Composed with Epsilon Notes in Android

Reversible reactions and chemical equilibrium (Advanced level Chemistry)

Contents

Reversible reactions

A **reversible reaction** is a reaction that can proceed in either direction.

One example of a reversible reaction is the reaction between nitrogen and hydrogen to form ammonia.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

A reversible reaction can be shown by the double arrow ($\rightleftharpoons$) in the equation, which means that the products can react or decompose to form the original reactants.

If this reaction was to happen in a closed container, as soon as the products are formed they react together and form the reactants again. So instead of there being reactants or products only, you get a mixture of both. Eventually the system reaches a point where there is a mixture in which the proportions of all the existing components remain constant. This mixture is called an **equilibrium mixture** and this type of reaction called an **equilibrium reaction**.

The maximum theoretical yield is not obtained, instead a mixture of products and reactants is formed. The products will be reacting together to form the reactants at the same time as the reactants are are reacting together to form the products.

Characteristics of chemical equilibrium

Under constant conditions, an equilibrium has the following characteristics:

- it is dynamic.
  - this means that the reactants are continuously reacting to form products and the products are continuously reacting to form back the reactants.
- the forward and reverse reactions occur at the same rate.
  - this means that the reactants are continuously reacting to form products and the products are continuously reacting to form back the reactants at the same rate.
- the concentration of reactants and products remain constant at equilibrium.
  - The concentrations remain constant because, at equilibrium, the rates of the forward and backward reactions are equal.
- it requires a closed system.
  - A closed system is a system in which neither the reactants nor products escape from the reaction mixture. If either the reactants or products escape, the equilibrium of the system is disturbed. The system does not have to be sealed. For example, an open beaker may be a closed system for a reaction that takes place in solution, as long as the reactants, products, and solvent do not evaporate.

Changing the position of equilibrium

Some industrial processes, for example the production of ammonia or sulphuric acid, are based on reversible reactions. In a closed system these reactions would produce equilibrium mixtures containing both products and reactants. In order to be able to increase the yield of the products, is it important to understand how to control the position of equilibrium of the reactions.

The position of equilibrium refers to the ratio of the amount of products to reactants present in an equilibrium mixture.

If in an equilibrium system a change of conditions causes the concentration of products to increased relative to the concentration of the reactants, we say that the position of equilibrium has shifted to the right.

However, if the concentration of products decrease relative to the reactants, we say that the position of equilibrium has shifted to the left.

For example in the reaction for the manufacture of ammonia,

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

- If the position of equilibrium shifts to the left, more NH_3 is produced in the equilibrium mixture.
- If the position of equilibrium shifts to the right, more N_2 and H_2 are produced in the equilibrium mixture.

Le Chatelier's principle

Le Chatelier's principle states that:

> If one or more factors that affect an equilibrium is changed, the position of equilibrium shifts in the direction that reduce the change.

How does a change in concentration affect the position of the equilibrium?

For reactants in solution, when the concentration of any of the reactants is increased, the

- system is no longer in equilibrium.
- the position of equilibrium moves to the right to reduce the concentration of the reactant that was increased.

This means that more products will form until the equilibrium is restored. For example, the reaction between ethanoic acid CH_3COOH and ethanol C_2H_5OH to produce ethyl ethanoate $CH_3COOC_2H_5$ and water H_2O is an equilibrium reaction which proceeds as follows:

$$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

If we add more ethanol,

- the concentration of ethanol increases.
- According to Le Chatelier's principle, the position of equilibrium shifts in the direction that reduces the concentration of the added ethanol.
- Therefore the position of equilibrium shifts to the right. More ethanol reacts with ethanoic acid and more ethyl ethanoate and waterare formed.

If we add more water,

- the concentration of water is increases.
- According to Le Chatelier's principle, the position of equilibrium shifts in the direction that reduces the concentration of the added water.
- The position of equilibrium shifts to the left.
- therefore more water reacts with ethyl ethanoate and more ethanoic acid and ethanol are formed. What happens when we remove some water?

If we remove water,

- the concentration of water decreases.
- According to Le Chatelier's principle, the position of equilibrium shifts in the direction that increases the concentration of the removed water.
- The position of equilibrium shifts to the right.
- More ethanoic acid reacts with ethanol and more water and ethyl ethanoate are formed.

How does a change in pressure affect the position of the equilibrium?

Pressure affects the position of equilibrium only in reactions where gases are reactants or products, because solids and liquids are incompressible.

If we look at the reaction between nitrogen and hydrogen to form ammonia, as shown below:

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

We can see that there are 4 moles (1 mole of nitrogen and 3 moles of hydrogen) of gas on the left hand side and 2 moles of gas (ammonia) on the right hand side.

If we increase the pressure of the reactants constant temperature:

- the molecules move closer together, because the volume is reduced.
- According to Le Chatelier's principle, the position of equilibrium shifts in the direction that reduces the increased pressure.
- therefore the position of the equilibrium shifts in the direction of fewer gas molecules (which results in a decrease in pressure)
- in this case, that is to the right where there are fewer moles of gas.
- more ammonia is produced until the equilibrium is reestablished.

If we reduce the pressure at constant temperature:

- the molecules move far apart, because the volume is reduced.
- According to Le Chatelier's principle, the position of equilibrium shifts in the direction that increases the reduced pressure.
- therefore the position of the equilibrium shifts in the direction of more gas molecules (which results in an increase in pressure)
- in this case, that is to the left where there are fewer moles of gas.
- more nitrogen and hydrogen are produced until the equilibrium is reestablished.

However, if there are equal numbers of molecules of gas on each side of the equation, the position of equilibrium is not affected by a change in pressure.

How does a change in temperature affect the position of the equilibrium?

The reaction between nitrogen and hydrogen to form ammonia is exothermic.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ **$- \Delta H$**

The forward reaction releases heat energy since the reaction is exothermic and the backward reaction absorbs heat energy.

If we increase the temperature:

- According to Le Chatelier's principle, the position of equilibrium shifts in the direction that absorbs the added heat.
- That is, the position of equilibrium shifts to the left, which is the endothermic reaction.
- more nitrogen and hydrogen are produced until the equilibrium is reestablished.

If we decrease the temperature:

- According to Le Chatelier's principle, the position of equilibrium shifts in the direction that increases the decreased heat.
- That is, the position of equilibrium shifts to the right, which is the exothermic reaction.
- more ammonia is produced until the equilibrium is reestablished.

How does a catalyst affect the position of equilibrium?

A catalyst is a substance that increases the rate of a chemical reaction without itself being used up in the reaction.

A catalyst speed up the time the reaction takes to reach equilibrium, but it has no effect on the position of equilibrium once this is reached. This is because they increase the rate of the forward and reverse reactions equally

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