CAIE IGCSE Chemistry

6.3 Reversible reactions and equilibrium

Notes

State that some chemical reactions are reversible as shown by the symbol ⇌

- In some chemical reactions, the products of the reaction can react to produce the original reactants
  - These are called reversible reactions
  - The direction of the reaction can be changed by changing the conditions
  - Reversible reactions are shown by the symbol ⇌

Describe how changing the conditions can change the direction of a reversible reaction for: (a) the effect of heat on hydrated compounds (b) the addition of water to anhydrous compounds limited to copper(II) sulfate and cobalt(II) chloride

- Hydrated salts/compounds contain water molecules in their structure whereas anhydrous salts/compounds do not

(a) The effect of heat on hydrated compounds
- By heating a hydrated compound, the water is evaporated, leaving the anhydrous compound

(b) The addition of water to anhydrous compounds
- By adding water to an anhydrous compound, the hydrated salt is formed

- Copper (II) sulfate are blue crystals when hydrated (in presence of water) and white crystals when anhydrous (absence of water)
  - Hydrated copper(II) sulfate ⇌ Anhydrous copper(II) sulfate + Water
  - $CuSO_4.5H_2O(s) \rightleftharpoons CuSO_4(s) + 5H_2O(l)$
  - Blue crystals ⇌ white crystals
  - Forward reaction heat the hydrated copper(II) sulfate (water evaporates)
  - Reverse reaction add water
- Cobalt (II) chloride are pink crystals when hydrated (in presence of water) and blue crystals when anhydrous (absence of water)
  - Hydrated cobalt (II) chloride ⇌ Anhydrous cobalt (II) chloride + Water
  - $CoCl_2. 6H_2O \rightleftharpoons CoCl_2 + 6H_2O$
  - Pink crystals ⇌ Blue crystals
  - Forward reaction heat the hydrated cobalt (II) chloride (water evaporates)
  - Reverse reaction add water

(Extended only) State that a reversible reaction…

- A reversible reaction is at dynamic equilibrium when these three conditions are met:
    1. The reaction is in a closed system
    2. The rate of the forward reaction is equal to the rate of the reverse reaction
    3. The concentration of the reactants and products are no longer changing

(Extended only) Predict and explain, for a reversible reaction, how the position of equilibrium is affected by:

- If a system is at equilibrium and a change is made to any of the conditions, then the system responds to counteract the change.
    - Effects of changing conditions on a system at equilibrium can be predicted using Le Chatelier's Principle.

(a) Changing temperature

- In a reversible reaction, one direction will be exothermic and the other will be endothermic
- Temperature increases:
    - Position of equilibrium shifts to the direction of the endothermic reaction.
    - The yield from the endothermic reaction increases.
    - The yield from the exothermic reaction decreases.
- Temperature decreases:
    - Position of equilibrium shifts to the direction of the exothermic reaction.
    - The yield from the endothermic reaction decreases.
    - The yield from the exothermic reaction increases.
- When answering, state which direction the reaction is exothermic and which is endothermic

(b) Changing pressure

- Changing the pressure will only affect reversible reactions with gaseous reactants and products
- Pressure increases:
    - Position of equilibrium shifts to the side with fewer gaseous molecules
- Pressure decreases:
    - Position of equilibrium shifts to the side with more gaseous molecules
- When answering, state how many gaseous molecules are on each side

(c) Changing concentration

- Concentration of reactant increases:
  - Position of equilibrium shifts to the right and more products are made until equilibrium is reached again
- Concentration of product decreases
  - Position of equilibrium shifts to the right so that more reactants will react until equilibrium is reached again
- Concentration of reactant decreases:
  - Position of equilibrium shifts to the left to produce more reactants until equilibrium is reached again
- Concentration of product increases
  - Position of equilibrium shifts to the left so that less products are made until equilibrium is reached again

(d) Using a catalyst using information provided

- Using a catalyst has no effect on the position of equilibrium
- A catalyst speeds up the forward and reverse reactions equally so the reaction reaches equilibrium more quickly

(Extended only) State the symbol equation for the production of ammonia in the Haber process:

- The production of ammonia is important because it is used to make many products such as fertilisers for farming.
- Ammonia is produced through the Haber process
- The symbol equation for the Haber process is:
  $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
  Nitrogen + Hydrogen ⇌ Ammonia

(Extended only) State the sources of the hydrogen (methane) and nitrogen (air) in the Haber process

- The reactants of the Haber process are hydrogen and nitrogen
- Source of hydrogen: Methane is reacted with steam to produce carbon dioxide and hydrogen gas, which is then collected for the Haber process
- Source of nitrogen: The air around us has a high proportion of nitrogen gas so nitrogen is extracted from the air using fractional distillation, since the other gases in the air have different boiling points to nitrogen.

(Extended only) State the typical conditions in the Haber process

- The Haber process most commonly occurs under the following conditions:
  - Temperature: 450°C
  - Pressure: 20,000 kPa or 200 atm
  - An iron catalyst is used

(Extended only) State the symbol equation for the conversion of sulfur dioxide to sulfur trioxide in the Contact process, $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

- The Contact process consists of three stages, where the second stage is the reversible reaction
- The Contact process is important because it produces sulfuric acid (in the third stage) which can be combined with ammonia to make fertilisers, or be used to produce products such as paint.
- The symbol equation for the second stage of the Contact process is:
  $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
  Sulfur dioxide + Oxygen ⇌ Sulfur trioxide

(Extended only) State the sources of the sulfur dioxide (burning sulfur or roasting sulfide ores) and oxygen (air) in the Contact process

- The reactants of the Contact process are sulfur dioxide and oxygen
- Source of sulfur dioxide: The first stage of the Contact process produces sulfur dioxide by burning sulfur in air (sulfur + oxygen). Sulfur dioxide can also be obtained from roasting sulfide ores.
- Source of oxygen: The air around us has oxygen gas, so can be extracted

(Extended only) State the typical conditions for the conversion of sulfur dioxide to sulfur trioxide in the Contact process as 450°C, 200kPa /2atm and a vanadium(V) oxide catalyst

- The conversion of sulfur dioxide to sulfur trioxide in the Contact process most commonly occurs under the following conditions:
  - Temperature: 450°C
  - Pressure: 200kPa or 2atm
  - A vanadium (V) oxide catalyst is used

(Extended only) Explain, in terms of rate of reaction and position of equilibrium, why the typical conditions stated are used in the Haber process and in the Contact process, including safety considerations and economics

The Haber process

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

- Typical conditions:
  - Temperature: 450°C
  - Pressure: 20,000kPa or 200atm
  - An iron catalyst is used
- Why?
  - Temperature
    The forward reaction of the Haber process is exothermic and the reverse reaction is endothermic. By using a higher temperature, the position of equilibrium shifts in the reverse reaction (endothermic), resulting in less ammonia being produced (lower yield). But low temperatures mean a low rate of reaction, so a compromise is reached by 450°C
  - Pressure
    There are fewer gaseous molecules on the right side of the equation (products) (2 gaseous moles on the right < 4 gaseous moles on the left). By increasing the pressure, the position of equilibrium shifts in the forward direction (the right side), so more ammonia is produced
  - Catalyst
    An iron catalyst is used to speed up the rate of the forward and reverse reaction equally so that equilibrium is reached faster, whilst having no effect on the position of equilibrium. Since the rate of reaction is faster, a lower temperature can be used in the Haber process whilst still keeping the production of ammonia high
- Safety considerations and economics
  - Despite higher pressure resulting in more ammonia being produced, maintaining high pressure means high cost due to high energy costs and more expensive equipment
  - Increasing the pressure too much in a closed system can also be highly dangerous as there is a risk of explosion
  - Recycling unreacted hydrogen and nitrogen back into the process reduces the cost of producing more reactants

The Contact process

Conversion of sulfur dioxide into sulfur trioxide:

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

- Typical conditions:
  - Temperature: 450°C
  - Pressure: 200kPa or 2atm
  - An vanadium (V) oxide catalyst is used
- Why?
  - Temperature
    The forward reaction of the Contact process is exothermic and the reverse reaction is endothermic. By using a higher temperature, the position of equilibrium shifts in the reverse reaction (endothermic), resulting in less sulfur trioxide being produced (lower yield). But low temperatures mean a low rate of reaction, so a compromise is reached by 450°C
  - Pressure
    There are fewer gaseous molecules on the right side of the equation (products) (2 gaseous moles on the right < 3 gaseous moles on the left). By increasing the pressure, the position of equilibrium shifts in the forward direction (the right side), so more sulfur trioxide is produced
  - Catalyst
    A vanadium (V) oxide catalyst is used to speed up the rate of the forward and reverse reaction equally so that equilibrium is reached faster, whilst having no effect on the position of equilibrium.
- Safety considerations and economics
  - Even though a higher pressure would result in more product, sulfur trioxide is an acidic gas so the risk of explosion is too high
  - Higher pressures also mean higher cost of equipment.