CIE A Level Chemistry

Your notes

26.2 Homogeneous & Heterogeneous Catalysts

Contents

* Homogeneous & Heterogeneous Catalysts

Homogeneous & Heterogeneous Catalysts

Your notes

Homogeneous & Heterogeneous Catalysis

- **Catalysts** increase the rate of reaction by providing an alternative pathway which has a lower **activation energy**
- Catalysts can be either **homogeneous** or **heterogeneous**

Homogeneous catalysts

- Homogeneous catalysts are those that are in the same phase as the reaction mixture
- For example, in the esterification of ethanoic acid (CH_3COOH) with ethanol (CH_3CH_2OH) to form ethyl ethanoate ($CH_3COOCH_2CH_3$) under acidic conditions:

$$CH_3COOH\ (aq) + CH_3OH\ (aq) \xrightarrow{H^+\ (aq)} CH_3COOC_2H_5\ (aq) + H_2O\ (l)$$

- The H^+ is a homogeneous catalyst and like the reactants and product it is in the **aqueous** phase

Heterogeneous catalysts

- Heterogeneous catalysts are those that are in a different phase to the rest of the reaction mixture
- For example, in the Born-Haber process to form ammonia (NH_3) from nitrogen (N_2) and hydrogen (H_2) an iron (Fe) catalyst is used:

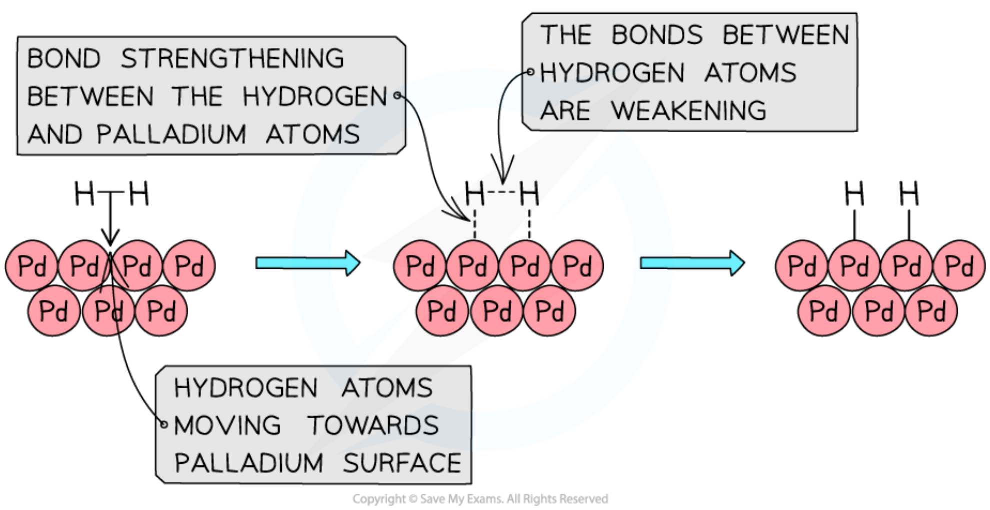
$$N_2\ (g) + 3H_2\ (g) \xrightarrow{Fe\ (s)} 2NH_3\ (g)$$

- The Fe catalyst is a heterogeneous catalyst as it is in **the** solid phase, whereas the reactants and products are all in the **gas** phase

Heterogeneous Catalysis

- In **heterogeneous catalysis,** the molecules react at the surface of a solid catalyst
- The mode of action of a heterogeneous catalyst consists of the following steps:
- **Adsorption** (or **chemisorption**) of the reactants on the catalyst surface
  - The reactants diffuse to the surface of the catalyst
  - The reactant is **physically adsorbed** onto the surface by **weak forces**
  - The reactant is **chemically adsorbed** onto the surface by **stronger bonds**
  - Chemisorption causes **bond weakening** between the atoms of the reactants
- **Desorption** of the products
  - The bonds between the products and catalyst weaken so much that the products break away from the surface
- For example, the adsorption of hydrogen molecules onto a palladium (Pd) surface

How heterogeneous catalysts generally work



The reactants are adsorbed on the catalyst surface causing bond weakening and eventually desorption of the products

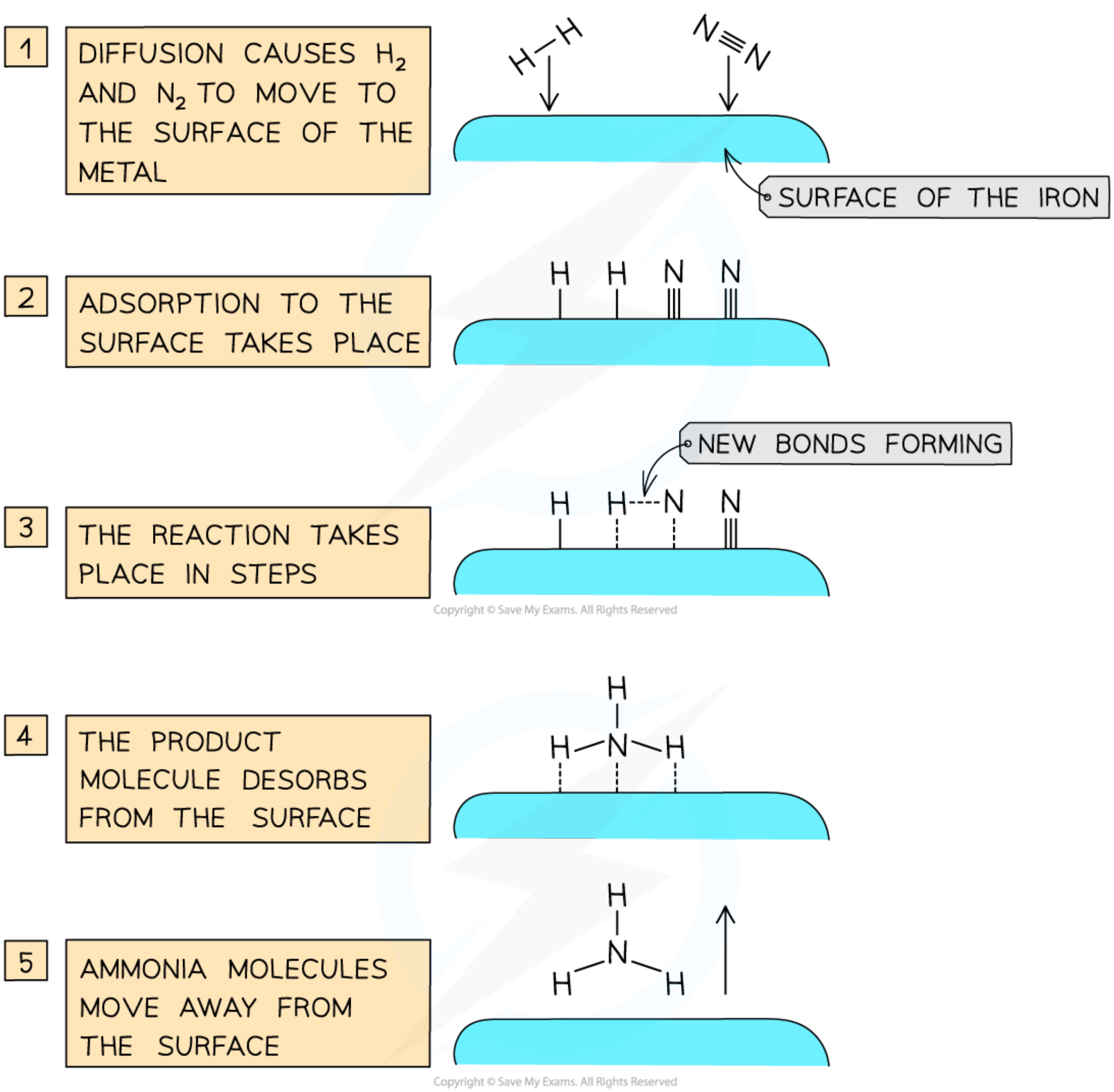
Iron in the Haber process

- In the **Haber process** ammonia (NH_3) is produced from nitrogen (N_2) and hydrogen (H_2)
- An **iron catalyst** is used which speeds up the reaction by bringing the reactants close together on the metal surface
- This increases their likelihood to react with each other
- The mode of action of the iron catalyst is as follows:
  - **Diffusion** of the nitrogen and hydrogen gas to the iron surface
  - **Adsorption** of the reactant molecules onto the iron surface by forming bonds between the iron and reactant atoms

Your notes

- These bonds are so strong that they weaken the covalent bonds between the nitrogen atoms in N_2 and hydrogen atoms in H_2
- But they are weak enough to break when the catalysis has been completed
- **The reaction** takes place between the adsorbed nitrogen and hydrogen atoms which react with each other on the iron surface to form NH_3
- **Desorption** occurs when the bonds between the NH_3 and iron surface are weakened and eventually broken
- The formed NH_3 **diffuses** away from the iron surface

Iron as a heterogeneous catalyst in the Haber Process



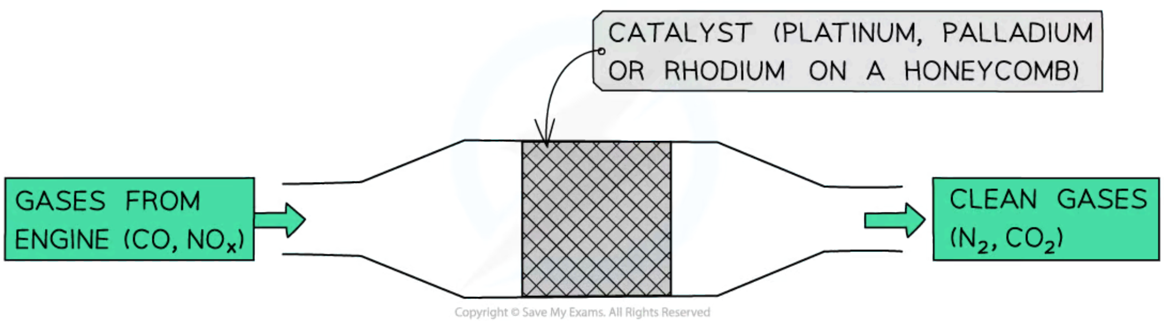
Iron brings the nitrogen and hydrogen closer together so that they can react and hence increases the rate of reaction

Your notes

Heterogeneous catalysts in catalytic converters

- Heterogeneous catalysts are also used in the **catalytic removal** of oxides of nitrogen from the exhaust gases of car engines
- The catalysts speed up the conversion of:
  - Nitrogen oxides (NO_y) into **harmless nitrogen gas** (N_2)
  - Carbon monoxide (CO) into carbon dioxide (CO_2)
- The catalytic converter has a **honeycomb** structure containing small beads coated with **platinum, palladium,** or **rhodium metals** which act as **heterogeneous catalysts**
- The mode of action of the catalysts is as follows:
  - **Adsorption** of the nitrogen oxides and CO onto the catalyst surface
  - **The weakening** of the covalent bonds within nitrogen oxides and CO
    - Formation of new bonds between:
    - Adjacent nitrogen atoms to form N_2 molecules
    - CO and oxygen atoms to form CO_2 molecules
  - **Desorption** of N_2 and CO_2 molecules which eventually **diffuse** away from the metal surface

Heterogeneous catalysts in car exhausts



The metals in catalytic converters speed up the conversion of nitrogen oxides and CO into N_2 and CO_2 respectively

Your notes

Homogeneous Catalysis

- **Homogeneous catalysis** often involves **redox reactions** in which the ions involved in catalysis undergo changes in their **oxidation number**
  - As ions of transition metals can change oxidation number they are often good catalysts
- Homogeneous catalysts are used in one step and are reformed in a later step

The iodine-peroxydisulfate reaction

- This is a very **slow** reaction in which the peroxydisulfate ($S_2O_8^{2-}$) ions **oxidise** the **iodide** to **iodine**

$$S_2O_8^{2-} (aq) + 2I^- (aq) \rightarrow 2SO_4^{2-} (aq) + I_2 (aq)$$

- Since both the $S_2O_8^{2-}$ and I^- ions have a negative charge, it will require a lot of energy for the ions to overcome the **repulsive forces** and collide with each other
- Therefore, Fe^{3+} (aq) ions are used as a **homogeneous catalyst**
- The catalysis involves two **redox reactions**:
  - First, Fe^{3+} ions are **reduced** to Fe^{2+} by I^-

$$2Fe^{3+} (aq) + 2I^- (aq) \rightarrow 2Fe^{2+} (aq) + I_2 (aq)$$

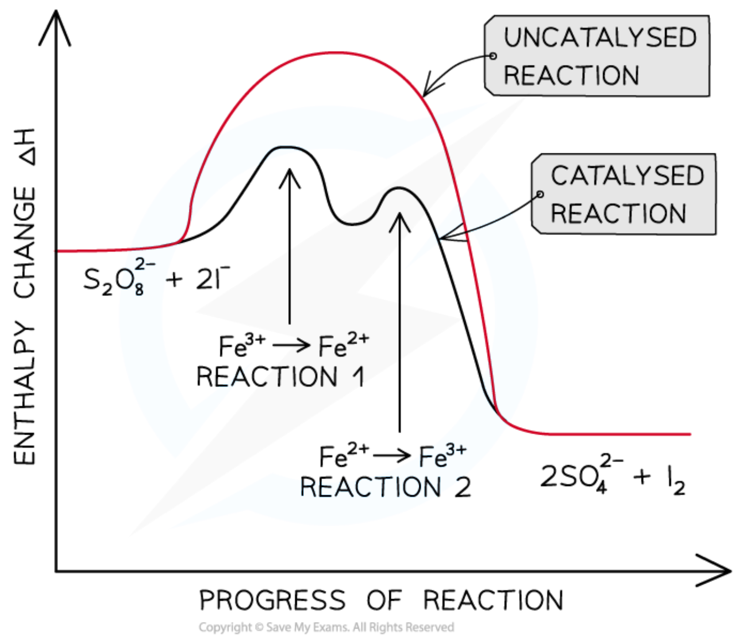
  - Then, Fe^{2+} is **oxidised** back to Fe^{3+} by $S_2O_8^{2-}$

$$2Fe^{2+} (aq) + S_2O_8^{2-} (aq) \rightarrow 2Fe^{3+} (aq) + 2SO_4^{2-} (aq)$$

- By reacting the reactants with a positively charged Fe ion, there are no repulsive forces, and the activation energy is significantly lowered
- The order of the two reactions does not matter
  - So, Fe^{2+} can be first oxidised to Fe^{3+} followed by the reduction of Fe^{3+} to Fe^{2+}

The reaction pathway diagram for a two-stage catalysed reaction

Your notes



The catalysed reaction has two energy 'humps' because it is a two-stage reaction

Nitrogen oxides & acid rain

- As fossil fuels contain sulfur, burning the fuels will release sulfur dioxide which oxidises in air to sulfur trioxide, and then **dilute sulfuric acid** (H_2SO_4) is formed by reaction with water. The result is acidification of rain:

$$SO_3 (g) + H_2O (l) \rightarrow H_2SO_4 (aq)$$

- Nitrogen oxides can act as **catalysts** in the formation of acid rain by catalysing the oxidation of SO_2 to SO_3

$$NO_2 (g) + SO_2 (g) \rightarrow SO_3 (g) + NO (g)$$

- The formed NO gets oxidised to regenerate NO_2

$$NO (g) + \frac{1}{2} O_2 (g) \rightarrow NO_2 (g)$$

- The regenerated NO_2 molecule can again oxidise another SO_2 molecule to SO_3 which will react with rainwater to form H_2SO_4 and so on