SLO 6: Enzymes

6.1 Characteristics of Enzymes

6.1.1 Define Metabolism

Thousands of chemical reactions take place in the body of an organism. These reactions of an organism are collectively called metabolic reactions and this phenomenon of chemical activity called metabolism.

6.1.2 Compare Catabolic And Anabolic Reactions

	Catabolic Reactions	Anabolic Reactions
Definition	The destructive reaction in which large molecules breakdown in small molecules to produce energy or to re-utilize further or to discard called catabolic reactions. The type of this metabolic activity is called catabolism.	In constructive reactions large molecules are formed to form a structure of cell or body. These reactions are called anabolic reactions and this type of metabolism is called anabolism.
Energy Requirement	These reactions release energy (usually in the form of ATP) when chemical bonds are broken.	These reactions require an input of energy (utilize ATP) to form new chemical bonds.
Molecular Changes	Large polymers (like starch) are converted into smaller monomers (like glucose).	Small monomers (like amino acids) are linked together to form large polymers (like proteins).
Significance	It provides the necessary energy (ATP) for all cellular activities and supplies raw materials for other reactions.	It is essential for growth, repair, and maintenance of tissues and the storage of energy for future use.
Example	Cellular Respiration: The breakdown of glucose into and to release energy.	Photosynthesis/Protein Synthesis: Building glucose from and water, or building muscle from amino acids.

6.1.3 Describe The Role Of Enzymes As Biological Catalysts

Inside human body normal temperature remain 37 C and pressure is 120/80 mm of Hg. These conditions of temperature and pressure are not enough to perform any chemical reactions. Each reaction requires some amount of minimum energy to initiate a reaction. This minimum amount of energy is called activation energy.

If this amount is high the difficult will be the reaction or vice versa e.g. the activation energy needed to break a glucose molecule initially requires energy of 2 ATP molecules. The high amount of activation energy cannot be provided by organism itself therefore they require some facilitators to reduce this activation energy. These facilitators are special molecules made up of mostly protein called enzymes (En=inside, zyme = yeast).

Enzyme are defined as the biocatalyst which facilitate chemical reaction by lowering activation energy. This action of enzyme allows biological reaction to proceed rapidly at relatively low temperature and pressure tolerable by living organism.

6.1.4 Explain The Key Characteristics Of Enzymes

High Specificity

Enzymes are extremely picky. A protease will never break down starch, and amylase will never break down protein. This is due to the unique 3D shape of the Active Site. The active site's geometry and charge are complementary only to a specific substrate. If the shape of the enzyme changes, it loses its specificity because the "key" (substrate) no longer fits the "lock" (active site).

Reusability

Enzymes are not consumed or "used up" in a chemical reaction. Once a reaction is complete, the enzyme releases the products and remains chemically unchanged. It is immediately ready to bind with a new substrate molecule. This is why the body only needs small concentrations of enzymes; a single enzyme molecule can catalyze thousands of reactions per second.

Sensitivity to Environment

Enzymes are made of proteins, which makes them highly sensitive to their surroundings. Even a small change can stop them from working. The heat breaks the hydrogen bonds holding the protein shape, permanently destroying the active site. Similarly, drastic changes in pH can change the charges on the amino acids at the active site, preventing the substrate from binding.

6.1.5 Compare The Functioning Of Enzymes With Inorganic Catalysts

Specificity

Enzymes (Organic)	Catalyst (Inorganic)
Enzymes are highly Specific, "one enzyme, one reaction".	A single inorganic catalyst can speed up many different reactions.
They have a complex 3D Active Site that only fits one specific substrate shape.	Inorganic catalysts work based on surface area and simple chemical affinity, not complex geometry.
Salivary Amylase only acts on starch; it cannot digest proteins.	Platinum (Pt) or Nickel (Ni) can catalyze dozens of different hydrogenation or oxidation reactions.

Reaction Conditions

Enzymes (Organic)	Inorganic Catalysts
Require Mild Temperatures (e.g., 37°C). High heat causes denaturation.	Can operate at Very High Temperatures and pressures without breaking down.
Highly sensitive; they work only within a narrow Optimum pH range.	Generally independent of pH or can work in highly acidic/basic environments.
Extremely fast; they can increase rates by millions of times under physiological conditions.	Generally slower than enzymes unless extreme heat/pressure is applied.

6.1.6 Define Cofactors

A Cofactor is a non-protein chemical component that is required by an enzyme for its biological activity. It acts as a "helper molecule" that binds to the enzyme to make it functional. A cofactor may be organic or inorganic.

6.1.7 Differentiate Between The Main Types Of Cofactors:

Metal Ions (Activators):

These are metal ions like Zn^{+2}, Mg^{+2}, Mn^{+2}, Fe^{+2}, Cu^{+2}, K^{+1} and Na^{+1}. They often help to stabilize the enzyme structure or help the substrate bind to the active site.

Prosthetic Groups (Organic):

These are organic molecules that are permanently and tightly bound to the enzyme. For example, the Heme group in the enzyme catalase (which breaks down hydrogen peroxide).

Co-enzymes (Organic):

These are non-protein organic molecules that are loosely and temporarily attached to the enzyme. They often act as "carriers," moving chemical groups or electrons from one enzyme to another. Many Vitamins (like Vitamin B complex derivatives) or NAD, NADP, FAD are examples.

6.1.8 Exemplify That Cofactors Assist Enzymes In Facilitating Biochemical Reactions

DNA Polymerase (used in DNA replication).

- The Cofactor: Magnesium ions.
- How it assists: The ions bind to the active site and help position the incoming nucleotides and the DNA template. Without these ions, the enzyme cannot maintain the correct electrical charge to catalyze the bond between DNA bases.

Dehydrogenases (used in Cellular Respiration).

- The Cofactor: NAD (Nicotinamide Adenine Dinucleotide, derived from Vitamin B3).
- How it assists: During the breakdown of glucose, the enzyme needs to remove hydrogen atoms. The enzyme itself cannot hold these hydrogens; instead, it hands them over to NAD. NAD acts as a temporary "shuttle bus" to carry these hydrogens to the mitochondria to produce ATP.

Catalase

- The Cofactor: Heme (an iron-containing organic group).
- How it assists: Catalase's job is to turn toxic Hydrogen Peroxide into water and oxygen. The Heme group sits at the heart of the enzyme. Its iron atom is the specific spot where the H_2O_2 is pulled in and split apart. Without the Heme group, the protein part of Catalase is just a useless string of amino acids.

6.1.9 Compare Intracellular And Extracellular Enzymes

There are TWO categories of enzymes: intracellular and extracellular. Intracellular enzymes work inside the cell such as ATPase, cytochrome C reductase etc. and extracellular enzymes work outside the cells such as pepsin, lipase etc.

6.2 Factors Affecting Activity of Enzymes

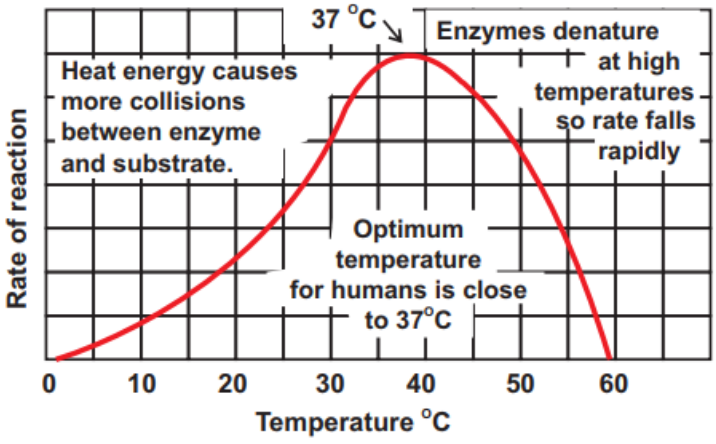
Activity of enzymes can be enhanced by activator and can be decreased by inhibitors. An enzyme inhibitor is a molecule that binds to an enzyme and decreases its activity. Since blocking an enzyme's activity can kill a pathogen.

6.2.1 Assess Impact of Varying Temperatures On Rate Of Enzyme-Catalyzed Reactions

The protein nature of the enzymes makes them extremely sensitive to thermal changes. Enzyme activity occurs within a narrow range of temperatures compared to ordinary chemical reactions. Enzymes catalyze by randomly colliding with substrate molecules, increasing temperature and increases collision which also increases the rate of reaction, forming more product.

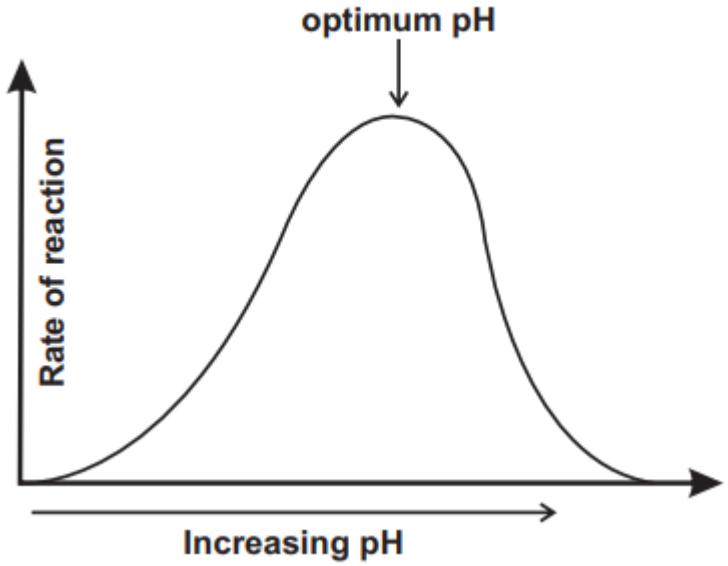
However, increasing temperature also increases the vibrations and structure of enzymes is lost i.e. denature enzyme. These changes decrease the rate of enzyme action or it may seized completely.

In summary, as temperature increases, initially the rate of reaction will increase, because of increased kinetic energy. However, the effect of bond breaking will become greater and greater, and the rate of reaction will begin to decrease.



6.2.2 Illustrate The Effect Of pH On Enzyme Activity

Enzymes are also sensitive to pH due to their protein nature. All enzymes work at their maximum rate at narrow range of pH. The point where the enzyme is most active is known as optimum pH. For example, pepsin works at a low pH i.e. it is highly acidic, while trypsin works at a high pH i.e. it is basic. Most enzymes work at neutral pH 7.4.



Small changes in pH above or below the optimum do not cause a permanent change to the enzyme, since the bonds can be reformed. However, extreme changes in pH can cause enzymes to denature and permanently lose their function.

6.2.3 Analyze Examples Of Enzymes That Work Best At Specific pH Levels

Stomach:

- Pepsin: This enzyme breaks down proteins into smaller polypeptides. It only becomes active in acidic conditions. If the pH rises above 5, Pepsin denatures.
- Renin (in infants): This enzyme curdles milk (converting liquid protein to semi-solid) so it stays in the stomach longer for digestion. Like pepsin, it requires the low pH of the stomach to function.

Amylase:

- Salivary Amylase: Digestion begins in the mouth. Amylase breaks down starch into maltose. It works best at a near-neutral pH. When we swallow food, the Amylase stops working once it hits the stomach because the high acidity there denatures it.
- Pancreatic Amylase (pH 7.5 – 8.5): Completes the starch digestion that was started in the mouth.

Small Intestine:

- Trypsin (pH 7.5 – 8.5): A protease that continues protein digestion. Unlike Pepsin, Trypsin would be destroyed in the stomach; it requires a basic pH to stay active.
- Lipase (pH 7.5 – 8.5): This enzyme breaks down fats (lipids) into fatty acids and glycerol. It requires an alkaline medium and the presence of bile to work efficiently.

The Cell

- Catalase: Found in almost all living cells (especially in the liver). Its job is to break down toxic Hydrogen Peroxide into water and oxygen. Since the cytoplasm of a cell is generally neutral, Catalase has an optimum pH of approximately 7.0.

6.2.4 Analyze The Relationship Between Rate Of Enzyme-Catalyzed Reactions And Substrate/ Enzyme Concentrations

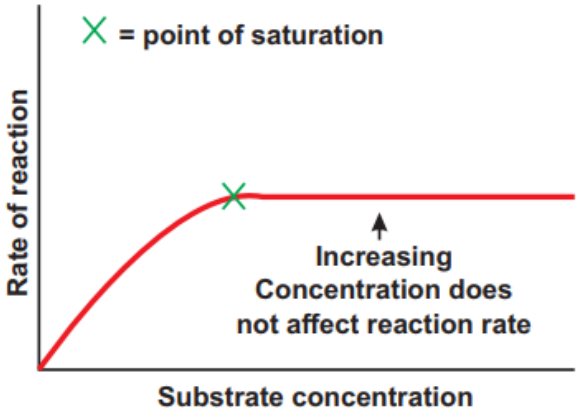
If the amount of enzyme is kept constant and the substrate concentration is then gradually increased, the reaction velocity will increase until it reaches a maximum after which further increase in the substrate concentration produces no significant change in the reaction rate.

In other words, the enzyme molecules are saturated with substrate. The excess substrate molecules cannot react until the substrate already bound to the enzymes has reacted and been released (or been released without reacting).

6.2.5 Evaluate The Progression Of Enzyme-Catalyzed Reactions By Measuring Changes In The Concentrations Of Reactants And Products Over Time

To evaluate the progress of an enzyme-catalyzed reaction, we can monitor two variables:

1. **Disappearance of Substrate (Reactant):** Measuring how fast the starting material is used up.
   Example: Measuring the decrease in Starch concentration using Iodine (the blue-black color fades).
2. **Appearance of Product:** Measuring how fast the final material is created.
   Example: Measuring the volume of Oxygen gas produced when Catalase breaks down Hydrogen Peroxide.



6.3 Mechanism of Enzyme Action

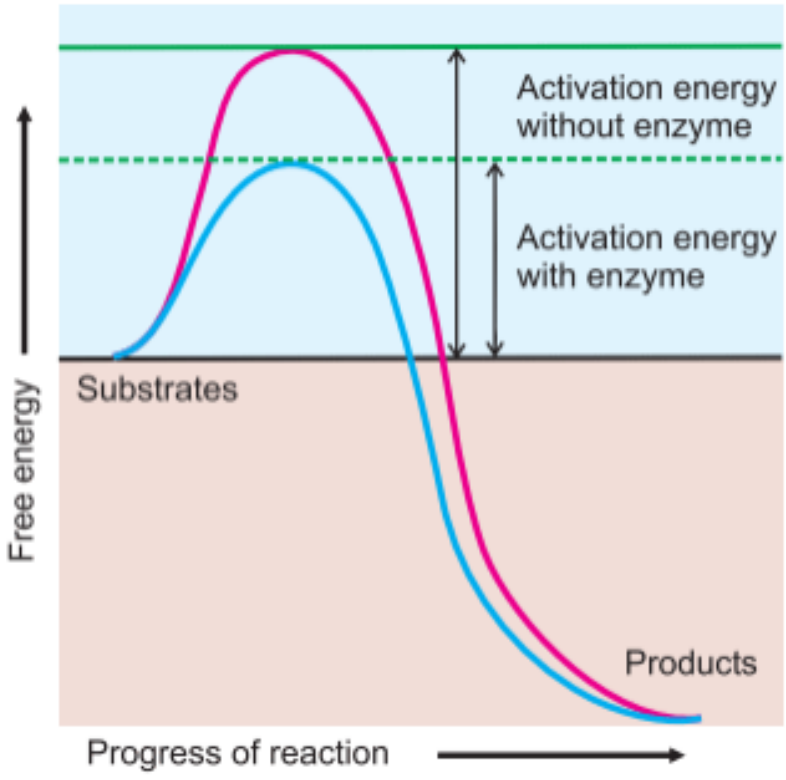
6.3.1 Define 'Activation Energy' Of Chemical Reaction

All chemical reactions require activation energy. It is defined as minimum energy required to start a reaction.

6.3.2 Analyze Graphs Showing Activation Energy Of Biochemical Reactions With And Without Enzymes

Enzymes lower the activation energy in several ways. They may alter the shape of substrate and reduce the requirement of energy for this change. Some enzymes do so by disrupting the charge distribution on substrates. Enzymes may also lower activation energy by bringing substrates in the correct orientation to react.

Enzymes can be categorized on the basis of the site where they work i.e., they may be intracellular enzymes (e.g. enzymes of glycolysis working in the cytoplasm) or may be extracellular enzymes (e.g. pepsin enzyme working in the stomach cavity).

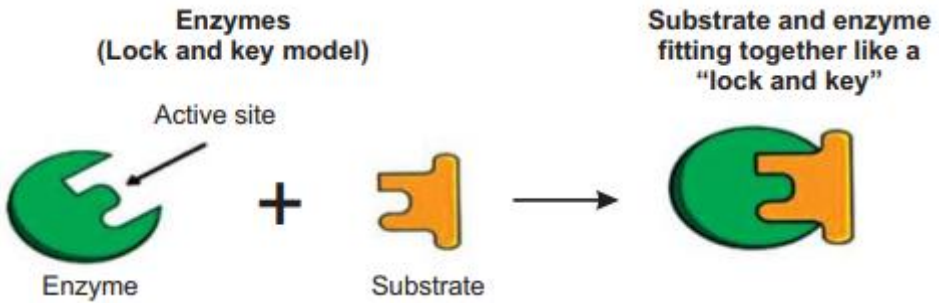


6.3.3 Illustrate The Mechanism Of Enzyme Action

The Lock and Key Model (Emil Fischer, 1894)

The Active Site is a rigid, pre-defined shape. Just as a specific lock only opens with one specific key, an enzyme only accepts a substrate that perfectly matches its geometry. It claims high Specificity. If the substrate shape is even slightly different, it cannot enter the active site.

Limitation: It does not explain how the enzyme actually "stresses" the bonds of the substrate to break them.



The Induced-Fit Model (Daniel Koshland, 1958)

The Active Site is flexible, not rigid. As the substrate approaches, the active site undergoes a slight conformational change (it "molds" or "handshakes") to wrap more tightly around the substrate. This "tight hug" puts physical stress on the bonds of the substrate, making them easier to break (lowering activation energy) like a glove changing shape slightly to fit a hand.