

## 8.3 HOMOGENOUS & HETEROGENOUS CATALYSTS

### Learning outcomes

Candidates should be able to:

1. explain and use the terms catalyst and catalysis
  - (a) explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy
  - (b) explain this catalytic effect in terms of the Boltzmann distribution
  - (c) construct and interpret a reaction pathway diagram, for a reaction in the presence and absence of an effective catalyst

### Initial assessment

1.  $\text{SO}_2$  reacts with  $\text{NO}_2$  in the atmosphere to form  $\text{SO}_3$  and  $\text{NO}$ .  
 $\text{NO}$  is then oxidised in air to form  $\text{NO}_2$ .  
 $\text{SO}_2 + \text{NO}_2 \rightarrow \text{SO}_3 + \text{NO}$   
 $2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$   
State the role of  $\text{NO}_2$  in this two-stage process.

[1]

### Introduction

**Catalysts increase the rate because they make the reaction go by a different reaction pathway (mechanism) that has a lower activation energy than the uncatalysed reaction.**

A **catalyst** is a substance that increases the rate of a reaction but remains chemically unchanged itself at the end of the reaction.

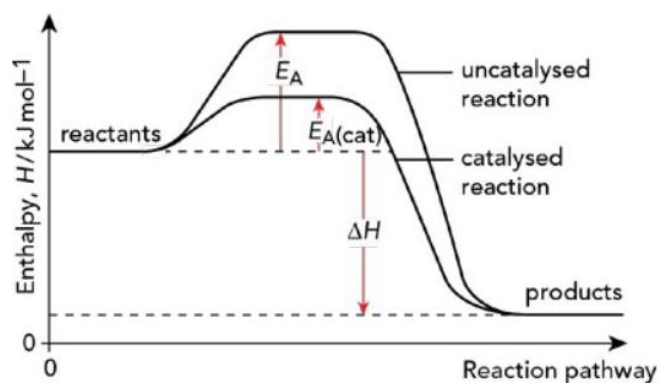
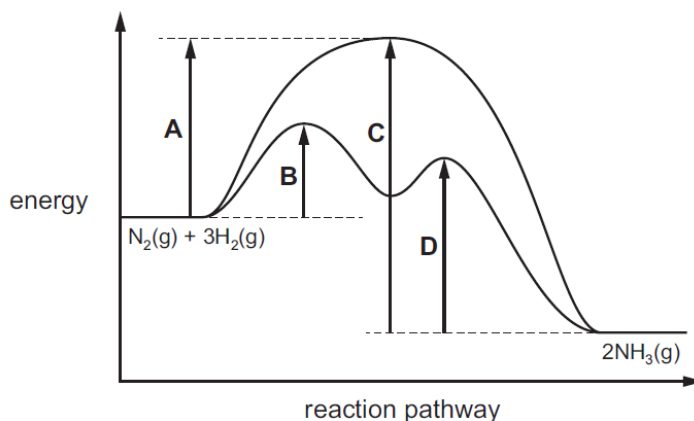


Figure: Effect of a catalyst on the activation energy of an exothermic reaction

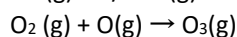
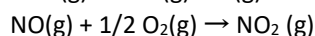
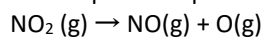
Catalysis: the increase in rate of a chemical reaction brought about by the addition of particular substances which are not used up in the reaction.

1. The reaction pathway diagram for the catalysed reaction and the uncatalysed reaction between  $\text{N}_2$  and  $\text{H}_2$  is shown.  
 $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$

Which letter represents the activation energy for the first step in the decomposition of  $\text{NH}_3$  in the presence of a catalyst?



2.  $\text{NO}$  and  $\text{NO}_2$  are both present in the lower atmosphere as pollutants.  
 The reaction sequence shows the production of ozone from oxygen in the lower atmosphere.  
 This sequence repeats many times.



Which statement about this reaction sequence is correct?

- A**  $\text{NO}$  is acting as a catalyst, but  $\text{NO}_2$  is not acting as a catalyst.  
**B**  $\text{NO}_2$  is acting as a catalyst, but  $\text{NO}$  is not acting as a catalyst.  
**C** Neither  $\text{NO}$  nor  $\text{NO}_2$  are acting as catalysts.  
**D** Both  $\text{NO}$  and  $\text{NO}_2$  are acting as catalysts.

2. Describe how a catalyst affects a reaction. Explain your answer.

[2]

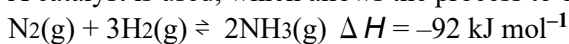
3. The reaction of ethene,  $\text{C}_2\text{H}_4$ , with a 1:1 mixture of  $\text{CO}$  and  $\text{H}_2$  is shown in equation 1.  
 equation 1  $\text{C}_2\text{H}_4(\text{g}) + \text{CO}(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{CH}_3\text{CH}_2\text{CHO}(\text{g})$

At atmospheric pressure a cobalt-based catalyst is used in this reaction.

State and explain the effect of using a catalyst on this reaction.

[2]

4. The Haber process involves the reaction of  $\text{N}_2$  and  $\text{H}_2$  to form ammonia,  $\text{NH}_3$ .  
 A catalyst is used, which allows the process to be carried out at a lower temperature and pressure.



Explain how the presence of a catalyst affects the reaction.

[1]

3. Which of the following factors can affect the value of activation energy of a reaction?

1. The presence of a catalyst.
2. Change in temperature.
3. Change in concentration of the reactants.

**A** 1 only

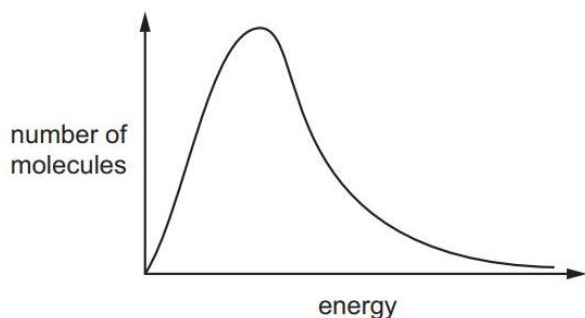
**B** 1 and 2

**C** 3 only

**D** 1, 2 and 3

5.  $\text{Al}_2\text{O}_3$  is used as a catalyst in the dehydration of alcohols.

State the effect of using  $\text{Al}_2\text{O}_3$  as a catalyst in the dehydration of alcohols. Use the Boltzmann distribution in Fig. 2.1 to help explain your answer.



4. The equations for two reactions are shown.



The two reactions have similar reaction mechanisms.

The initial rate of reaction X is greater than that of reaction Y when measured under identical conditions of temperature, pressure and reactant concentration.

Which statements explain this difference?

- 1 The activation energy for reaction X is less than that of reaction Y.
- 2 The Br-Br bond is weaker than the Cl-Cl bond.
- 3 A higher frequency of collisions between molecules of NOBr occur than between molecules of NOCl.

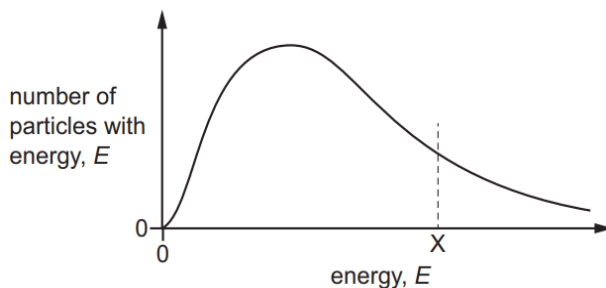
**A** 1 and 2

**B** 2 and 3

**C** 1 only

**D** 3 only

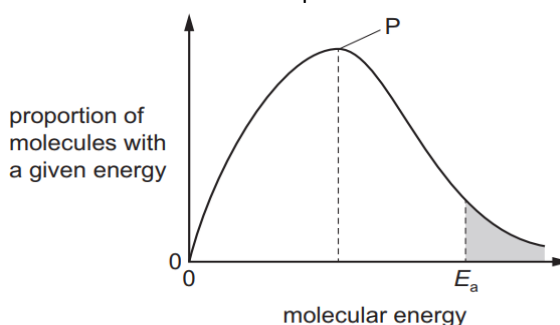
5. The diagram shows the Boltzmann distribution of energies for a reactant gas. For a particular reaction, the activation energy is X.



Which change to the diagram occurs if an effective catalyst is added at the same temperature?

- A** More particles will possess higher values of E.
- B** The peak will move to the left.
- C** The peak will move to the right.
- D** The value of the activation energy decreases.

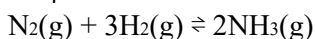
6. The diagram shows the Boltzmann distribution of energies in a gas. The gas can take part in a reaction with an activation energy,  $E_a$ . The gas is maintained at a constant temperature.



Which statement is correct?

- A If a catalyst is added, peak P will be lower and  $E_a$  will move to the left.
- B If a catalyst is added, peak P will be lower and  $E_a$  will move to the right.
- C If a catalyst is added, peak P will be the same and  $E_a$  will move to the left.
- D If a catalyst is added, peak P will be the same and  $E_a$  will move to the right.

6. The Haber process is carried out with a nitrogen partial pressure of 50kPa, a hydrogen partial pressure of 150 kPa, a temperature of 400°C and an iron catalyst.



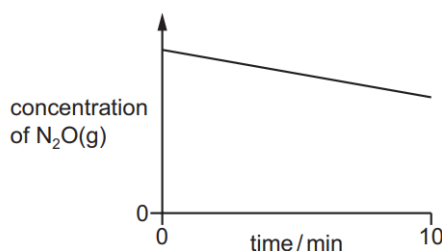
If all other conditions are kept the same, which change will result in a raised activation energy?

- A Both the nitrogen and hydrogen partial pressures are changed to 100 kPa.
- B The iron is removed.
- C The nitrogen partial pressure is increased to 150 kPa.
- D The temperature is increased to 500°C.

7. A large amount of  $\text{N}_2\text{O}(\text{g})$  decomposes into nitrogen gas and oxygen gas in the presence of a tiny amount of a gold foil catalyst.

The gold foil provides a solid surface on which the catalysed reaction takes place.

The graph shows the concentration of  $\text{N}_2\text{O}(\text{g})$  against time as it decomposes. The graph is a straight line.



Which row describes:

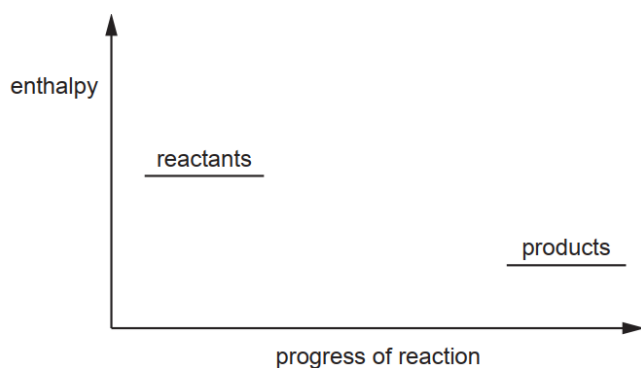
- the change in rate of reaction as  $\text{N}_2\text{O}(\text{g})$  decomposes from 0 to 10 minutes
- the effect of adding more gold foil catalyst on the rate of decomposition of the same amount and concentration of  $\text{N}_2\text{O}(\text{g})$ ?

|   | change in rate of reaction as $\text{N}_2\text{O}(\text{g})$ decomposes | effect of adding more gold foil on the rate of decomposition |
|---|-------------------------------------------------------------------------|--------------------------------------------------------------|
| A | none                                                                    | increases                                                    |
| B | none                                                                    | none                                                         |
| C | decreases                                                               | increases                                                    |
| D | decreases                                                               | none                                                         |

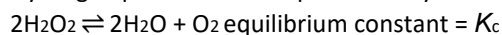
7.  $\text{KClO}_3(\text{s})$  decomposes when heated.

$\text{MnO}_2(\text{s})$  catalyses the exothermic decomposition reaction.

Complete and label the diagram in Fig. 3.1 to show the effect of  $\text{MnO}_2(\text{s})$  on the decomposition of  $\text{KClO}_3(\text{s})$ .



8. Hydrogen peroxide decomposes slowly at 20 °C to form water and oxygen.

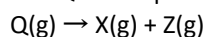


The reaction is faster when a catalyst is present.

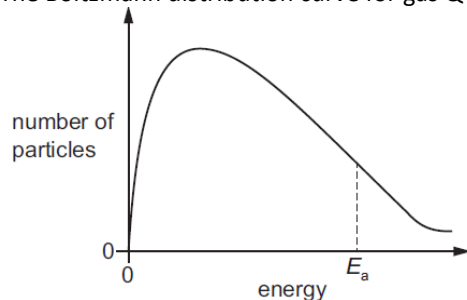
Which statement is correct?

- A** The catalyst alters the Boltzmann distribution so that the reactant molecules have more energy.
- B** The catalyst has no effect on the value of  $K_c$ .
- C** The catalyst increases the value of  $K_c$ .
- D** The catalyst provides a different reaction mechanism with a higher activation energy.

9. Gas Q decomposes slowly at room temperature.



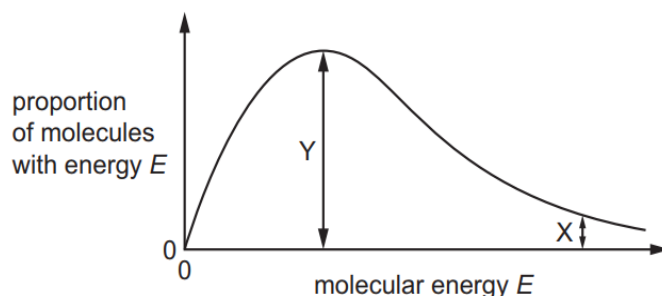
The Boltzmann distribution curve for gas Q at room temperature is shown.



Which change occurs when a catalyst is added to gas Q?

- A** The peak of the curve moves to the right on the diagram.
- B** The number of particles with enough energy to decompose increases.
- C** The kinetic energy of the unreacted particles increases.
- D** The value of  $E_a$  decreases, moving the vertical dotted line to the right on the diagram.

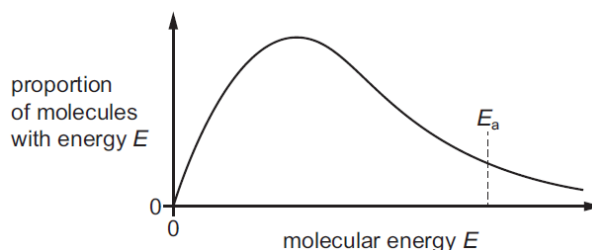
10. The diagram shows the Boltzmann distribution of the energy of gaseous molecules at a particular temperature.



Which statement is correct?

- A** If the temperature of the gas is raised, the height of the maximum of the curve increases.
- B** If the temperature of the gas is raised, the maximum of the curve moves to the right.
- C** The length of the line labelled X shows the activation energy for the reaction.
- D** The length of the line labelled Y shows the enthalpy change of the reaction.

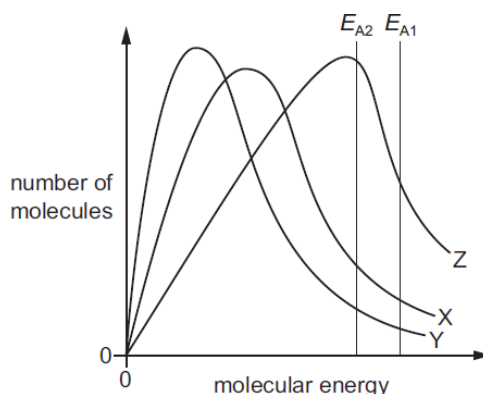
11. The Boltzmann distribution for the hydrogenation of an alkene at a particular temperature in the absence of a catalyst is shown.



Which row correctly describes the effects of adding a nickel catalyst to the reaction vessel?

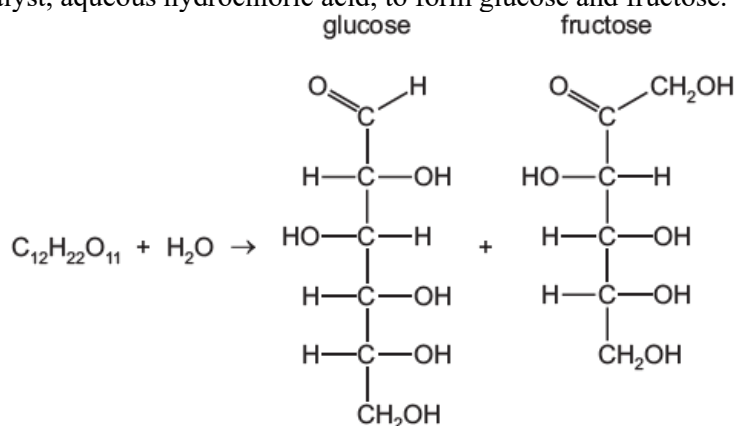
|   | the shape of the Boltzmann distribution | activation energy, $E_a$ |
|---|-----------------------------------------|--------------------------|
| A | Changes                                 | decreases                |
| B | Changes                                 | increases                |
| C | does <b>not</b> change                  | decreases                |
| D | does <b>not</b> change                  | increases                |

12. In the diagram, X is the Boltzmann distribution for the energies of the particles in a reaction and  $E_{A1}$  is the activation energy for that reaction.



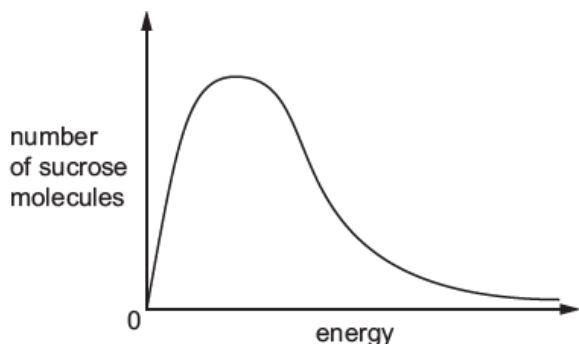
Which statement is correct?

- A  $E_{A2}$  is the activation energy at a higher temperature.
  - B  $E_{A2}$  is the activation energy at a lower temperature.
  - C Y is the Boltzmann distribution at a lower temperature.
  - D Z is the Boltzmann distribution at a higher temperature.
8. Sucrose is a white crystalline solid,  $C_{12}H_{22}O_{11}$ . In reaction Z, sucrose reacts with water in the presence of a catalyst, aqueous hydrochloric acid, to form glucose and fructose.



If no catalyst is added in reaction Z, the reaction is very slow.

Label the Boltzmann distribution to show the effect of adding a catalyst to the sample of sucrose and water molecules at constant temperature.



Explain your labelled diagram.

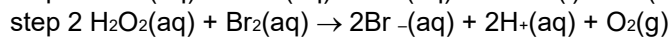
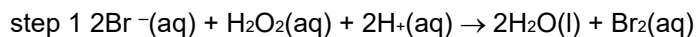
[3]

### Homogeneous and Heterogeneous catalysts

When a catalyst and the reactants in a catalysed reaction are in the **same phase**, we describe the catalyst as a **homogeneous** catalyst. For example, we can describe a catalyst as homogeneous if it is dissolved in water and the reactants are also present as an aqueous solution.

If the catalyst is in a **different phase** to the reactants, we describe the catalyst as a **heterogeneous** catalyst.

13. Hydrogen peroxide,  $\text{H}_2\text{O}_2$ , decomposes to form water and oxygen.  
The reaction is catalysed by bromide ions.



Which row is correct?

|          | type of catalyst | in step 1                 |
|----------|------------------|---------------------------|
| <b>A</b> | heterogeneous    | bromide ions are oxidised |
| <b>B</b> | heterogeneous    | bromide ions are reduced  |
| <b>C</b> | homogeneous      | bromide ions are oxidised |
| <b>D</b> | homogeneous      | bromide ions are reduced  |

14. Which statement about catalysts is correct?

- A** They change the reaction pathway by decreasing the activation energy.
- B** They increase the rate of reaction by lowering the enthalpy change of the reaction.
- C** They increase the number of particles that have sufficient energy to react.
- D** Heterogeneous catalysts are in the same state as the reactant.

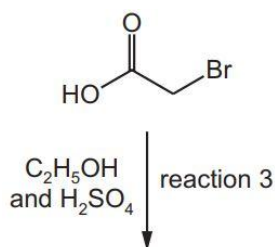
9. Lucas's reagent is a mixture of  $\text{HCl}$  and  $\text{ZnCl}_2$ . Primary, secondary and tertiary alcohols can be distinguished by their reaction with Lucas's reagent.

Alcohols react with the  $\text{HCl}$  in Lucas's reagent to form halogenoalkanes.

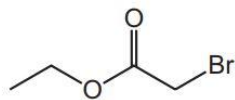
$\text{ZnCl}_2$  acts as a homogeneous catalyst for these reactions.

Explain the meaning of the term *homogeneous*.

[1]



**B**



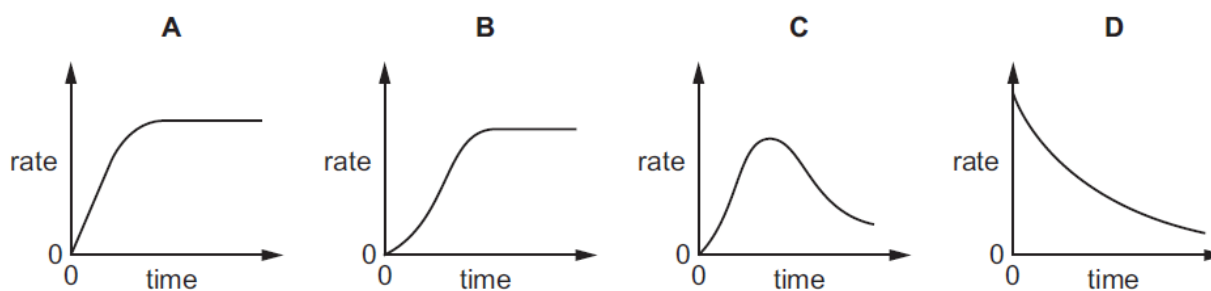
10.  $\text{H}_2\text{SO}_4$  acts as a homogeneous catalyst in reaction 3. Explain why  $\text{H}_2\text{SO}_4$  is described as **homogeneous**.

[1]

11. Nitrogen dioxide,  $\text{NO}_2$ , acts as a homogeneous catalyst in the oxidation of atmospheric sulfur dioxide. Explain why  $\text{NO}_2$  is described as a homogeneous catalyst.

[3]

15. An autocatalytic reaction is a reaction in which one of the products catalyses the reaction. Which curve would be obtained if the rate of an autocatalytic reaction is plotted against time?

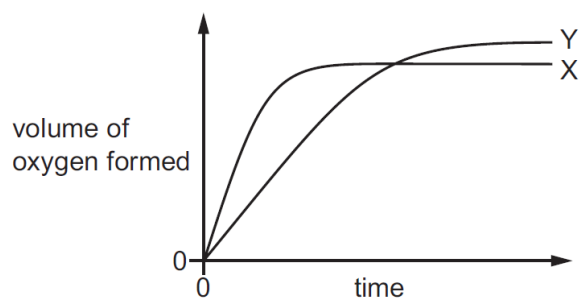


16. Two experiments are carried out to study the reaction between zinc and sulfuric acid.  
 experiment 1 Small lumps of zinc are added to excess dilute sulfuric acid.  
 experiment 2 The reaction is carried out at a lower temperature and with one other change.  
 Both experiments produce the same total volume of gas and are completed in the same time.  
 What is the second change made in experiment 2?

- A A catalyst is added.
- B A greater mass of zinc is added.
- C A greater volume of sulfuric acid is added.
- D Larger lumps of zinc are used.

17. In the diagram, curve X was obtained by measuring the volume of oxygen produced during the decomposition of 100 cm<sup>3</sup> of 1.0 mol dm<sup>-3</sup> hydrogen peroxide. A catalyst of manganese(IV) oxide was used.





Which alteration to the original experimental conditions would produce curve Y?

- A adding more manganese(IV) oxide
- B adding some  $0.1 \text{ mol dm}^{-3}$  hydrogen peroxide
- C adding water
- D raising the temperature

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