

26.2 HOMOGENEOUS AND HETEROGENEOUS CATALYSTS

Learning outcomes

Candidates should be able to:

1. Explain that catalysts can be homogeneous or heterogeneous
2. Describe the mode of action of a heterogeneous catalyst to include adsorption of reactants, bond weakening, and desorption of products, for example:
 - (a) Iron in the Haber process
 - (b) palladium, platinum, and rhodium in the catalytic removal of oxides of nitrogen from the exhaust gases of car engines
3. Describe the mode of action of a homogeneous catalyst by being used in one step and reformed in a later step, for example:
 - (a) Atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide
 - (b) Fe^{2+} or Fe^{3+} in the $\text{I}^-/\text{S}_2\text{O}_8^{2-}$ reaction

Introduction

1. Explain what is meant by the following terms:

homogeneous catalyst

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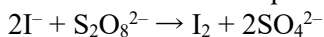
heterogeneous catalyst

..... [1]

Homogenous catalysts

2. Fe^{2+} ions act as a homogeneous catalyst in the reaction between $\text{I}^-(\text{aq})$ and $\text{S}_2\text{O}_8^{2-}(\text{aq})$.
Write equations for the two reactions that occur when $\text{Fe}^{2+}(\text{aq})$ is added to a mixture of $\text{I}^-(\text{aq})$ and $\text{S}_2\text{O}_8^{2-}(\text{aq})$.
equation 1 $\text{S}_2\text{O}_8^{2-} + \dots\dots\dots$
equation 2 [2]
3. The reaction of I^- ions with persulfate ions, $\text{S}_2\text{O}_8^{2-}$, can be catalysed by Fe^{3+} ions.
 $2\text{I}^- + \text{S}_2\text{O}_8^{2-} \rightarrow \text{I}_2 + 2\text{SO}_4^{2-}$
Write equations to show how Fe^{3+} catalyses this reaction.
.....
..... [2]
4. The reaction of persulfate ions, $\text{S}_2\text{O}_8^{2-}$, with iodide ions is catalysed by Fe^{2+} ions.
Write **two** equations to show how Fe^{2+} catalyses reaction 1.
equation 1
equation 2 [2]

5. Iodide ions react with peroxydisulfate ions.



This reaction is slow, but it is catalysed by Fe^{2+} ions.

Write two equations to explain how this reaction is catalysed by Fe^{2+} ions.

1

2[2]

(iii) Suggest why the alternative route in the presence of Fe^{2+} ions has a lower activation energy than the route in the absence of a catalyst.

.....

..... [1]

6. The reaction between $\text{S}_2\text{O}_8^{2-}(\text{aq})$ and $\text{I}^-(\text{aq})$ is catalysed by adding a few drops of $\text{Fe}^{3+}(\text{aq})$.
(i) Use equations to show the catalytic role of Fe^{3+} in this reaction. [2]

$\text{Fe}^{3+}(\text{aq})$ can oxidise $\text{I}^-(\text{aq})$, whereas $[\text{Fe}(\text{CN})_6]^{3-}(\text{aq})$ cannot oxidise $\text{I}^-(\text{aq})$.

Use E° values to explain these observations.

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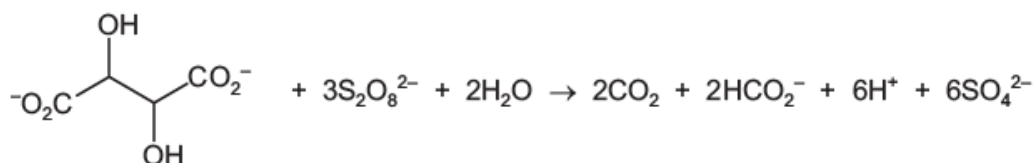
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..... [2]

7. When aqueous solutions of $\text{S}_2\text{O}_8^{2-}$ and tartrate ions are mixed the reaction proceeds very slowly. However, this reaction proceeds quickly in the presence of an $\text{Fe}^{3+}(\text{aq})$ catalyst.

The overall equation for this reaction is shown.

tartrate ions



- (i) Suggest why this reaction is slow without the Fe^{3+} catalyst.

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..... [1]

(ii) Use the overall equation to deduce the half-equation for the oxidation of tartrate ions, $\text{C}_4\text{H}_4\text{O}_6^{2-}$, to carbon dioxide, CO_2 , and methanoate ions, HCO_2^- .

$\text{C}_4\text{H}_4\text{O}_6^{2-} + \dots\dots\dots$ [1]

8. NO_2 acts as a homogeneous catalyst in the oxidation of atmospheric sulfur dioxide, SO_2 .

Write equations for the two reactions that occur.

equation 1

equation 2[1]

9. Sulfur dioxide, SO_2 , reacts very slowly with oxygen in the atmosphere, forming sulfur trioxide, SO_3 . This reaction is much faster in the presence of NO .
Explain the role of NO in this process.
Include chemical equations in your answer.

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 [3]

Heterogenous catalysts

10. The exhaust systems of most modern gasoline-fuelled cars contain a catalytic converter with three metal catalysts. These metals act as heterogeneous catalysts.

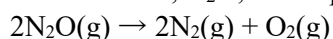
(i) Name three metal catalysts used in catalytic converters.

1 2 3 [1]

(ii) Explain what is meant by a heterogeneous catalyst.

.....
 [1]

11. Nitrous oxide, N_2O , decomposes into its elements.



At a high temperature, a small amount of platinum wire is added to a large amount of nitrous oxide. The reaction follows zero-order kinetics. The platinum wire behaves as a catalyst.

(i) Platinum behaves as a heterogeneous catalyst in this reaction.

Describe the mode of action of a heterogeneous catalyst.

{MS: adsorption of reactants onto catalyst surface [1]

bonds in reactants weaken [1]

reaction occurs followed by desorption of products [1] } [3]

(ii) Suggest a reason why this reaction has zero-order kinetics when the amount of nitrous oxide is large and the amount of platinum is small.

.....{MS: all active sites on catalyst surface are occupied } [1]

12. The decomposition of $\text{H}_2\text{O}_2(\text{aq})$ is catalysed by aqueous iron(III) chloride and by silver metal.

Identify which of these two catalysts is acting as a homogeneous catalyst.

Explain your answer.

homogeneous catalyst

explanation[1]

(ii) Name the metal catalyst in the Haber process and explain why it is a heterogeneous catalyst.

metal

..... [1]

- (iii) Platinum acts as a heterogeneous catalyst in the removal of nitrogen dioxide, NO_2 , from the exhaust gases of car engines.

Describe the mode of action of a platinum catalyst in this process.

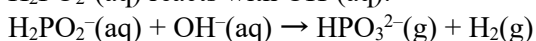
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..... [2]

13. Manganese(IV) oxide, MnO_2 , acts as a heterogeneous catalyst in the decomposition of hydrogen peroxide, H_2O_2 .

(i) Explain what is meant by a heterogeneous catalyst. [1]

(ii) Describe the mode of action of a heterogeneous catalyst in a reaction. [3]

14. $\text{H}_2\text{PO}_2^-(\text{aq})$ reacts with $\text{OH}^-(\text{aq})$.



A student suggests that the reaction between $\text{H}_2\text{PO}_2^-(\text{aq})$ and $\text{OH}^-(\text{aq})$ might happen more quickly in the presence of a heterogeneous catalyst.

Describe the mode of action of a heterogeneous catalyst. [2]

15. Manganese(VII) oxide, Mn_2O_7 , can be made by treatment of KMnO_4 with concentrated sulfuric acid (reaction 1). Mn_2O_7 readily decomposes at room temperature to form manganese(IV) oxide and a colourless diatomic gas (reaction 2).

Construct equations for **both** the reactions described.

reaction 1

reaction 2 [2]

16. Catalysts may be homogeneous or heterogeneous.

(i) Identify two metals that act as heterogeneous catalysts in the removal of NO_2 from the exhaust gases of car engines.

..... and [1]

(ii) Iron acts as a heterogeneous catalyst in the Haber process.

Describe the mode of action of this iron catalyst.

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.....
..... [2]

(iv) Explain the difference between a homogeneous catalyst and a heterogeneous catalyst.

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..... [1]

This is not a complete note. It is to guide you. It is recommended to study the prescribed textbooks along with this material.