Edexcel GCSE Chemistry

Your notes

Reversible Reactions & Equilibria

Contents

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Reversible Reactions & Equilibrium

Reversible Reactions

- Some reactions go to **completion**, where the reactants are used up to form the product molecules and the reaction stops when the reactants have been exhausted
- In reversible reactions, the product molecules can themselves **react with each other** or **decompose** and form the reactant molecules again
- It is said that the reaction can occur in **both directions**: the forward reaction (which forms the products) and the reverse direction (which forms the reactants)
- When writing chemical equations for reversible reactions, two opposing arrows are used to indicate the forward and reverse reactions occurring at the same time
- Each one is drawn with just half an arrowhead – the top one points to the right, and the bottom one points to the left
- The direction a reversible reaction takes can be changed by changing the reaction conditions

Thermal Decomposition of Ammonium Chloride

- Heating ammonium chloride produces ammonia and hydrogen chloride gases:

$$NH_4Cl\ (s) \rightarrow NH_3\ (g) + HCl\ (g)$$

- As the hot gases cool down they recombine to form solid ammonium chloride

$$NH_3\ (g) + HCl\ (g) \rightarrow NH_4Cl\ (s)$$

- So, the reversible reaction is represented like this:

$$NH_4Cl\ (s) \rightleftharpoons NH_3\ (g) + HCl\ (g)$$

Dehydration of Hydrated Copper(II) Sulfate

- Reversible reactions can be seen in some hydrated salts
- These are salts that contain **water of crystallisation** which affects their shape and colour
- Water of crystallisation is the water that is included in the structure of some salts during the crystallisation process
- A common example is copper(II) sulfate which crystallises forming the salt copper(II) sulfate pentahydrate, $CuSO_4.5H_2O$
- Water of crystallisation is indicated with a dot written in between the salt and the surrounding water molecules

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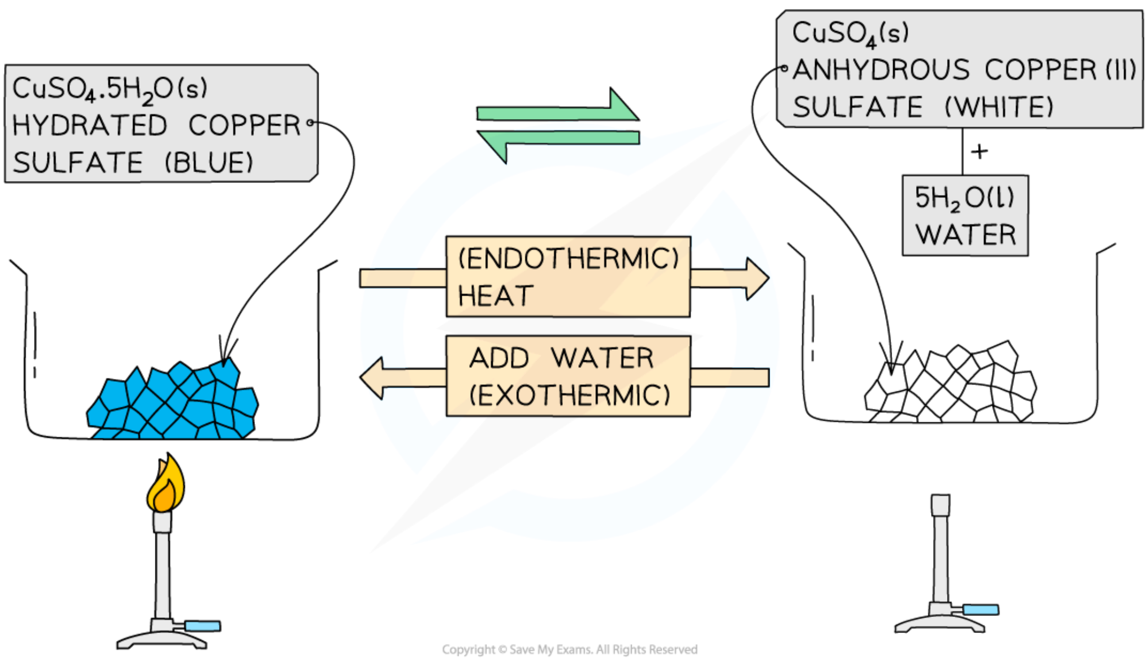
- Anhydrous salts are those that have lost their water of crystallisation, usually by heating, in which the salt becomes **dehydrated**
- When anhydrous copper(II) sulfate is added to water, it turns **blue** and heat is given off so the reaction is exothermic
- When hydrated copper(II) sulfate crystals are heated in a test tube, the blue crystals turn into a **white** powder and a clear, colourless liquid (water) collects at the top of the test tube
- The equation for the reaction is:

$$\mathbf{CuSO_4.5H_2O\ (s) \rightleftharpoons CuSO_4\ (s)\ +\ 5H_2O\ (l)}$$



The dehydration of hydrated salts is often a reversible reaction

Examiner Tips and Tricks

The reverse reaction may also be called the backwards reaction. A generic reversible reaction is shown as

$$\mathbf{A + B \rightleftharpoons C + D}$$

Dynamic Equilibrium

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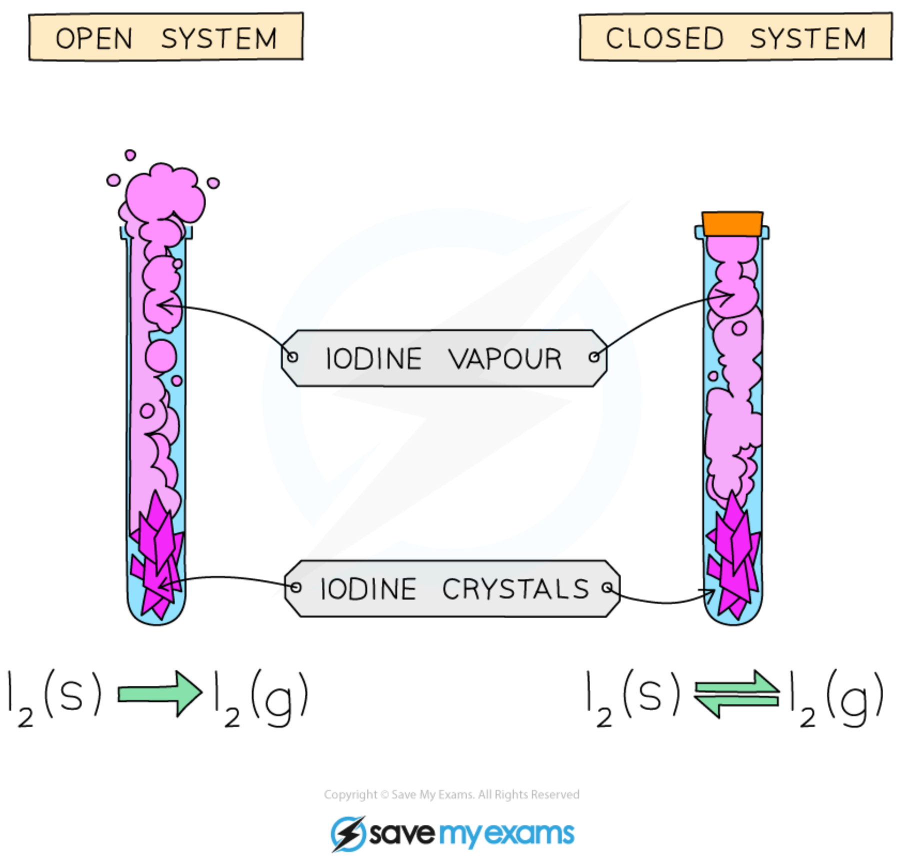
- We have already seen that a reversible reaction is one that occurs in **both** directions
- When during the course of reaction, the rate of the forward reaction equals the rate of the reverse reaction, then the overall reaction is said to be in a state of **equilibrium**
- Equilibrium is **dynamic** i.e. the molecules on the left and right of the equation are **changing** into each other by chemical reactions constantly and at the same rate
- The concentration of reactants and products remains **constant** (given there is no other change to the system such as temperature and pressure)
- It only occurs in a **closed system** so that none of the participating chemical species are able to leave the reaction vessel



Equilibrium can only be reached in a closed container

- An example of a dynamic equilibrium is the reaction between H_2 and N_2 in the Haber process

- When only nitrogen and hydrogen are present at the beginning of the reaction, the rate of the forward reaction is at its **highest,** since the **concentrations** of hydrogen and nitrogen are at their **highest**
- As the reaction proceeds, the concentrations of hydrogen and nitrogen gradually decrease, so the rate of the forward reaction will **decrease**
- However, the concentration of ammonia is gradually increasing and so the rate of the **backward** reaction will increase (ammonia will decompose to reform hydrogen and nitrogen)
- Since the two reactions are interlinked and none of the gas can escape, the rate of the forward reaction and the rate of the backward reaction will eventually become **equal** and equilibrium is reached:

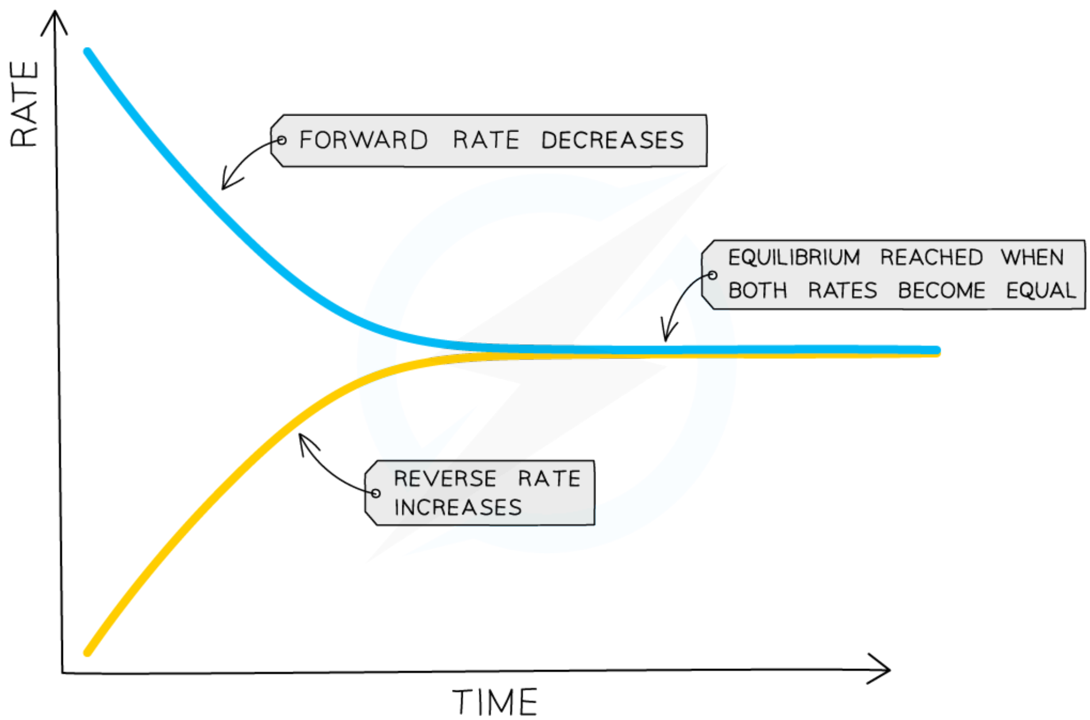


Diagram showing when the rates of forward and backward reactions become equal

Examiner Tips and Tricks

Remember equilibrium is only reached in a closed vessel.

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The Haber Process

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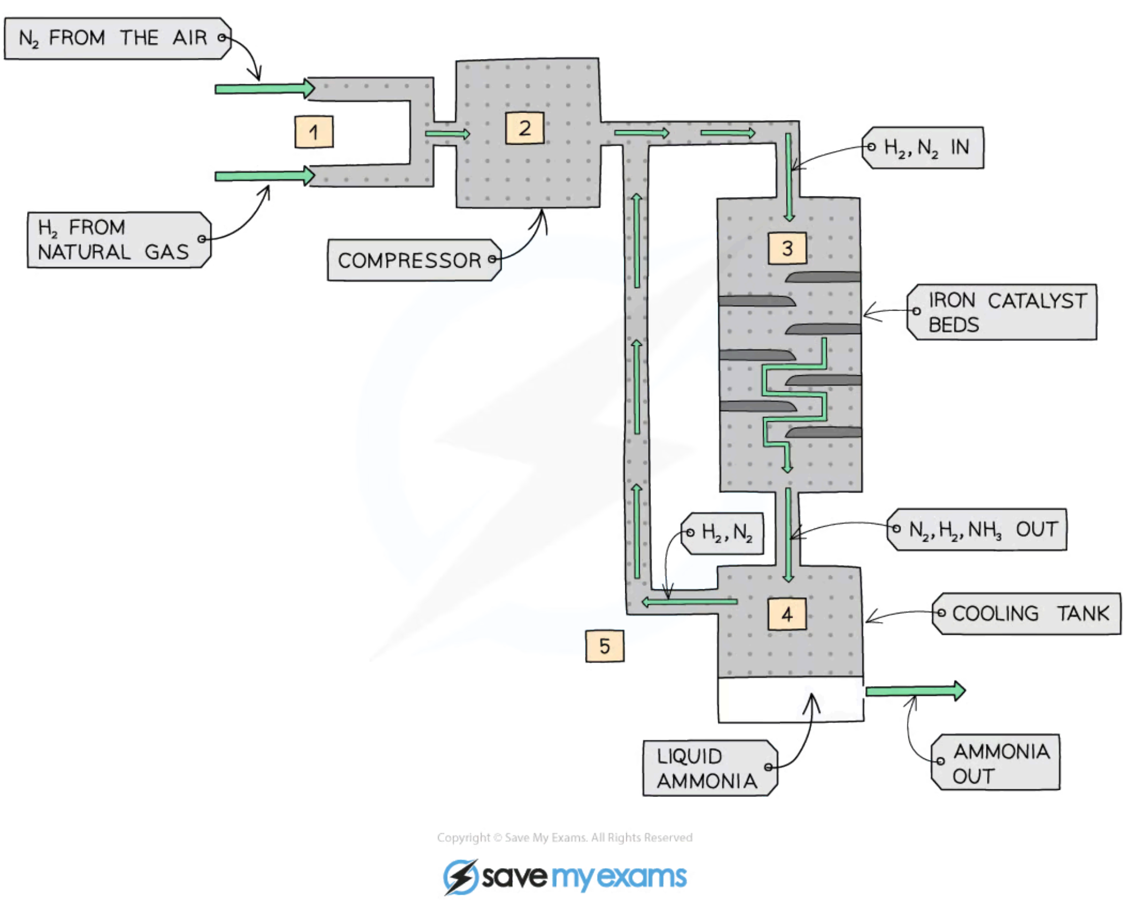
The Haber Process

- Ammonia is manufactured using **The Haber Process** which occurs in five stages
- **Stage 1:** H_2 and N_2 are obtained from natural gas and the air respectively and are pumped into the compressor through pipe
- **Stage 2:** the gases are compressed to about 200 atmospheres inside the compressor
- **Stage 3**: the pressurised gases are pumped into a tank containing layers of catalytic iron beds at a temperature of 450°C. Some of the hydrogen and nitrogen react to form ammonia:

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

- **Stage 4:** unreacted H_2 and N_2 and product ammonia pass into a cooling tank. The ammonia is liquefied and removed to pressurised storage vessels
- **Stage 5**: the unreacted H_2 and N_2 gases are recycled back into the system and start over again



The production of ammonia by the Haber Process

Conditions

Temperature: 450°C

- A **higher** temperature would favour the reverse reaction as it is endothermic (takes in heat) so a higher yield of **reactants** would be made
- If a **lower** temperature is used it favours the forward reaction as it is exothermic (releases heat) so a higher yield of **products** will be made
- However at a lower temperature the rate of reaction is very **slow**
- So 450°C is a compromise temperature between having a **lower yield** of products but being made more quickly

Pressure: 200 atm

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- A **lower** pressure would favour the reverse reaction as the system will try to increase the pressure by creating more molecules (4 molecules of gaseous reactants) so a higher yield of **reactants** will be made
- A **higher** pressure would favour the forward reaction as it will try to decrease the pressure by creating less molecules (2 molecules of gaseous products) so a higher yield of **products** will be made
- However high pressures can be dangerous and very expensive equipment is needed
- So 200 atm is a **compromise** pressure between a lower yield of products being made **safely** and **economically**

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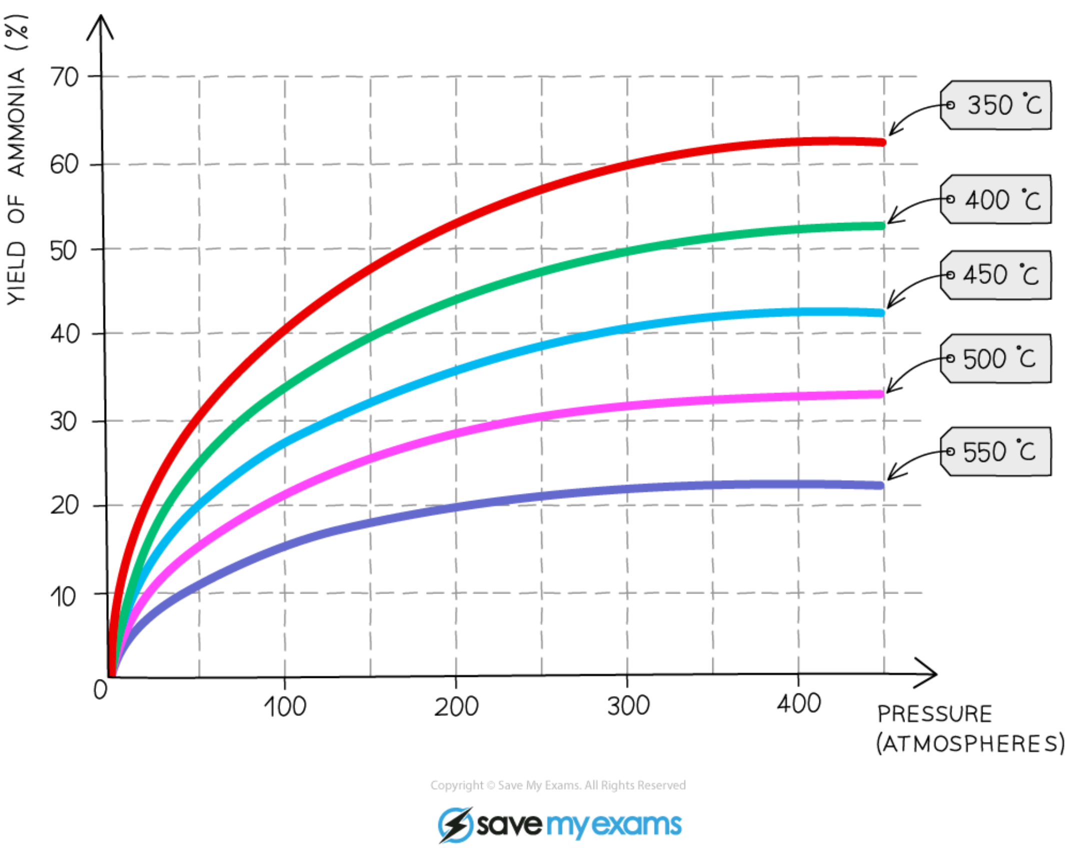
Catalyst

- A catalyst of iron is used to speed up the reaction



Choosing the conditions for the Haber Process

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Examiner Tips and Tricks

The reaction conditions chosen for the Haber process are not ideal in terms of the yield but do provide balance between product yield, reaction rate and production cost. These are called **compromise conditions** as they are chosen to give a good compromise between the yield, rate and cost.

The Position of Equilibrium

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The Position of Equilibrium

- The relative amounts of all the reactants and products at equilibrium depend on the conditions of the reaction
- This balance is framed in an important concept known as Le Chaterlier's Principle, named after Henri Le Chatelier who was a French military engineer in the 19th century
- This principle states that when a change is made to the conditions of a system at equilibrium, the system automatically moves to **oppose** the change
- The principle is used to predict changes to the position of equilibrium when there are changes in **temperature**, **pressure** or **concentration**
- Knowing the energy changes, states and concentrations involved allows us to use the principle to manipulate the outcome of reversible reactions

Changes in Temperature

- Le Chatelier's Principle can be used to predict the effect of changes in temperature on systems in equilibrium
- To make this prediction it is necessary to know whether the reaction is exothermic or endothermic
- The following table summarises how a temperature change alters the position of equilibrium:

Effect of Temperature Changes on an Equilibrium Table

Change in reactant	How the equilibrium shifts
Increase in temperature	Equilibrium moves in the endothermic direction to reverse the change
Decrease in temperature	Equilibrium moves in the exothermic direction to reverse the change

Changes in Pressure

- Changes in pressure only affects gases so firstly you have to identify all gaseous reactants and products
- The following table summarises how a pressure change alters the position of equilibrium:

Effect of Pressure Changes on an Equilibrium Table

Change in reactant	How the equilibrium shifts
Increase in pressure	Equilibrium shifts in the direction that produces the smaller number of molecules of gas to decrease the pressure again
Decrease in pressure	Equilibrium shifts in the direction that produces the larger number of molecules of gas to increase the pressure again

Changes in Concentration

- The following table summarises how a concentration change alters the position of equilibrium:

Effect of Concentration Changes on an Equilibrium Table

Change in reactant	How the equilibrium shifts
Increase in concentration	Equilibrium shifts to the right to reduce the effect of increasing the concentration of a reactant
Decrease in concentration	Equilibrium shifts to the left to reduce the effect of a decrease in reactant (or an increase in the concentration of product)

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Examiner Tips and Tricks

You do not need to learn the name Le Chatelier's Principle for an exam but you do need to make qualitative predictions about the effect of changes on systems at equilibrium when given appropriate information.

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