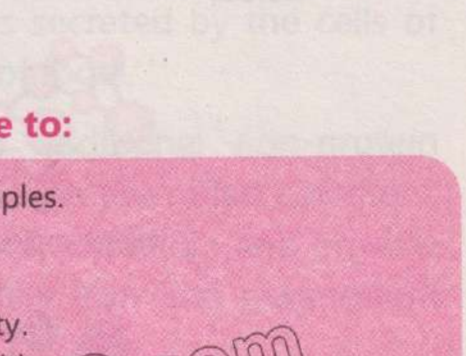
Chapter 7
ENZYMES

After studying this chapter, students will be able to:

- Define metabolism, catabolism and anabolism with examples.
- Define enzymes and describe their characteristics.
- Describe and depict the mechanism of enzyme action.
- Describe the factors which could influence enzyme activity.
- Describe competitive and non-competitive enzyme inhibition.

Enzymes are remarkable proteins which speed up biochemical reactions that would otherwise occur at very slow speed. In this chapter, we will study the unique characteristics of enzymes and uncover how they perform their work. We will also explore the various factors that influence their activity.

7.1- METABOLISM



Metabolism is the sum of all chemical reactions that occur within an organism to sustain life. There are two sub-sets of metabolism i.e., catabolism and anabolism.

1. **Catabolism** involves the breakdown of complex molecules into simpler ones, releasing energy in the process. Examples include:
   - Cellular respiration in which food (glucose) molecule is broken into CO_2 and H_2O to get energy.

Hummingbirds have one of the highest metabolic rates of any animal. They need to eat constantly to keep up their energy levels.

- Lipolysis in which lipid (fat) is broken into fatty acids and glycerol, which can be used for getting energy.

2. **Anabolism** involves building up complex molecules from simpler ones. This process consumes energy. Examples include:
   - Photosynthesis in which CO_2 and H_2O are joined to make glucose using sunlight. Oxygen is also produced as byproduct.
   - Protein synthesis in which proteins are formed by joining the amino acids.

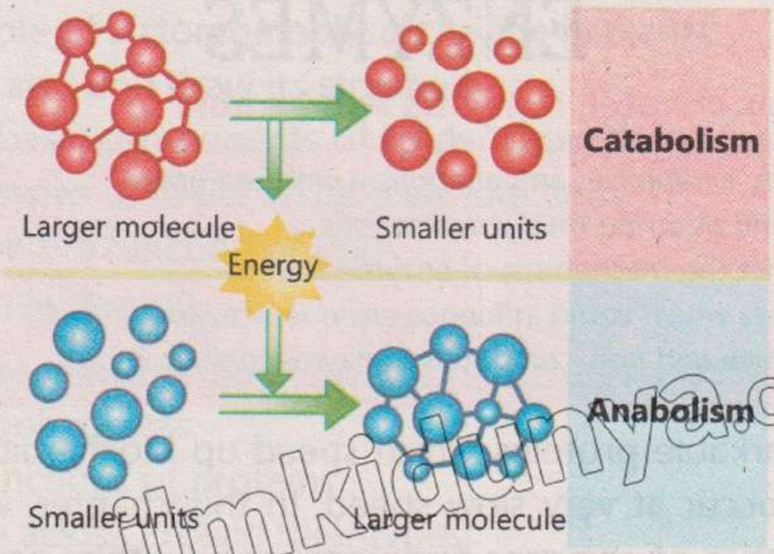


FIGURE 7.1: Types of metabolism

7.2- ENZYMES

Enzymes are biological catalysts that speed up chemical reactions in living organisms without being consumed in the process. They are primarily proteins and are highly specific to their substrates (the molecules that undergo enzyme-controlled reactions). Most enzymes can speed up reactions millions of times faster than uncatalyzed reactions.

Characteristics of Enzymes

> Some RNA molecules also act as enzymes. Such RNA is called **ribozyme**. Ribozymes are primarily found in ribosome. They are also found in specific viruses and bacteria.

Chemical nature of enzymes: Enzymes are predominantly proteins. Typically, they contain 100 to 1,000 amino acids.

Globular structure: Enzymes possess a three-dimensional globular structure. This structure allows them to form active sites that can bind specifically to substrates.

Specificity of enzymes: Enzymes are highly specific to the reactions they catalyse. They are also very specific for the nature of substrate. For example, the enzyme amylase specifically catalyses the breakdown of starch into simple sugars.

Intracellular and extracellular enzymes: Enzymes can be classified based on the location where they function. Intracellular enzymes operate within cells e.g., enzymes of cellular respiration. Extracellular enzymes are secreted outside the cells to catalyse reactions e.g., enzymes secreted by the cells of stomach walls into stomach cavity for the digestion of food.

Cofactors of enzymes: Many enzymes require additional non-protein molecules to be fully active. Such non-protein molecules are called cofactors. There are two main groups of cofactors. i.e., inorganic cofactors and organic cofactors. Inorganic cofactors include metal ions like iron and magnesium ions. The organic cofactors are of two types.

- **Prosthetic groups** tightly bind with the enzymes. Example are certain vitamins (e.g., biotin) and the haem group .
- **Coenzymes** loosely bind to the enzyme and may be released during the reaction. Examples include many vitamins and nucleotides (NAD and NADP).

Enzyme actions in complex metabolic reactions: Multiple enzymes work in a sequence to carry out a series of reactions. Each enzyme in the series catalyses a specific step. After speeding up the reaction, the product is passed on to the next enzyme for further reaction.

Use of enzymes in different industries: Enzymes have extensive applications in various industries. For example:

- **Food industry:** Enzymes that break starch into simple sugars are used in production of white bread, buns, and rolls. Enzymes are also used for the production of cheese.
- **Paper Industry:** Enzymes degrade starch to lower its viscosity that aid in making paper.

- **Biological detergent:** Protease enzymes are used for the removal of protein stains from clothes. Amylase enzymes are used in dish washing to remove resistant starch residues.
- **Fermentation industry:** Enzymes degrade starch and proteins to produce simple sugar, amino acids and peptides. These substances are used by microorganisms e.g., yeast in fermentation to produce different products of human use.

7.3- Mechanism of Enzyme Action

An enzyme has one or more pockets or clefts on its surface. These are called **active sites**. The active sites are directly involved in catalysis. Two models have been proposed to explain the mechanism of enzyme action.

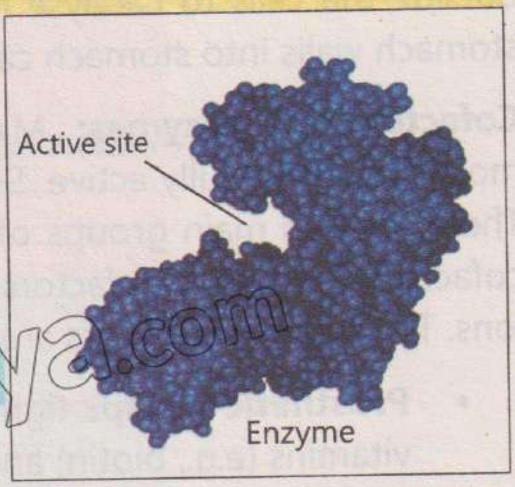


FIGURE 7.2: Active site of enzyme

1- Lock and Key Model of Enzyme Action

This model was proposed by a German chemist **Emil Fischer** in 1894. According to it, the active site of enzyme has a fixed structure. The substrate molecule fits precisely into it to form an **enzyme-substrate complex**. The enzyme catalyzes the reaction and substrate is transformed into product/s. Then, the product is released from the enzyme.

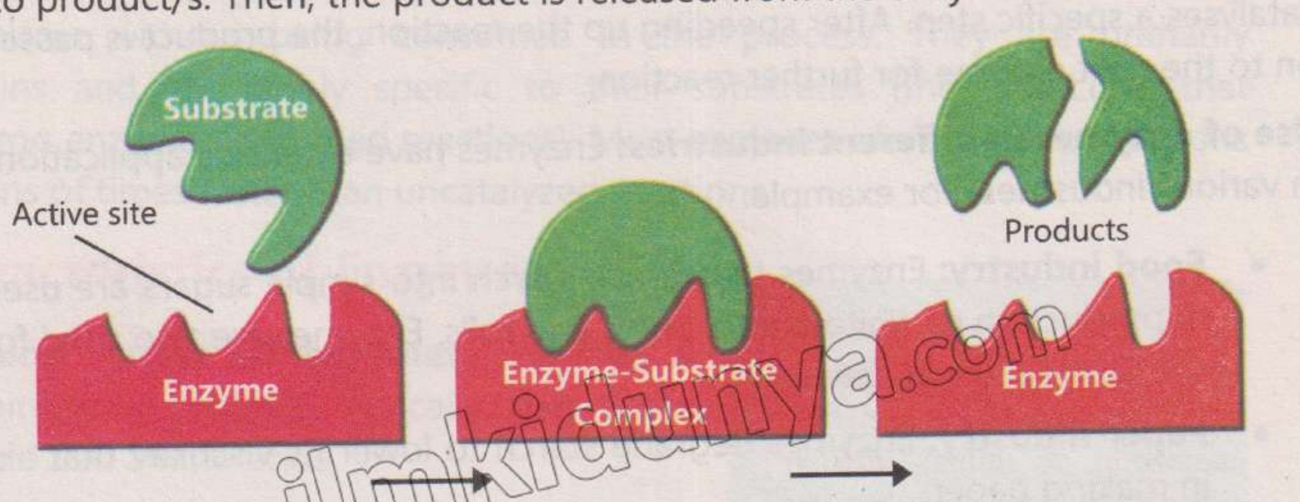


FIGURE 7.3: Lock and key model of enzyme action

2. Induced Fit Model

This model was proposed by an American biologist **Daniel Koshland** in 1958. According to this model, the active site of enzyme is not rigid. When substrate interacts with the enzyme, its active site is reshaped to perform its function.

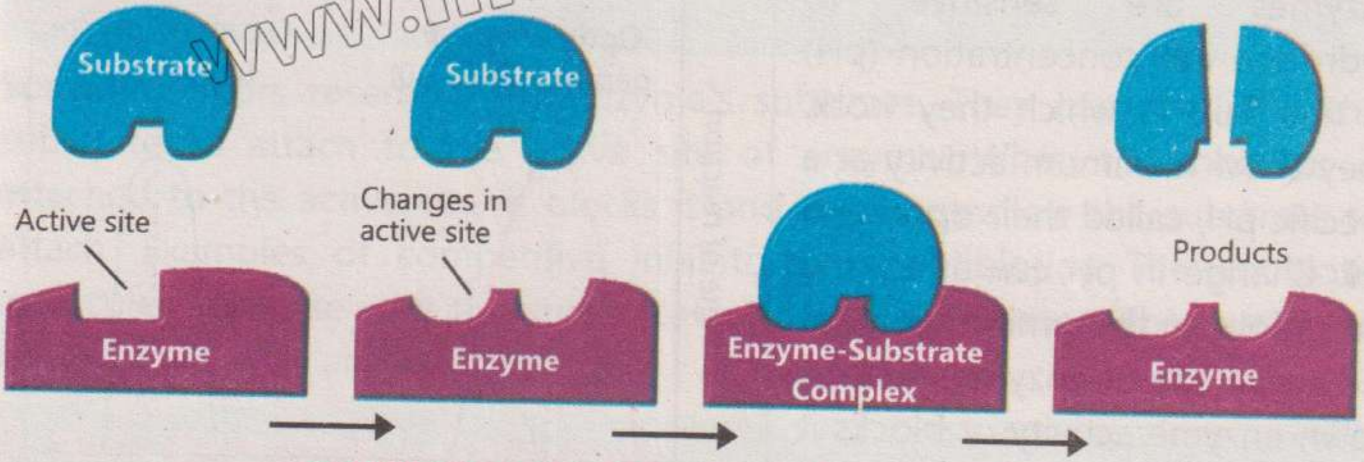


FIGURE 7.4: Induced fit model of enzyme action

7.4- Factors that Affect the Activity of Enzymes

Enzymes are sensitive to their environment. The activity of an enzyme is affected by the following factors:

1. Temperature

Each enzyme works at maximum rate at a specific temperature called optimum temperature. The optimum temperature for most of the human enzymes is 37°C. When temperature rises to a certain limit, the heat adds in the movement of molecules. So, the rate of enzyme action increases. But when temperature is raised well above the optimum temperature, heat breaks the bonds in enzyme molecule. In this way the globular structure of enzyme is lost. This is called

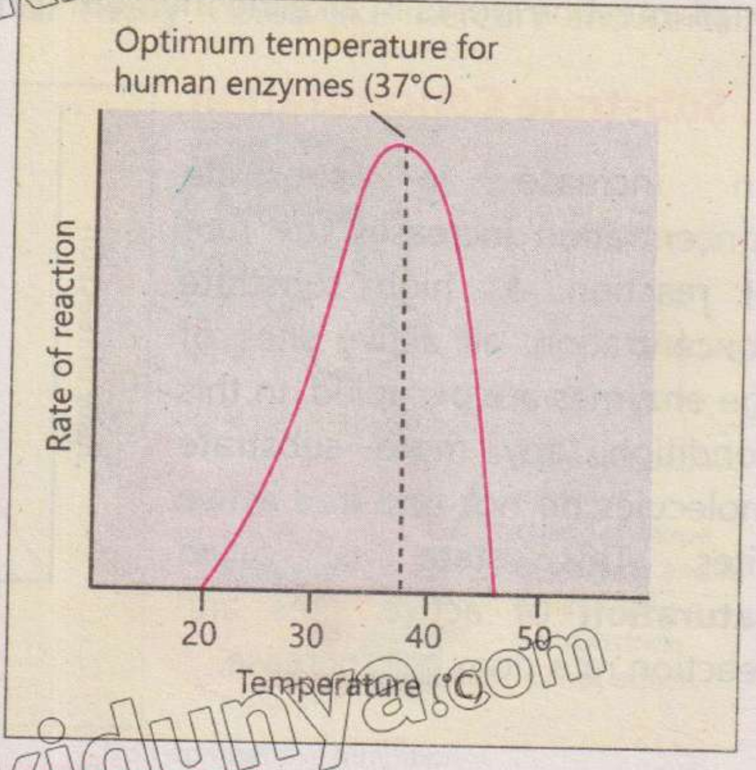


FIGURE 7.5: Effect of temperature on enzyme activity

denaturation of enzyme. It results in a rapid decrease in the rate of enzyme action.

2. pH

Enzymes are sensitive to hydrogen ion concentration (pH) of the fluid in which they work. They show maximum activity at a specific pH, called their **optimum pH**. Change in pH can affect the ionization of the amino acids at the active site of enzyme. It slows down enzyme activity or blocks it completely. Different enzymes have different optimum pH values. For example, **pepsin** in stomach works in acidic medium (pH 1.5 to 2.0) while **trypsin** in small intestine works in alkaline medium (pH 7 to 8).

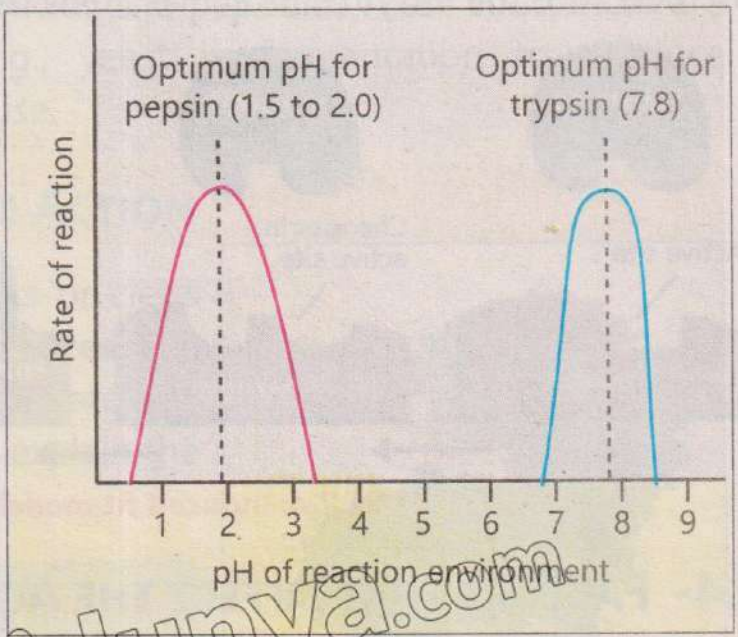


FIGURE 7.6: Effect of pH on enzyme activity

3. Substrate Concentration

An increase in substrate concentration increases the rate of reaction. At high substrate concentration, all active sites of the enzymes are occupied. In this condition, any more substrate molecules do not find free active sites. This state is called **saturation** of active sites and reaction rate does not increase.

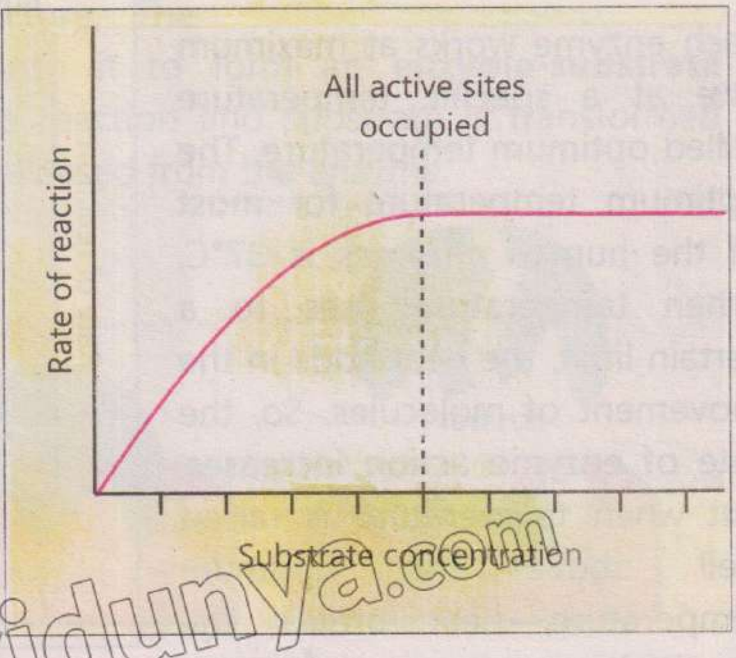


FIGURE 7.7: Effect of substrate concentration on enzyme activity

7.5- Enzyme Inhibition

Certain substances, called enzyme inhibitors, bind to enzyme and decrease its activity. This phenomenon is known as enzyme inhibition.

1. Competitive Inhibition

Some inhibitors resemble the enzyme's substrate. They compete with the substrate to attach to the active site of enzyme. When the inhibitor is attached to the active site, it blocks it and does not allow the substrate to attach. Examples of competitive inhibitors are antibiotics. The antibiotic molecules compete with the substrates of bacterial enzymes. They attach to bacterial enzymes and inhibit them.

2. Non-Competitive Inhibition

Some enzyme inhibitors do not have similarity to the substrate. They do not attach to the active site of enzyme. Rather, they attach to some other location of enzyme. This attachment changes the overall shape of enzyme and also the shape of active site. So, this changed active site does not fit substrate and enzyme is inhibited. Examples include heavy metals like mercury and certain drugs used in cancer therapy.

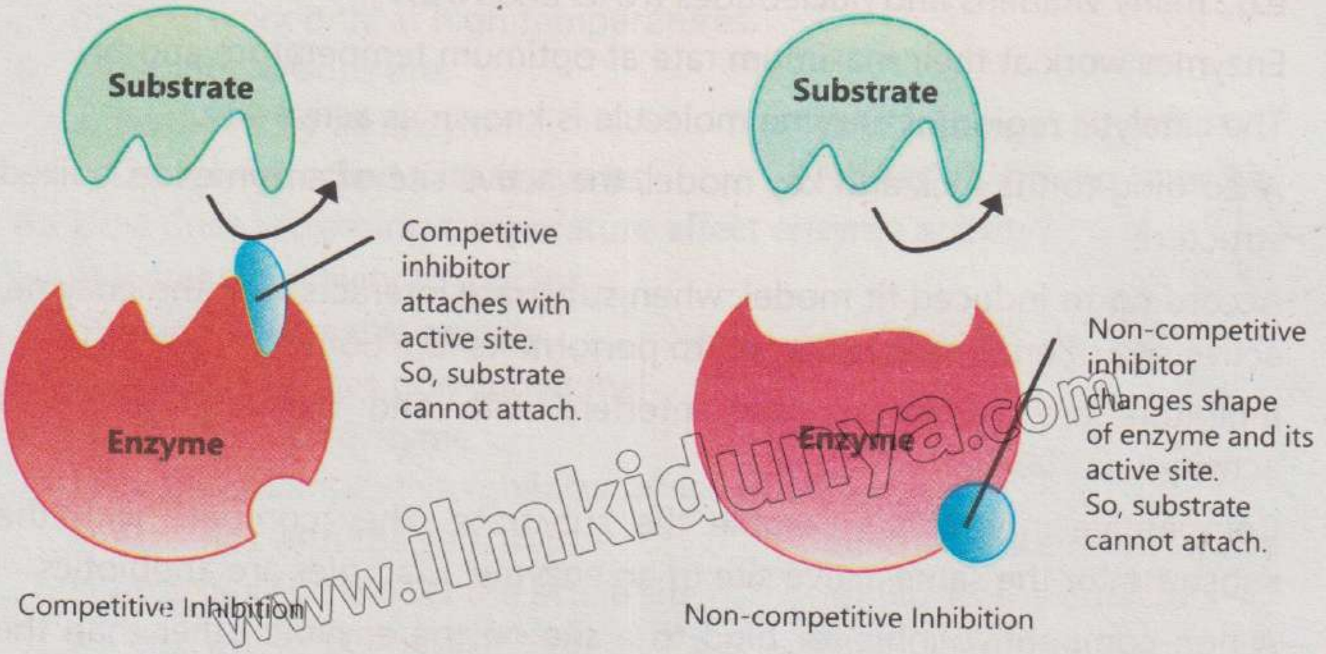


FIGURE 7.8: Types of enzyme inhibition

KEY POINTS

- The biochemical reactions occurring in living organisms are called metabolism.
- In anabolism, small molecules combine to form large molecules. In catabolism, larger molecules are broken down into smaller molecules.
- Enzymes are proteins that catalyze (i.e. speed up) biochemical reactions.
- Enzymes are highly specific to the reactions and also for the substrate.
- Intracellular enzymes operate within cells e.g., enzymes of cellular respiration.
- Extracellular enzymes are secreted outside the cells to catalyse reactions e.g., enzymes working in stomach cavity for the digestion of food.
- Cofactors are the non-protein molecules required by enzymes to be fully active.
- Inorganic cofactors include metal ions like iron and magnesium ions.
- The organic cofactors are of two types.
- Prosthetic groups are the organic cofactors which tightly bind with the enzymes e.g., certain vitamins (e.g., biotin) and the haem group .
- Coenzymes are the organic cofactors which loosely bind to the enzyme e.g., many vitamins and nucleotides (NAD and NADP).
- Enzymes work at their maximum rate at optimum temperature and pH.
- The catalytic region of enzyme molecule is known as active site.
- According to the lock and key model, the active site of enzyme has a fixed structure.
- According to induced fit model, when substrate interacts with the enzyme, active site of enzyme is reshaped to perform its function.
- Inhibitors are substances that interfere with and block an enzyme's activity.
- Competitive inhibitors resemble the substrate. They compete with the substrate for the same active site of an enzyme. Examples are antibiotics.
- A non-competitive inhibitor bind to a site on the enzyme other than the active site. Examples are heavy metals and certain drugs used in cancer therapy.

EXERCISE

A. Select the correct answers for the following questions.

1. Primarily, all enzymes are;
   a) Nucleic acids b) Proteins
   c) Carbohydrates d) Lipids
2. Which best defines an enzyme?
   a) A chemical that breaks down food.
   b) A hormone that regulates metabolism.
   c) A protein that speeds up reactions.
   d) A molecule that stores energy.
3. What can happen if an enzyme is exposed to temperature that is higher than its optimal temperature?
   a) Enzyme activity rate will increase.
   b) Enzyme's shape will change, potentially reducing its activity.
   c) Enzyme will speed up the reaction and remain stable.
   d) Enzyme will become a substrate itself.
4. Enzymes are specific in their action because:
   a) Their active sites fit specific substrates.
   b) They are always proteins.
   c) They are consumed in reactions.
   d) They work only at high temperatures.
5. Prosthetic groups are;
   a) Required by all enzymes. b) Proteins in nature.
   c) Loosely attached with enzymes. d) Tightly bound to enzyme.
6. How does increasing temperature affect enzyme activity?
   a) Increases activity to a point
   b) Always decreases activity
   c) Makes enzymes non-functional
   d) No effect on enzyme
7. How does competitive inhibitor affect enzyme action?
   a) Attaches with the substrate. b) Changes enzyme shape.
   c) Attaches and blocks the active site. d) Blocks the cofactors.
8. An enzyme works best at a pH of 7.4. It is placed in an acidic solution with a pH of 4.0. How will this affect the enzyme?
   a) The active site will be modified, reducing substrate binding.

b) The enzyme will catalyse reactions faster due to increased H ions.

c) The enzyme will gain additional active sites.

d) The substrate will become inactive in an acidic environment.

9. What is TRUE according to the induced fit model of enzyme action?

a) Enzyme's active site changes shape to bind the substrate.

b) Substrate changes shape to bind to active site.

c) No shape changes occur in active site or substrate.

d) Substrate attaches the enzyme at a site other that active site.

10. What is TRUE about the optimum pH values of the following enzymes of digestive system?

a) Pepsin works at low pH while trypsin works at high pH

b) Both work at high pH

c) Both work at low pH

d) Pepsin works at high pH while trypsin works at low pH

B. Write short answers.

1. Define metabolism. Differentiate between catabolism and anabolism.
2. Which type of metabolism demands input of energy? Give an example.
3. Define an enzyme. What is its role in metabolism?
4. What is the active site of enzyme? State its importance in enzyme specificity.
5. Provide an example of a specific enzyme-substrate pair.
6. What is the effect of substrate concentration on enzyme activity?
7. Provide two examples of enzymes that operate optimally at specific pH.
8. What do you mean by optimum temperature and pH?
9. Which type of enzyme inhibitors inhibit the enzymes without attaching to the active site?
10. Differentiate between competitive and non-competitive inhibition.

C. Write answers in detail.

1. Describe the characteristics of enzymes.
2. Describe how temperature extremes can inhibit enzyme activity and lead to enzyme denaturation.
3. How does pH affect enzyme activity?
4. Describe the factors that affect the activity of enzymes.
5. Compare the Lock-and-Key and Induced Fit models of enzyme action.