Lesson 15: Catalysis

*Read through the lesson notes. You can write them out, print them or save them.

*Once you have tried to understand the lesson answer the questions that follow at the end.

*The answers to the question sheet(s) will be posted later and this will allow you to self-evaluate your learning.

Learning Intentions

-Learn about heterogeneous catalysts.

-Learn about homogeneous catalysts.

Background

From S2 through to Higher level chemistry we have gained basic knowledge about catalysts and even carried out experiments using them. In this lesson we learn to classify catalysts and look at the way in which they work.

Transition metals and their compounds can act as catalysts in many important industrial processes.

Process	Catalyst used
Haber	Iron granules
Contact	Vanadium(V) oxide
Ostwald	Platinum gauze
Catalytic converters in cars	Platinum, palladium and rhodium
Preparation of methanol	Copper
Preparation of margarine	Nickel
Polymerisation of alkenes	Titanium compounds

You are not required to learn this table for the course. It is for reference only.

Transition metals can act as catalysts because they can have variable oxidation states with unfilled d-orbitals. This allows intermediate complexes to form providing reaction pathways with lower activation energies.

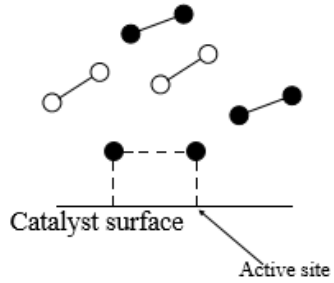
Catalysts can be classified as heterogeneous or homogeneous.

-Heterogeneous catalysts are in a different physical state from the reactants.

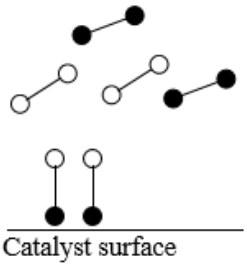
-Homogeneous catalysts are in the same physical state as the reactants.

Heterogeneous Catalysts

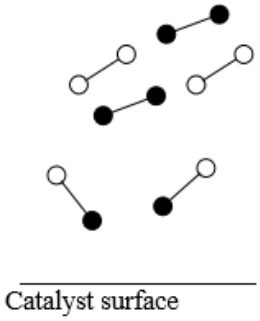
Heterogeneous catalysis can be explained in terms of the formation of activated complexes and the adsorption (with "d") of reactive molecules onto active sites. **The presence of unpaired d electrons or unfilled d orbitals allows activated complexes to form. This can provide reaction pathways with lower activation energies compared to the uncatalysed reaction.**



Reactants form weak bonds with the catalyst (adsorption). This weakens the bonds inside the reactant molecules.



Molecules react on the catalyst surface.



The product leaves the active site (desorption).

Homogeneous Catalysts

Homogeneous catalysts can be explained in terms of changing oxidation states and the formation of intermediate complexes. By considering the following reaction, we can gather a better understanding of how a homogeneous catalyst works.

$Cu^{2+}(aq)$ is described as a homogeneous catalyst as it is in the same physical state as the other reactant, i.e. $V^{3+}(aq)$.

$$Cu^{2+}(aq) + V^{3+}(aq) \xrightarrow{\text{slow}} Cu^{+}(aq) + V^{4+}(aq)$$

$$Cu^{+}(aq) + Fe^{3+}(aq) \xrightarrow{\text{fast}} Cu^{2+}(aq) + Fe^{2+}(aq)$$

It is important to also note that the $Cu^{2+}(aq)$ catalyst temporarily changes oxidation state to $Cu^{+}(aq)$. However, at the end of the reaction it returns to its original oxidation state $Cu^{2+}(aq)$. It is worthwhile considering that the Cu^{2+} catalyst is participating in the reaction BUT remains unchanged at the end of the reaction.

Additional Resources

-Watch the clips from Youtube.

https://www.youtube.com/watch?v=aKzTtURgTgA

-Read Scholar Section 3.6.

-Read BrightRed text book pages 25.

-Answer the questions from Sheet 1.19 and check the answers when you have completed them.

-If there are any questions regarding this lesson or the questions from sheet 1.19, then please leave a post on Microsoft Teams.

1.19 Catalysis

1. Hydrogenation normally involves converting an alkene into an alkane. The reaction increases the degree of saturation as carbon to carbon double bonds are converted to single bonds. The reaction is normally carried out at high temperatures and pressures with the use of a solid nickel catalyst. The catalyst is often in the form of a fine powder.

   One example of hydrogenation is shown below.

   $$C_4H_8(g) + H_2(g) \xrightarrow{Ni} C_4H_{10}(g)$$

   a) Give the spectroscopic notation of nickel in terms of s, p and d orbitals.
   b) Explain why the catalyst is the form of a fine powder.
   c) Classify the nickel catalyst for the above reaction.
   d) Briefly outline how the nickel catalyst works for the above reaction.

2. The study of reaction rates is referred to as kinetics in chemistry. One common kinetics reaction involves persulfate ions reacting with iodide ions.

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

   The reaction takes place using aqueous Fe^{2+} as a catalyst. There are two main steps involved in the reaction.

   Step 1: $S_2O_8^{2-}(aq) + Fe^{2+}(aq) \rightarrow 2SO_4^{2-}(aq) + Fe^{3+}(aq)$

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

   a) Draw the orbital box notation for the Fe^{2+} ion.
   b) How many unpaired electrons does the Fe^{3+} ion contain?
   c) Explain why $Fe^{2+}(aq)$ can be described as a homogeneous catalyst in this reaction.

3. Hydrogen peroxide oxidises potassium sodium tartrate to carbon dioxide. The reaction is catalysed by aqueous Co^{2+} ions. During the reaction, the colour of the reaction mixture turns from pink to green and returns to pink again within a few seconds as the reaction dies down. The brief formation of the green colour indicates that an activated complex exists momentarily.

   a) What causes the colour change in the reaction mixture to alter from pink to green and then back to pink?

   b) What evidence is there that the Co^{2+} ions actually participate in the reaction?

   c) Is Co^{2+} acting as a heterogeneous or homogeneous catalyst? Explain your choice.

   d) Show on a potential energy diagram (not to scale), how the activated complex would differ if the reaction was carried out without a catalyst, i.e. draw two lines to show the comparison.