SESSION 12: ENERGY & CHEMICAL CHANGE

Key Concepts
In this session we will focus on summarising what you need to know about:

- Activation energy and activation complex
- Energy profile of a reaction
- Enthalpy (ΔH)
- Endothermic and exothermic reactions

X-planation

ENERGY CHANGES DURING CHEMICAL REACTIONS

- Most reactions do not begin until an amount of energy (activation energy) has been added to the reaction mixture.

- The activation energy is often called the ‘energy hill’ which must be ‘overcome’ by the addition of this amount of energy before a reaction can take place.

- When activation energy is added to the reactants, a so-called activated complex is formed.

- Activated complex is a temporary, unstable, high-energy composition of atoms, which represents a transition state between reactants and the products.

- When the activated complex is formed during a reaction, this complex can lead either to the formation of new bonds, i.e. molecules of the products, or to re-formation of the old bonds, thereby returning to being reactants.

- For the reaction

  \[ AB + C \rightarrow A + BC \]

  The formation of an activated complex as a transitional step can be represented as follows:

  \[ AB + C \rightarrow [ABC] \rightarrow A + BC \]

  The peak of the energy hill indicates the energy of the activated complex.

- When an activated complex is formed during a reaction, this complex can lead either to the formation of new bonds, i.e. molecules of the products, or to the re-formation of the old bonds thereby returning to being the reactants. This is reversibility for the reaction.
ENTHALPY (HEAT OF REACTION)

- Enthalpy (\(\Delta H\)) is the difference between the energy of the products and the energy of the reactants.

\[
\Delta H = E_{\text{products}} - E_{\text{reactants}}
\]

- For an endothermic reaction, \(E_{\text{products}} > E_{\text{reactants}}\), therefore, \(\Delta H\) is positive.

- For an exothermic reaction, \(E_{\text{products}} < E_{\text{reactants}}\), \(\Delta H\) is negative.

- A catalyst mechanism: the function of a catalyst is to provide an alternate route for the reaction to take place. This route has a lower activation energy and the rate of the reaction increases. A catalyst forms part of the activated complex and when this decomposes, the catalyst is released unchanged.

The Mechanism of a Catalyst

- The function of a catalyst is to provide an alternate route for the reaction to take place. This route has a lower activation energy and the rate of the reaction increases.

- A catalyst forms part of the activated complex and when this decomposes, the catalyst is released unchanged.

- Two kinds of catalysis:
  - Homogenous – catalyst is the same phase as the reactants.
  - Heterogeneous – catalyst in different phase from the reactants.

- Catalysts cannot cause a reaction to occur; they can only affect the rate of the reaction.
X-ample Questions

Question 1
The contact process is used in the industrial preparation of sulphuric acid. Sulphur trioxide is prepared by reacting sulphur dioxide with oxygen and using vanadium pentoxide as a catalyst.

\[ 2 \text{SO}_2 (g) + \text{O}_2 (g) \rightarrow 2 \text{SO}_3 (g) \quad \Delta H < 0 \]

1.1 Draw the potential energy versus reaction co-ordinate graph for the reaction above. (6)

1.2 Is the reaction exothermic or endothermic? Define the applicable term to illustrate your answer. (3)

1.3 Calculate the molecular mass of each of the substances. (6)

Question 2
The bombardier beetle fights off enemies with a chemical spray. The beetle has two glands. One gland has an aqueous solution of hydroquinone and hydrogen peroxide. The other gland contains a mixture of enzymes. When threatened, the beetle squeezes fluid from the first gland into the other compartment. In the presence of enzymes, a reaction takes place.

The reaction happens in three steps

i. \[ \text{C}_6\text{H}_4(\text{OH})_2 (aq) \rightarrow \text{C}_6\text{H}_4\text{O}_2 (aq) + \text{H}_2 (g) \quad \Delta H = 177 \text{ kJ} \]

ii. \[ \text{H}_2\text{O}_2 (aq) \rightarrow \text{H}_2\text{O} (ℓ) + \frac{1}{2} \text{O}_2 (g) \quad \Delta H = -94.6 \text{ kJ} \]

iii. \[ \text{H}_2 (g) + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{H}_2\text{O} (ℓ) \quad \Delta H = -286 \text{ kJ} \]

Final combined equation:

\[ \text{C}_6\text{H}_4 (\text{OH})_2 (aq) + \text{H}_2\text{O}_2 (aq) \rightarrow \text{C}_6\text{H}_4\text{O}_2 (aq) + 2 \text{H}_2\text{O} (ℓ) \]

2.1 Show by means of a calculation that the mixture ejected by the beetle is extremely hot. (3)

2.2 Sketch a potential energy graph for the reaction in equation i. (5)

2.3 Explain the significance of the negative values in graph ii and iii. (3)

2.4 Why should people be cautious about playing with bombardier beetles? (2)
Question 3
During the process of cellular respiration, glucose is broken down to form carbon dioxide and water according to the following equation:

$$C_6H_{12}O_6 \ + \ 6 \ O_2 \ \rightarrow \ 6 \ CO_2 \ + \ 6 \ H_2O$$

The reaction is catalysed by enzymes. The change in potential energy is given in the graph below.

3.1 Is the breakdown of glucose endothermic or exothermic? (2)
3.2 Explain how enzymes influence the rate of the reaction. (2)
3.3 Is the reverse reaction endothermic or exothermic? (2)
3.4 How much energy is needed to break the oxygen into atoms? (2)
3.5 The oxygen molecule is broken up into two atoms. Explain the changes in potential energy and distance between the atoms. (4)
Question 4

The diagram below shows the change in potential energy of a chemical system represented by the equation

\[ 2 \text{CO (g)} + \text{O}_2 \text{(g)} \rightarrow 2 \text{CO}_2 \text{(g)} \]

at temperature of 304 K.

4.1 What is the potential energy of the reactants in the above reaction? (1)

4.2 What is the potential energy of the products in the above reaction? (1)

4.3 Write down the value of the activation energy for the reaction. (2)

4.4 What is the value of \( \Delta H \) for the forward reaction? (2)

4.5 Is this reaction endothermic or exothermic? Motivate your answer. (2)
X-ercise

Question 1

1.1 Consider the reaction

\[ \text{H}_2 + \text{I}_2 \rightarrow 2\text{HI} \quad (\Delta H < 0) \]

1.1 Is this reaction exothermic or endothermic? (1)

1.2 How does the energy of the products compare to that of the reactants? (1)

Question 2

The contact process is used in the industrial preparation of sulphuric acid. The reaction is given below:

\[ 2\text{SO}_2 (g) + \text{O}_2 (g) \leftrightharpoons 2\text{SO}_3 (g) \quad \Delta H < 0 \]

2.1 Draw the potential energy versus reaction coordinate graph for the forward reaction. Indicate the following on the graph:

- Activation energy for the forward reaction
- Activation energy for the reverse reaction
- Activation complex
- Heat of the reaction for the forward reaction
- Heat of reaction for the reverse reaction (7)

2.2 Is the forward reaction endothermic or exothermic? (1)

2.3 Is the reverse reaction endothermic or exothermic? Give a reason for your answer. (2)