Learning Outcomes

1.4.1 describe the actions of enzymes as proteins that are biological catalysts which speed up the rate of reactions without being used up, to include carbohydrase (amylase), lipase and protease, and interpret the results using the lock and key model to illustrate substrate specificity; and

1.4.2 interpret how temperature, pH, enzyme concentration and inhibitors affect the action of enzymes, including:
- low temperature causing reduced rates of collision between substrate and enzyme.
- describing the maximum rate of reaction as the optimum;
- denaturation occurring increasingly at levels above the optimum, explained as irreversible change to the shape of the active site that inhibits enzyme action; and
- inhibitors as molecules that fit the active site but are not broken down (no further detail required);

Practical 1.4 investigate the effect of temperature on the action of an enzyme; and

1.4.3 demonstrate knowledge and understanding that in food digestion, enzymes are needed to break down (digest) large, insoluble molecules into small, soluble ones that can then be absorbed into the bloodstream and that they have commercial and economic uses, including biological washing powders.

1.4.4 relate the structure of the ileum to its function of absorbing digested nutrient molecules and how it is adapted: large surface area (length, folds and villi), good blood supply, and thin and permeable membranes; and

1.4.5 explain how the structure of a villus (finger-like shape, single layer of surface cells, capillary network and lacteal) is adapted to absorb digested food molecules efficiently.

Enzymes as catalysts

Enzymes are biological catalysts. A catalyst is a substance that speeds up a reaction without itself being used up. Catalysts speed up reactions by lowering the activation energy required for a collision to be successful. The graph below shows the effect of a catalyst on the course of a reaction.

As you can see when a catalyst is present, the amount of activation energy required for the reaction to be successful is lowered and therefore more of the collisions are successful and the reaction will go faster.

Without enzymes to catalyse the reactions in the human body, the rate at which the reactions
occur would be too slow to sustain life. Enzymes are involved in many of the body’s reactions from digestion, to respiration, to the clotting of blood.

Enzymes are proteins made up of a long chain of amino acids that fold into a specific 3D shape. The enzyme will fold into the shape depending on the order of the amino acids in the chain (remember this is determined by our DNA). The surface of the enzyme has an area called the active site which is specific to particular substrate(s). The enzyme works by holding that specific substrate(s) in place to allow the reaction to occur more easily. The enzyme itself is not reacting with the substrate but is facilitating a reaction that would otherwise occur too slowly.

**Lock and Key Theory of enzyme reactions**

Each substrate has a specific enzyme, just as any lock has a specific key. For example, an enzyme that works with carbohydrates will not work with proteins or fats, that is each enzyme is substrate specific.

‘The Lock and Key Theory’ of enzyme action suggests that the enzyme active site is the exact shape of the substrate. The enzyme being the lock and the substrate being the key. The substrate fits exactly into the active site of the enzyme which will hold it in place to facilitate the reaction.

The diagram below shows the course of an enzyme reaction.

**Factors that affect the rate of an enzyme controlled reaction**

**Temperature**

Like any chemical reaction, collisions between the enzyme and the substrate must occur for the reaction to proceed. This requires the molecules to be moving, that is, they have kinetic energy. The graph below shows how the rate of the reaction is affected by temperature.

At low temperatures the enzyme and substrate molecules have little kinetic energy and move slowly. Therefore, there are few successful collisions and the rate of the reaction is slow.

At the optimum temperature for the enzyme (usually 37 – 40°C in body reactions) the molecules are moving more quickly and have sufficient kinetic energy to allow collisions to be successful.

At high temperatures the molecules have a lot of kinetic energy and begin to vibrate vigorously, this weakens the bonds that hold the enzyme in a specific shape. As bonds weaken they can break thus changing the shape of the enzyme active site. The enzyme is said to be ‘denatured’ and the active site no longer matches the shape of the substrate; this is an irreversible change in the structure. The rate of the reaction decreases as the enzyme can no longer catalyse the reaction.
**pH**

Enzymes each work best at a particular pH. Enzymes found in the mouth and small intestine, work best in slightly alkaline conditions whilst those found in the stomach work best in acidic conditions. The graph below shows how pH affects the course of an enzyme reaction.

![Effect of pH on enzyme activity](image)

The optimum pH is that in which the enzyme works best. The active site is the ideal shape to fit the substrate and the reaction will proceed at its maximum rate. Either side of the optimum the changes in pH change the bonds in the enzyme structure. This means the active site alters its shape and is not the ideal fit for the substrate. At extremes of pH the bonds are so badly damaged that the enzyme denatures and stops working.

**Enzyme Concentration**

The graph below shows how enzyme concentration affects the rate of the reaction. Provided there is an unlimited supply of substrate, the higher the enzyme concentration, the faster the rate of the reaction. This is because as the concentration increases there are more enzyme molecules in the same volume of solution, therefore there will be a greater chance of substrate colliding with the enzyme active site and the reaction will be faster. However, if the amount of substrate is limited the rate of the reaction will level off as there are fewer substrate molecules left to collide with the enzyme as time goes on.

![Effect of enzyme concentration on the rate of a reaction](image)

**Inhibitors**

The rate of some enzyme reactions in the body can be limited by molecules called inhibitors. Inhibitors are molecules that are identical in shape to the substrate. They reduce the rate of the reaction by competing with the substrate for the active site of the enzyme. Once the inhibitor gets into the active site it stays there as it is not broken down. This means those enzymes that bind with the inhibitor are no longer available to bind with the substrate. Sometimes competitive inhibition is an important way of controlling the body’s reactions to prevent over stimulation. Some medications also work by inhibiting enzyme reactions and cyanide, which is a poison, inhibits some of the reactions involved in respiration causing the body to stop working.

**Commercial use of enzymes**

As enzymes can speed up biological reactions they are useful in many commercial industries. They are used to speed up processes and make them more efficient. As they are so specific they can be used in small amounts to speed up reactions that would otherwise be very slow. Enzymes are used in many industrial processes such as pre digestion of baby food, cheese making etc. They are also used for ecological benefit as well as economic benefit. Enzymes are used in biological washing powder, they can break down stains at lower temperatures, this not only saves the user money (in heating the water) but it is better for the environment.

**Enzymes in digestion**

Enzymes control many reactions in the human body. However, we are going to look specifically at those involved in digestion.
There are three main groups of enzymes involved in digestion:

- Carbohydrases, for example amylase – which break down carbohydrates into simple sugars;
- Proteases – which break down protein into amino acids;
- Lipases – which break down fats into fatty acids and glycerol.

**Definition:** Digestion is the breakdown of large insoluble molecules, into small soluble molecules that can be absorbed across the walls of the ileum into the blood.

The diagram below shows the structure of the digestive system.

Once food has been digested it is soluble and small enough to be passed through the walls of the ileum into the blood so it can be transported around the body to where it is required. The process of digestion is complete in the ileum.

**Structure of the Ileum**

The diagram below shows a cross section of the ileum. The ileum has two main functions:

- To complete digestion;
- To absorb food into the blood.

<table>
<thead>
<tr>
<th>Part of digestive system</th>
<th>Enzyme Released</th>
<th>Released from</th>
<th>Substrate</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td>Carbohydrase (amylase)</td>
<td>Salivary Glands</td>
<td>Starch</td>
<td>Glucose</td>
</tr>
<tr>
<td>Stomach</td>
<td>Protease</td>
<td>Stomach wall</td>
<td>Protein</td>
<td>Amino Acids</td>
</tr>
<tr>
<td>Small intestine (ileum)</td>
<td>Carbohydrase</td>
<td>Intestinal walls and pancreas</td>
<td>Carbohydrates</td>
<td>Simple sugars</td>
</tr>
<tr>
<td></td>
<td>Protease</td>
<td></td>
<td>Protein</td>
<td>Amino Acids</td>
</tr>
<tr>
<td></td>
<td>Lipase</td>
<td></td>
<td>Lipids</td>
<td>Fatty acids and Glycerol</td>
</tr>
</tbody>
</table>
**Adaptations of the ileum**

In order to ensure that the digested food is all absorbed into the blood, the ileum has some special adaptations.

- **It is long** – the ileum is approximately 6 metres long in humans. This allows plenty of time and a larger surface area for food to diffuse across the walls and into the blood.

- **It has villi and microvilli** – the folding of the internal walls of the ileum increase the surface area over which absorption can occur.

- **It has a thin wall** – the thin wall is made of **columnar epithelial tissue** that is only one cell thick to decrease the diffusion distance of the food products, making absorption faster.

- **It has a good blood supply** – the continual flow of blood through the ileum ensures there is a good concentration gradient meaning products of digestion will diffuse faster into the blood.

**Structure of a Villus**

The lacteal absorbs the products of lipid digestion (fatty acids and glycerol). They are later returned to the blood.

The capillary network absorbs the products of protein digestion (amino acids) and carbohydrate digestion (glucose).

Single layer of epithelial cells shortens the diffusion pathway.
Test your Knowledge

1. The diagram shows a model of how an enzyme molecule acts on a substrate.

(a) (i) Name this model. _____________________________ [1]

(ii) Complete Stage 2 and Stage 3 of this model. [2]

A cell contains only a small amount of this enzyme, yet each enzyme molecule is able to act on thousands of substrate molecules in a minute.

(iii) Explain what happens to this enzyme molecule, after Stage 3, to allow it to act on thousands of substrate molecules.

_______________________________________________________________________________
_______________________________________________________________________________ [1]
Soft-centred mint chocolates are made using enzymes. The mint centre is hard when first made so that it will not melt when covered with hot chocolate. After the chocolate has solidified the sweet is kept at 18 °C for fourteen days. During this time an enzyme called invertase breaks down the complex sugar in the mint centre making it softer and sweeter.

One manufacturer wanted to find a new enzyme to use in this process to reduce the time needed to soften the mints. Their scientists carried out experiments using four new enzymes A, B, C and D. Each experiment used the same mass of solid mint centre and the same concentration of enzyme.

The table shows the time taken by each of the new enzymes to make the mint go soft.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Time taken to soften the mint/days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invertase</td>
<td>14</td>
</tr>
<tr>
<td>A</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>18</td>
</tr>
<tr>
<td>D</td>
<td>17</td>
</tr>
</tbody>
</table>

(b) (i) **Suggest** which of the new enzymes, A, B, C or D, the manufacturer would choose to reduce the time taken to soften the mints.

Give a reason for your answer.

Enzyme _________________________________ [1]

Reason _________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________ [1]
Another scientist checked the method of the experiment and concluded that some of the factors had not been controlled.

(ii) Choose two factors from the list below, which should have been controlled in the manufacturer’s experiments.

Place a tick ([J]) in two of the boxes.

- temperature
- humidity
- light intensity
- oxygen concentration
- pH
- softness of the mint at the end

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