

Catalysts

After this module you will be able to...

- Define a catalyst in terms of a HTL reaction
- Differentiate between homogeneous and heterogeneous catalysts
- Compare the benefits and limitations of various catalysts in HTL reactions

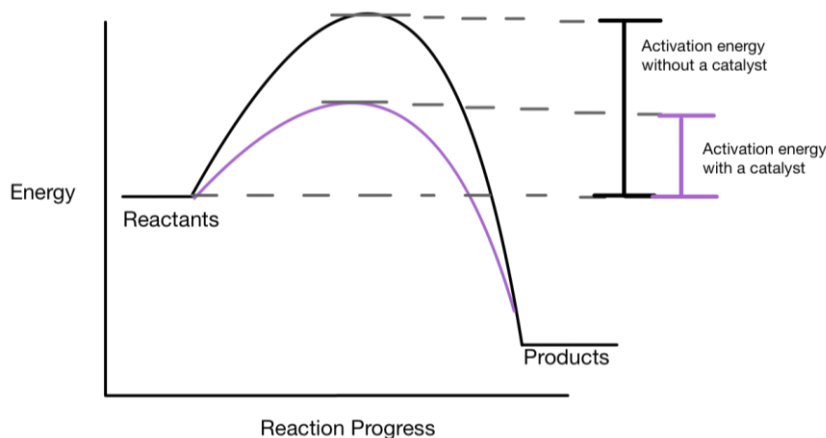
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Lesson 1: Introduction to Catalysts

What is a catalyst?

Thermodynamics determines whether a reaction will take place or not. Kinetics determines how slowly or quickly a reaction will take place. Generally, reactions with high activation energies, the energy needed for a chemical reaction to occur, will proceed slower than reactions with lower activation energies. A **catalyst** is a chemical substance that lowers the activation energy by creating a new route that the reaction can proceed through. This means that a catalyzed reaction can proceed at a lower temperature or pressure. After the chemical reaction is complete, the catalyst should remain unchanged and in many cases can be reused a number of times.



Types of Catalysts

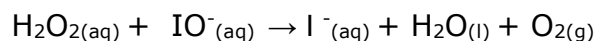
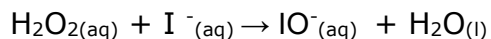
Many catalysts used in chemical reactions can be categorized into homogeneous and heterogeneous catalysts. In the hydrothermal liquefaction of algae, homogeneous catalysts are soluble in water at room temperature and can include salts, acids, and bases. Heterogeneous catalysts are insoluble in water at room temperature and include solids such as metals, metal oxides, and gases.

In HTL, subcritical water is able to act as both the solvent, the reactant, and the catalyst. In the subcritical range, water has a higher K_w value which increases the amount of H^+ and OH^- ions in solution. This increase can further accelerate acid and base catalyzed reactions.¹

Check Quiz

Choose the best answer for each question below. Check your answers using the answer key at the end of the module. You should score at least an 80% before moving on to the next section.

- Which of the following best describes how a catalyst increases the rate of a chemical reaction?
 - They increase the amount of product
 - They increase the temperature of the reaction
 - They reduce the amount of reactants
 - They decrease the activation energy
- Consider the reaction for the decomposition of hydrogen peroxide. Identify the catalyst.



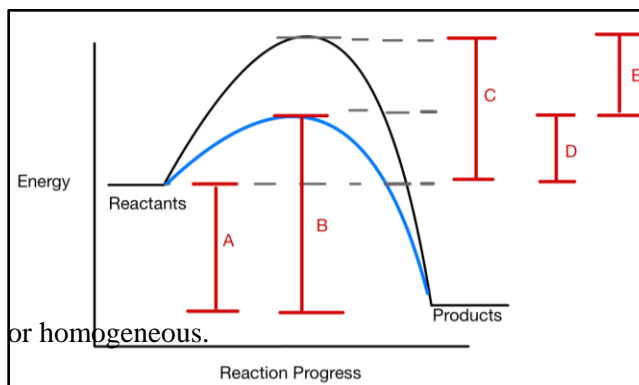
- $H_2O_{2(aq)}$
- $I^-_{(aq)}$
- $IO^-_{(aq)}$
- $H_2O_{(l)}$

¹ Toor, S. S., Rosendahl, L., & Rudolf, A. (2011). Hydrothermal Liquefaction of Biomass: A Review of Subcritical Water Technologies. *Energy*, 2328-2342.

e. $O_{2(g)}$

3. The potential energy diagram below shows two different mechanisms for the same reaction. Which value represents the activation energy for the catalyzed reaction?

- a. A
- b. B
- c. C
- d. D
- e. E



4. Identify the following catalysts as either heterogeneous or homogeneous.

- a. KOH
- b. Acetic acid
- c. Zeolite
- d. Na_2CO_3
- e. Pt/C
- f. Al_2O_3

Lesson 2: Guided Reading

Nagappan, S.; et. al. Catalytic hydrothermal liquefaction of biomass into bio-oils and other value added products - A review. *Fuel*. **2021**, 285, 119053.

Carefully read the information presented in the article. We will focus on four sections of the paper but you are encouraged to spend time learning from the other sections of the paper as well. For each section you should attempt to answer the guiding questions as you read the article. Then watch the video discussion to assess how well you answered the questions.

Introduction

- What are some factors that make HTL of bio-oils a promising source of energy?
- How will catalysts improve the potential for bio-oils in industrial applications?
- What are some of the main challenges of using catalysts for HTL?

⇒[Discussion Video](#)⇐

Use of Catalysts in HTL

- Identify some positive and negative features of the following types of catalysts:
 - Alkali
 - Acidic
 - Heterogeneous

- Why is catalyst recovery important for industrial processes?
- How successful has catalyst recovery been so far?

⇒[Discussion Video](#)⇐

Physio-chemical Properties of Catalytic Bio-Oil

- For each type of reaction below, identify effective catalysts:
 - Decarboxylation
 - Deoxygenation
 - Hydrogenation
 - Denitrogenation
 - Desulfurization
- Why is it important to reduce the amount of heteroatoms in the bio-oil?

⇒[Discussion Video](#)⇐

Perspectives & Challenges

- Identify the characteristics that must be considered for a catalyst to be used in HTL.
- Identify one of the catalysts described in this section. Describe the qualities that make it an effective catalyst and qualities that present challenges.

⇒[Discussion Video](#)⇐

Check Quiz Answer Key

1. **Answer: D;** A catalyst provides an alternative route for the reaction to take place. This alternate route has a lower activation energy and therefore increases the rate of reaction.
2. **Answer: B;** A catalyst must remain unchanged after the reaction. I^- is the only species that is a reactant and a product of the chemical reaction.
3. **Answer: D;** Activation energy is the minimum amount of energy required for a chemical reaction to occur. Looking at the graph, the activation energy is defined as the difference between the energy of the reactants and the greatest energy along the reaction progress. A catalyst lowers the activation energy of the reaction. Value C represents the activation of the uncatalyzed reaction.
4. **Answers:**
 - a. KOH - homogeneous
 - b. Acetic acid - homogeneous
 - c. Zeolite - heterogeneous
 - d. Na_2CO_3 - homogee
 - e. Pt/C - heterogeneous
 - f. Al_2O_3 - heterogeneous