume. If there is a change in pressure it can also affect the gaseous reaction because the total number of gaseous reactants and products are now different. In the heterogeneous chemical equilibrium, according to the principle of Le Chatelier, if there is a change of pressure in both liquids and solids it can be ignored because the volume is independent of the pressure.

- **Change in Temperature**

The effect of temperature on chemical equilibrium depends upon the sign of ΔH of the reaction and it also follows Le-Chatelier's Principle.

When the temperature increases, the equilibrium constant of an exothermic reaction decreases.

In the case of an endothermic reaction the equilibrium constant increases with an increase in temperature.

Together with the equilibrium constant, the rate of reaction is also affected by the change in temperature. In the case of exothermic reactions according to Le Chatelier's principle, the equilibrium shifts towards the reactant side when there is increased temperature. In the case of endothermic reactions, the equilibrium shifts towards the product side with an increase in temperature.

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- **Effect of a Catalyst**

  A catalyst does not affect the chemical equilibrium. It only speeds up a reaction. The same number of reactants and products will be present at equilibrium in a catalyzed in a non-catalyzed reaction. The presence of a catalyst only facilitates when the reaction proceeds through a lower-energy transition state of reactants to products.

- **Effect of Addition of an Inert Gas**

  When an inert gas like argon is added to a constant volume it does not take part in the reaction so the equilibrium remains in an undisturbed state. If the gas added is a reactant or product that is involved in the reaction then the reaction quotient will change.

Examples of Chemical Equilibrium

In chemical reactions, the reactants are converted into products by the forward reaction and the products can be converted into the reactants by the backward reaction. They are two states, reactants, and products both are present in different compositions.

Importance of Chemical Equilibrium It is useful in many industrial processes like,

It is used in the preparation of ammonia with the help of Haber's process. Here nitrogen gas combines with hydrogen gas to form ammonia. The yield of ammonia happens more at low temperature, high pressure, and in the presence of iron as a catalyst. It is used in the preparation of sulphuric acid by contact process: In this process, the fundamental reaction is the oxidation of Sulphur dioxide into Sulphur trioxide. This involves chemical **equilibrium.**

Chemical solubility

Chemical solubility refers to the ability of a substance (solute) to dissolve in a solvent, forming a homogeneous solution. The solubility of a chemical depends on several factors, including temperature, pressure, and the nature of the solute and solvent. The solubility of a substance can be expressed in terms of the maximum amount of solute that can dissolve in a given amount of solvent at a specific temperature and pressure, often measured in grams per liter (g/L), moles per liter (mol/L), or other units.

Types of Solubility

- **Solubility in Water (Aqueous Solubility):** Some substances are highly soluble in water (e.g., sodium chloride, sugar), while others are only slightly soluble or insoluble (e.g., oil, sand).
- **Gas Solubility:** Gases can dissolve in liquids (like CO_2 in water) and their solubility depends on the gas's partial pressure and temperature.
- **Solubility of Ionic Compounds:** Ionic compounds (like salts) have varying solubilities depending on the ions involved. For example, sodium chloride (NaCl) is highly soluble in water, whereas barium sulfate ($BaSO_4$) is almost insoluble in water.

Factors Affecting Chemical Solubility

- **Nature of Solute and Solvent:**

  Polarity: Polar solutes dissolve in polar solvents, and non-polar solutes dissolve in non-polar solvents. This is often summarized by the phrase "like dissolves like." For example, sugar (polar) dissolves well in water (polar), while oil (non-polar) does not dissolve in water.

  Intermolecular Forces: The strength of interactions between solute and solvent molecules (e.g., hydrogen bonds, Van der Waals forces) can influence solubility. Stronger interactions typically result in higher solubility.

- **Temperature:**

  In general, the solubility of most solid solutes increases with temperature. However, for gases, solubility usually decreases as the temperature increases. For example, sugar dissolves more easily in hot water than in cold water, but carbon dioxide dissolves less in warm soda than in cold soda.

- **Pressure:**

  Pressure has a significant effect on the solubility of gases. As pressure increases, the solubility of a gas in a liquid increase. This is described by **Henry's Law**, which states that the amount of gas that dissolves in a liquid is directly proportional to the pressure of the gas above the liquid.

- **Common Ion Effect:**

  When a salt dissolves in water, if one of the ions present in the solution is already in the solution (due to the presence of a common ion), the solubility of the salt can decrease. This phenomenon is known as the common ion effect.

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Example of Chemical Solubility:

the solubility of **salt (sodium chloride, NaCl)** in **water:** When you add a spoonful of sodium chloride (NaCl) to a glass of water, the salt begins to dissolve. The NaCl dissociates into sodium (Na^+) and chloride (Cl^-) ions. The water molecules surround and separate these ions due to the polarity of water molecules. The solubility of a substance is the maximum amount of solute that can dissolve in a given amount of solvent at a specific temperature. At 25°C, the solubility of NaCl in water is approximately **357 grams per liter (g/L).** This means that you can dissolve up to 357 grams of NaCl in 1 liter of water at this temperature. The sodium chloride crystals dissolve in water because the positive part of the water molecule (hydrogen) is attracted to the chloride ions (Cl^-), and the negative part (oxygen) is attracted to the sodium ions (Na^+). The ions are separated and surrounded by water molecules, creating a homogeneous solution. If you keep adding more NaCl to the water beyond its solubility limit, it will stop dissolving and will begin to collect at the bottom of the container. This indicates that the solution has become saturated, meaning it can't hold any more dissolved solute at that temperature.

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