4 Enzymes

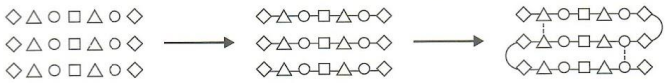
Study Station ▸▸

A Enzymes

Learning Outcome

- Define enzymes as biological catalysts which are involved in metabolic reactions.

1. A **catalyst** is a substance that speeds up the rate of a chemical reaction, without itself being altered at the end of the reaction.
2. Enzymes are **biological catalysts**.
   - They are found in living things and are made of protein.
   - They are able to alter the rate of chemical reactions without being changed themselves at the end of the reactions.
3. Enzyme-catalysed reactions can be classified into two groups:
   - Anabolic reactions in which complex substances are synthesised from simpler ones.
   - Catabolic reactions in which complex substances are broken down into simpler ones.
4. The table below shows some examples of enzyme-catalysed reactions.

Type of Reaction	Example
Synthesis of complex substances	• Special enzymes in the cytoplasm build up proteins from amino acids.  amino acids → polypeptides → protein • Enzymes are involved in the synthesis of glucose from carbon dioxide and water during photosynthesis.
Breaking down of complex substances	• Enzymes such as **digestive enzymes** break down large molecules in food into smaller ones which are soluble in water and can pass through the cell membrane. • Certain enzymes break down large molecules that are toxic into smaller, safer ones. - For example, hydrogen peroxide is produced during some chemical reactions in plant and animal cells. It is toxic to the cells. - Catalase breaks down hydrogen peroxide to form water and oxygen. - Catalase is abundant in the blood and liver of mammals. • Various enzymes break down glucose to release energy, carbon dioxide and water in cell respiration.

5. The table below shows the types of digestive enzymes in the body.

Type of Digestive Enzymes	Function	Example(s)
Carbohydrases	Digest carbohydrates	• Amylase digests starch to maltose • Maltase digests maltose to glucose • Sucrase digests sucrose to glucose and fructose
Proteases	Digest proteins	• Protease digests proteins to polypeptides and then to amino acids
Lipases	Digest fats (lipids)	• Lipase digests fats to fatty acids and glycerol

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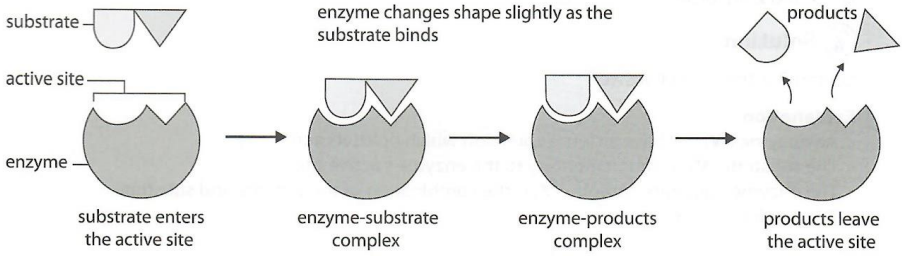
B How Enzymes Work

Learning Outcomes

- Describe how enzymes work using the terms 'active site' and 'enzyme-substrate complex'.
- Explain enzyme specificity using the 'lock-and-key' hypothesis.

1. **Substrates** are the substances that enzymes work on.
2. A substrate fits into an **active site**, which are depressions on the surface of an enzyme.
3. Enzymes are highly specific in their action.
   - Each chemical reaction is catalysed by a unique enzyme. This specificity is due to the enzyme's three-dimensional shape.
   - This means that only a substrate, with a shape **complementary** (matching) to that of the enzyme's active site, can fit into the active site.
4. According to the 'lock-and-key' hypothesis, the enzyme is like a lock and the substrate is like a key.
5. When a substrate binds to the active site of an enzyme, an **enzyme-substrate complex** is formed.
6. Chemical reactions occur at the enzyme's active site to convert the substrate into products.



Mode of action of an enzyme

7. Once the reactions are completed, the products leave the active site.
8. The enzyme remains unchanged and is free to catalyse another reaction. The same enzyme molecule can be used repeatedly and hence, only a small amount of an enzyme is needed to catalyse the reaction for a large amount of substrate.

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Common Error

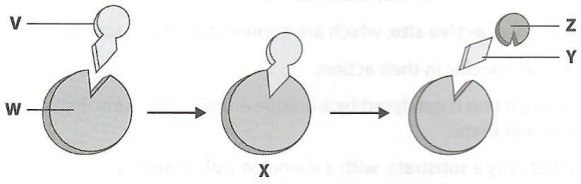
✗ The shape of the substrate is the same as the enzyme's active site.

✓ The substrate has a shape that is complementary to the enzyme's active site.

Explanation
The shape has to be complementary in order to form a close fit — the protruded surfaces of the substrate are matched with depressed surfaces of the enzyme's active site.

Worked Example 4.1

A schematic diagram of an enzyme-catalysed reaction is shown below.



Which of the following statements about the above reaction is **not** true?

A **W** is the substrate.
B **X** is the enzyme-substrate complex.
C **W** remains chemically unchanged at the end of the reaction.
D **Y** and **Z** are products of the reaction.

Solution

Option **A** is the correct answer.

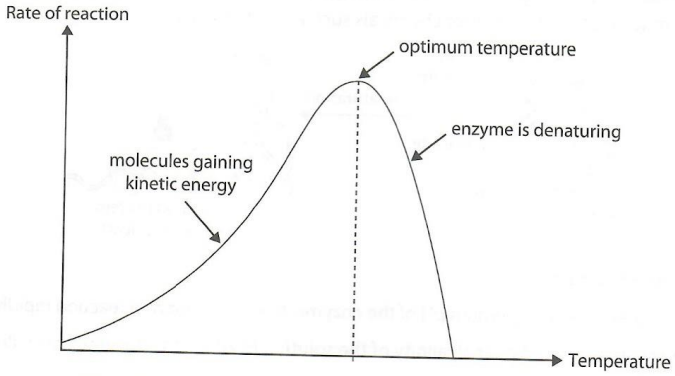
Explanation
- An enzyme (**W**) will have a cleft/depression which holds its active site.
- The substrate (**V**) is complementary to the enzyme's active site.
- The enzyme-substrate complex (**X**) is the combination of the enzyme and substrate.
- The products are **Y** and **Z**.

C Factors Affecting Rate of Enzyme-catalysed Reactions

Learning Outcome

- Investigate and explain the effects of temperature and pH on the rate of enzyme-catalysed reactions.

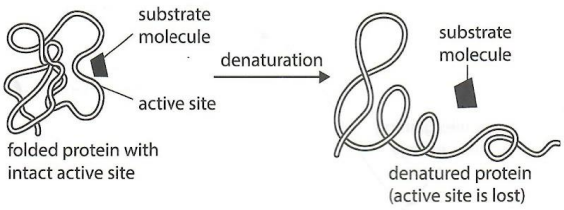
1. **Temperature** and **pH** directly affect the rate of enzyme reactions.
2. Enzymes work best at their optimum temperature and pH.
3. Enzymes are **temperature sensitive**.



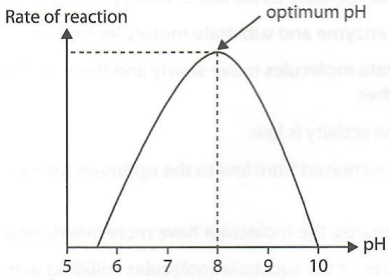
Effect of temperature on the rate of an enzyme-catalysed reaction

4. At low temperatures, the enzyme and substrate molecules have low kinetic energy.
   - The enzyme and substrate molecules move slowly and there is a lower chance of the molecules colliding with one another.
   - Thus, the rate of enzyme activity is low.
5. When the temperature is increased from low to the optimum temperature, the rate of enzyme reactions increases.
   - As the temperature increases, the molecules have more kinetic energy.
   - This increases the chances of the substrate molecules colliding with the enzymes and fitting into the active site.
   - For every 10°C increase in temperature, the rate of enzyme reaction doubles, until the optimum temperature is reached.
   - Human enzymes have an optimum temperature of 37°C which is the same temperature as the body.

6. When the temperature is increased beyond the optimum temperature, the rate of enzyme reaction rapidly decreases.
   - High temperatures irreversibly break the bonds that keep the enzyme in shape.
   - As a result, the active site of the enzyme loses its original shape and the substrate molecule can no longer fit into the active site.
   - The enzyme is said to be **denatured** and can no longer act as a catalyst.
   - Most enzymes are irreversibly denatured above 60°C. Thus, boiling denatures enzymes.
7. **Denaturation** is the change in the three-dimensional structure of an enzyme or any other soluble protein. It may be caused by heat or chemicals such as acids and alkalis.



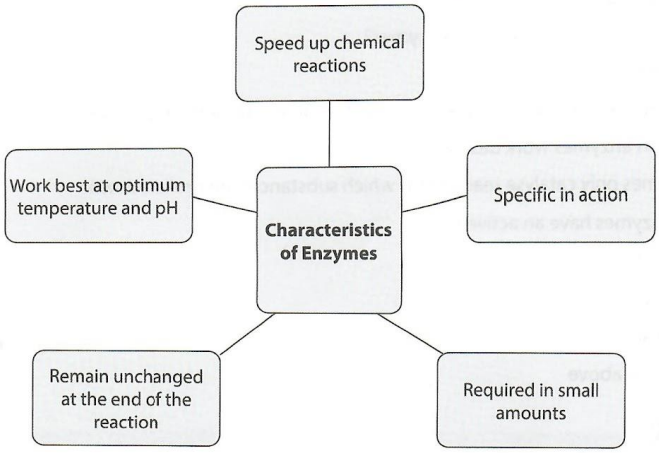
8. Enzymes are **pH sensitive**.
   - As pH deviates from the optimum pH of the enzyme, the rate of enzyme reaction rapidly decreases.
   - Extreme changes in acidity or alkalinity of the solution in which the enzyme acts will denature the enzyme.



Effect of pH on rate of enzyme reaction

9. Different enzymes have different optimum pH values at which they work best.
   - Protease in the stomach works best in acidic conditions.
   - Intestinal enzymes require alkaline conditions.

10. The diagram below summarises the characteristics of enzymes.



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Common Error

✗ Low temperatures cause an enzyme to become denatured.

✓ Low temperatures reduce the rate of enzyme activity.

Explanation
Low temperatures do not denature the enzyme but rather, reduce the chances of the enzymes colliding with the substrates due to the lower kinetic energy of the molecules.

Tip

- The effect of temperature on the rate of enzymatic reaction has an asymmetrical bell-shaped curve.
- The effect of pH on the rate of enzymatic reaction has a symmetrical bell-shaped curve.

Checkpoint 4.1

1. Which statements are **true** for all enzymes?

   1 Enzymes have an optimum pH.

   2 The shape of the active site is permanently altered by high temperature.

   3 Human enzymes work best at 37°C.

   4 Enzymes only catalyse reactions in which substances are broken down.

   5 All enzymes have an active site.

   A 1, 2 and 3

   B 1, 3 and 4

   C 1, 2, 3 and 5

   D All of the above

Tip

The characteristics of enzymes have been asked in examination questions. One example can be found in N GCE N(A) Level Science (Biology) Sep/Oct 2015 Paper 6 Q7. This knowledge is also vital for the practical assessment.

2. The enzyme–substrate complex is formed when maltase attaches to _____.

   A starch

   B maltose

   C glucose

   D sucrose

3. Which of the following enzymes are found in commercial bio-detergents to help remove blood stains from clothes?

   A Proteases

   B Carbohydrases

   C Lipases

   D Amylases

4. Oily buttery stains can be removed using a detergent that contains _____.

   A proteases

   B sucrase

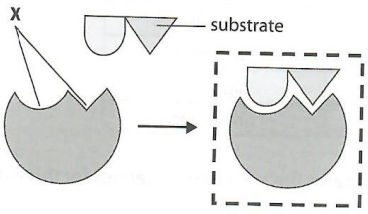
   C lipases

   D carbohydrases

Tip

The functions of various enzymes have been asked in examination questions. One example can be found in Q GCE 'O' Level Science (Biology) Oct/Nov 2020 Paper 1 Q23 or N GCE N(A) Level Science (Biology) Sep/Oct 2019 Paper 5 Q7.

5. The diagram below illustrates the action of enzyme **A** on a substrate.



Enzyme **A** Complex **Y**

(a) State the chemical nature of enzyme **A**.

(b) Name the region **X**.

(c) Explain the lock-and-key hypothesis with reference to region **X**.

(d) Name the complex **Y**.

(e) What happens to the enzyme at the end of the reaction?

Tip

The concept of enzyme-substrate specificity as illustrated by the lock-and-key hypothesis has been asked in examination questions. One example can be found in Q GCE 'O' Level Science (Biology) Oct/Nov 2018 Paper 1 Q24 or N GCE N(A) Level Science (Biology) Sep/Oct 2020 Paper 5 Q4.

Test Station ▸▸

1. What happens when an enzyme catalyses a reaction?
   - **A** The enzyme fits into the substrate.
   - **B** The enzyme molecules will be used up.
   - **C** The enzyme modifies the final product(s) of the reaction.
   - **D** The enzyme changes the speed of the reaction.

2. Some oil and egg yolk stains were found on a tablecloth. What should a biological detergent contain to remove the respective stains on the tablecloth?

	Oil Stains	Egg Yolk Stains
A	proteases	carbohydrases
B	carbohydrases	proteases
C	carbohydrases	lipases
D	lipases	proteases

3. The graph in Figure 4.1 illustrates the preferred pH ranges for three different enzymes, **A**, **B** and **C**.

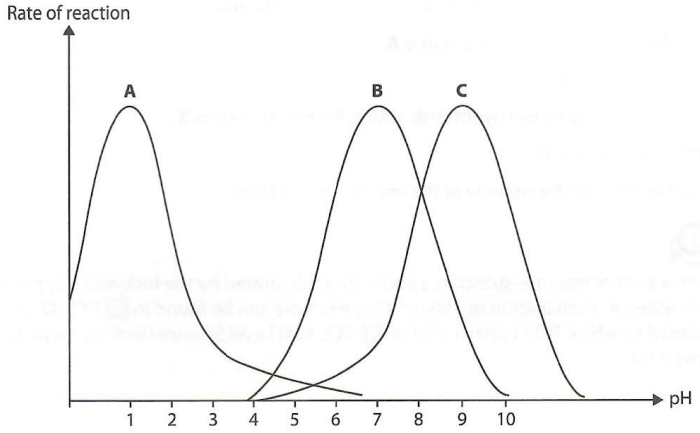


Figure 4.1

(a) State the optimum pH for each of the enzymes. [3]

(b) Omeprazole is a drug that works by reducing the amount of acid in the stomach. If enzyme **A** is found in the stomach, suggest how this drug might affect its activity. [2]

4. (a) Describe the nature and function of enzymes. [2]

(b) The enzyme amylase breaks down the substrate starch. Explain why it does not act on other substrates. [2]

(c) The graph in Figure 4.2 illustrates the effect of temperature on the rate of reaction of enzymes **Q** and **R**. Explain which of the two enzymes is found in humans. [3]

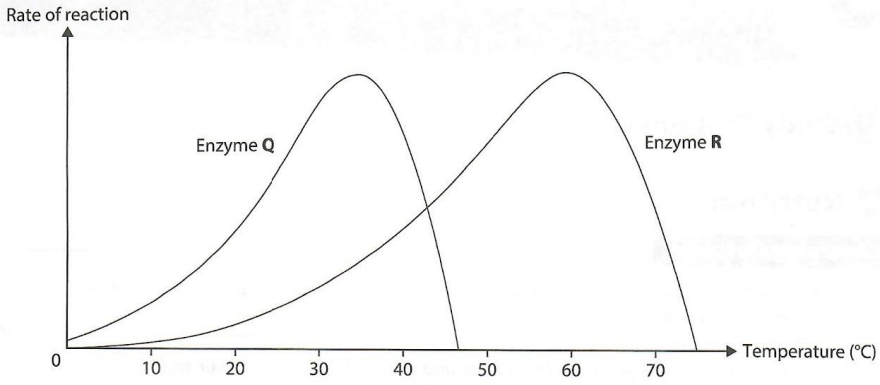


Figure 4.2

5. In an investigation, hydrogen peroxide solution was added to a beaker containing a solution of the enzyme catalase. Catalase breaks down hydrogen peroxide to form water and oxygen.

Figure 4.3 shows the effect of temperature on the rate of reaction between the substrate and enzyme.

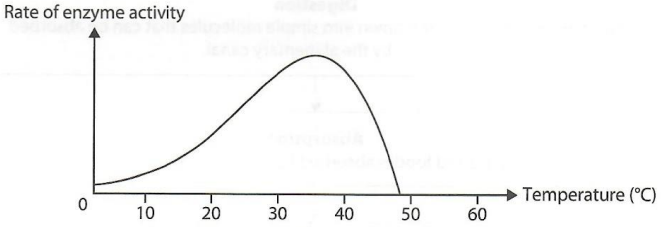


Figure 4.3

(a) State the substrate and product(s) of the chemical reaction between hydrogen peroxide and catalase. [2]

(b) State the optimum temperature of the enzyme. [1]

(c) Explain in detail the enzyme activity between 17–37°C. [2]

(d) Explain in detail the enzyme activity beyond 37°C. [2]