Unit 2 - What Chemical Processes Support Life:

Chapter 2

GLOBAL CONTEXT – *Scientific and technical innovation*

STATEMENT OF INQUIRY

*The **systems** of life are supported by biochemical reactions and the **transformations** of energy that occur within cells. **Innovations** in science could lead to these reactions being utilised to meet growing energy and food needs.*

STUDENT PROGRESS

Self-assess before and after each subtopic.

What chemical processes support life?

Subtopic	Self 😊😐😕	Objectives	Self 😊😐😕	Peer ✓
Metabolism		• Define the term: metabolism • Distinguish between anabolic and catabolic reactions • Discuss the factors affecting rates of reaction • Compare examples of anabolic and catabolic reactions		
Respiration		• State the word and balanced chemical equation for aerobic respiration • State the word equation for anaerobic respiration • Label the structure of a mitochondrion and describe the functions of the parts • Outline the process of respiration (SL DP) • Compare aerobic and anaerobic respiration • Suggest uses of anaerobic respiration in industry		
Photosynthesis		• Define photosynthesis • State the word and balanced chemical equation for photosynthesis • Discuss the limiting factors that affect the rate of photosynthesis – CO2 concentration, light intensity and temperature • Draw and label the structure of a leaf • Sketch graphs to show the effect of limiting factors on photosynthesis • Design an investigation to measure the rate of photosynthesis		
Enzymes		• Define the terms: catalyst, kinetic energy, limiting factor, energy transfer, yield , active site • Describe the structure and function of enzymes • Explain what is meant by the lock and key theory • Discuss why the induced fit model is now used to describe the lock and key theory • Distinguish between substrate, enzyme, product and enzyme-substrate complex • Outline limiting factors of enzyme activity • List 3 enzymes that function within the human body		

Checked by peer ☐ **Checked by teacher** ☐	**Extension toward DP level** • Draw a molecular diagram of a glucose molecule • Describe the 4 stages of aerobic respiration • Sketch an absorption spectra for chlorophyll and discuss why this is important • Discuss the production and advantages of producing lactose-free milk

APPROACHES TO LEARNING UTILISED (highlight ATLs applicable)

Thinking **Social** **Communication** **Self-Management** **Research**

Metabolism:

Metabolism encompasses the chemical reactions in organisms to convert food into energy for cellular functions and tissue repair. It involves the breakdown of molecules for energy release and the synthesis of molecules for growth and maintenance.

Anabolic and Catabolic Reactions:

Video:https://www.youtube.com/watch?v=onDQ9KgDSVw

Anabolic reactions involve the synthesis of complex molecules from simpler ones, requiring energy input. These reactions build larger molecules essential for growth and repair, such as protein synthesis.

Catabolic reactions, on the other hand, involve the breakdown of complex molecules into simpler ones, releasing energy. These reactions degrade large molecules into smaller ones, such as the breakdown of glucose during cellular respiration.

Factors Affecting Rate of Reactions:

Video:https://www.youtube.com/watch?v=5qoK6JZqw-w

Several factors influence the rate of metabolic reactions:

1. **Enzymes**: Biological catalysts that speed up chemical reactions. Enzyme activity is influenced by factors such as temperature, pH, and substrate concentration.
2. **Temperature**: Metabolic reactions generally occur faster at higher temperatures due to increased molecular motion. However, excessively high temperatures can denature enzymes, reducing reaction rates.
3. **pH**: Enzymes have optimal pH ranges for activity. Deviation from this range can alter enzyme structure, affecting their ability to catalyze reactions and thus impacting metabolic rate.

4. **Substrate Concentration**: Increasing substrate concentration generally increases the reaction rate until all enzyme active sites are saturated, after which further increases do not affect the rate.
5. **Presence of Inhibitors**: Molecules that bind to enzymes, either blocking their active sites (competitive inhibitors) or altering enzyme shape (non-competitive inhibitors), thereby slowing down metabolic reactions.
6. **Hormones**: Regulatory molecules that can influence metabolic rate by affecting enzyme activity or substrate availability. For example, thyroid hormones can increase metabolic rate.
7. **Genetic Factors**: Individual variations in enzyme structure and function can affect metabolic rate. Genetic disorders or mutations may lead to abnormal metabolic rates.
8. **Physical Activity**: Exercise increases metabolic rate as cells require more energy to perform work. Regular physical activity can also enhance metabolic efficiency.
9. **Nutritional Status**: The availability of nutrients, vitamins, and minerals required for metabolic reactions can influence metabolic rate. Deficiencies or excesses can disrupt metabolic processes.
10. **Age**: Metabolic rate typically decreases with age due to factors such as loss of muscle mass and decreased hormone production.

Anabolic and Catabolic Reactions:

Anabolic Reactions:

1. **Protein Synthesis**: Anabolic reactions build proteins from amino acids, requiring energy input. For example, ribosomes in cells synthesize proteins from amino acids, facilitated by enzymes and energy from ATP.
2. **Photosynthesis**: In plants, anabolic reactions occur during photosynthesis, where carbon dioxide and water are converted into glucose (a complex carbohydrate) and oxygen using energy from sunlight. This process involves multiple enzymatic steps and is essential for plant growth.

3. **Glycogenesis**: Anabolic reactions in the liver and muscles build glycogen (a storage form of glucose) from glucose molecules. This process occurs when blood glucose levels are high, and excess glucose is stored for later use.

Catabolic Reactions:

1. **Cellular Respiration**: Catabolic reactions break down glucose (a complex carbohydrate) into simpler molecules such as carbon dioxide and water, releasing energy. Cellular respiration occurs in mitochondria and involves glycolysis, the citric acid cycle, and oxidative phosphorylation.
2. **Digestion**: Catabolic reactions occur during digestion, where complex nutrients such as proteins, carbohydrates, and fats are broken down into smaller molecules that can be absorbed by cells. Enzymes in the digestive system catalyze these reactions.
3. **Glycolysis**: In glycolysis, a catabolic pathway, glucose molecules are broken down into pyruvate, producing ATP and NADH as energy carriers. This process occurs in the cytoplasm and is the first step in both aerobic and anaerobic respiration.

In summary, anabolic reactions involve the synthesis of complex molecules from simpler ones, requiring energy input, while catabolic reactions involve the breakdown of complex molecules into simpler ones, releasing energy. These processes are essential for maintaining cellular function and energy balance in living organisms.

Respiration:

Video:https://www.youtube.com/watch?v=eJ9Zjc-jdys

Aerobic Respiration:

Aerobic respiration is a cellular process that occurs in the presence of oxygen, breaking down glucose to release energy. This energy is used to produce ATP, vital for cell functions.

Word Equation:
Glucose + Oxygen → Carbon Dioxide + Water + Energy (ATP)

Balanced Chemical Equation:
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Energy (ATP)

Video:https://www.youtube.com/watch?v=ZkqEno1r2jk

Anaerobic Respiration:

Anaerobic respiration is a cellular process occurring without oxygen, where glucose is partially oxidized to release energy. It produces less ATP than aerobic respiration and may result in byproducts like lactic acid or ethanol.

The word equation for anaerobic respiration is:

Glucose → Lactic Acid (in animals) or Ethanol + Carbon Dioxide (in plants and some microorganisms) + Energy (ATP)

The chemical equation for anaerobic respiration in animals is:

Glucose → 2 Lactic Acid + Energy (ATP)

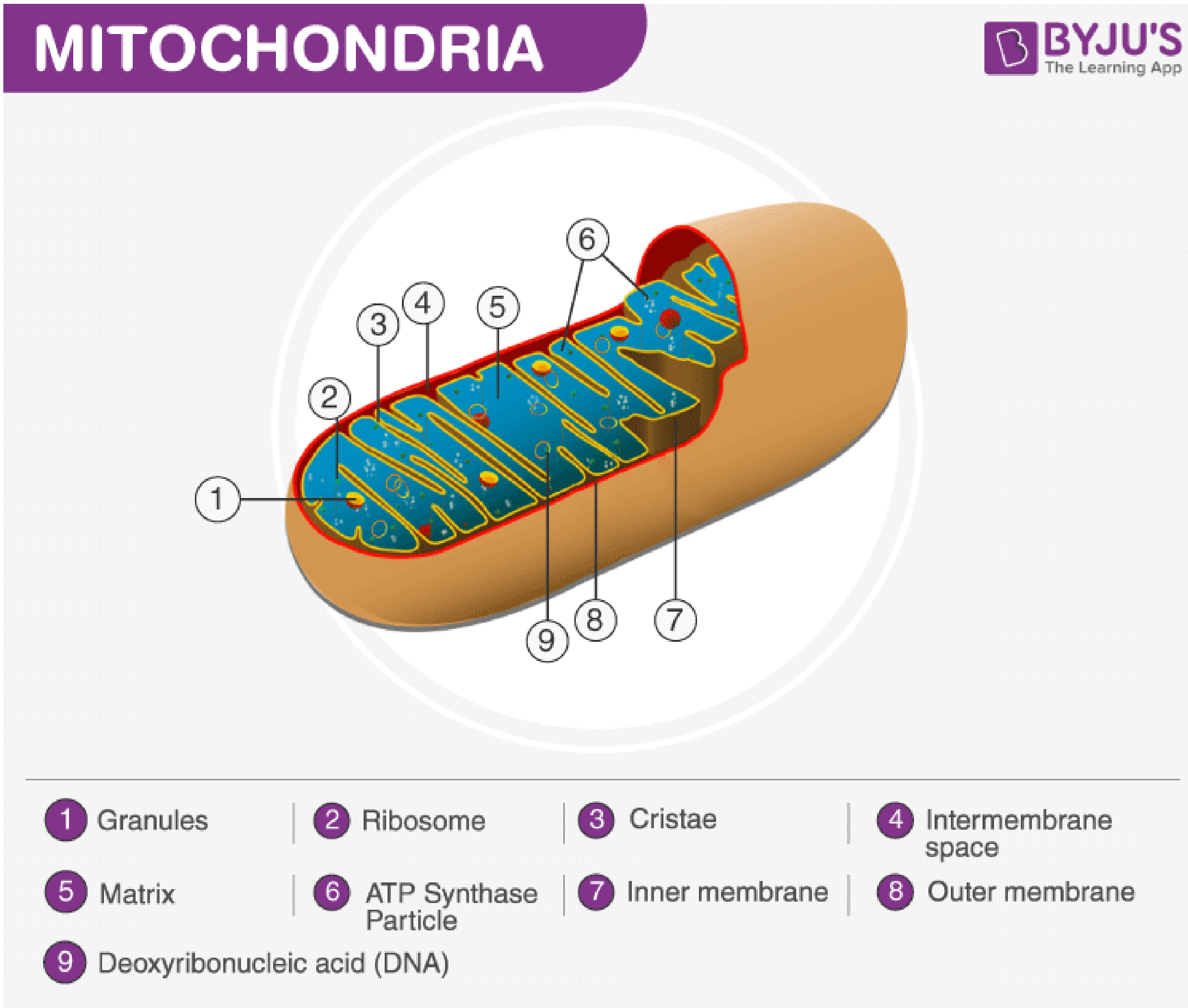
The chemical equation for anaerobic respiration in plants and some microorganisms (such as yeast) is:

Glucose → 2 Ethanol + 2 Carbon Dioxide + Energy (ATP)

Video:https://www.youtube.com/watch?v=HZtXLhm7ISA

Mitochondrion:

Mitochondria are known as the powerhouses of the cell. It is involved in different cellular activities like respiration, differentiation, cell signalling, cell senescence, controlling the cell cycle, cell growth, and other metabolic activities of the cell. They are rod-shaped, a double-membraned organelle found both in the plant as well as animal cells.



Matrix:

It is a viscous or gel-like fluid containing a mixture of enzymes, ribosomes, inorganic ions, mitochondrial DNA, nucleotide cofactors, and organic molecules. It is involved in cellular respiration and the production of ATP molecules.

Cristae:

The inner layer, surrounded by the folds of the mitochondrial matrix, is collectively referred to as Cristae. These inner membranes increase the surface area of the inner membrane and have different roles in cellular respiration, generation of ATP molecules- the energy currency of the cell and other chemical reactions.

Ribosomes:

The ribosomes found within the mitochondria are called the mitochondrial ribosome or mitoribosome. It is a protein complex which functions by translating mitochondrial mRNAs encoded in mtDNA.

Inner membrane:

The inner mitochondrial membrane holds proteins and functions by permitting the entry of only the selected molecules. Therefore they are also called special membrane transporters.

Outer membrane:

The outermost layer of the Mitochondria holds proteins called porins and forms channels that allow the movement of proteins across the inner and outer membrane of mitochondria. It also holds several enzymes with a wide variety of functions.

Intermembrane Space:

This is the area between the inner and outer membranes. It is subdivided into two distinct sub-compartments: the intra-cristae space and the lumen. Both are separated by tubular structures measuring 10 to 40nm in diameter called the cristae junctions. The Intermembrane space is mainly involved with the transportation, modification of protein coordinates, apoptosis, and also in regulation of the respiratory chain complexes.

Process:

Video:https://www.youtube.com/watch?v=GjfD55C9v38

1. **Glycolysis**:
    - Location: Cytoplasm
    - Glucose is broken down into two molecules of pyruvate.
    - ATP and NADH are produced.
    - Oxygen is not required.
2. **Pyruvate Oxidation**:
    - Location: Mitochondrial matrix

- Pyruvate is transported into the mitochondria.
- It is converted to acetyl-CoA.
- CO_2 is released, and NADH is produced.

3. **Citric Acid Cycle (Krebs Cycle)**:
   - Location: Mitochondrial matrix
   - Acetyl-CoA combines with oxaloacetate to form citrate.
   - Citrate is broken down, releasing CO_2 and producing NADH, $FADH_2$, and ATP.
   - Oxaloacetate is regenerated to continue the cycle.
4. **Electron Transport Chain (ETC)**:
   - Location: Inner mitochondrial membrane
   - NADH and $FADH_2$ donate electrons to the ETC.
   - Electrons are passed through a series of protein complexes, generating a proton gradient across the membrane.
   - ATP synthase uses the proton gradient to produce ATP via oxidative phosphorylation.
   - Oxygen serves as the final electron acceptor, combining with protons to form water.
5. **Chemiosmosis**:
   - ATP synthesis driven by the flow of protons back across the inner mitochondrial membrane through ATP synthase.
   - ATP is produced from ADP and inorganic phosphate.

Anaerobic vs. Aerobic Respiration:

Aerobic Respiration	**Anaerobic Respiration**
Oxygen is present when this form of respiration takes place.	Oxygen is absent when this form of respiration takes place.

Gases are exchanged in this form of respiration.	Gases are not exchanged in this form of respiration.
It can be found in the cytoplasm and the mitochondria.	It can be found only in the cytoplasm.
Glucose breaks down into carbon dioxide and water.	Glucose breaks down into ethyl alcohol, carbon dioxide, and energy.
All higher organisms such as mammals have this type of respiration.	Lower organisms such as bacteria and yeast use this type. In other organisms, it occurs during heavy activities.

Possible Uses of Aerobic Respiration in Industries:

- **Food and Beverage**: Anaerobic fermentation is vital in food production. For instance, bacteria ferment lactose to lactic acid in yogurt, while yeast converts sugars to alcohol in brewing. These processes create diverse flavors and textures in foods like yogurt, cheese, bread, beer, and wine.
- **Wastewater Treatment**: Anaerobic digestion breaks down organic matter in sewage, generating biogas. This renewable energy source, mainly methane, is utilized for heating, electricity, and fuel, contributing to sustainable wastewater treatment and energy production.
- **Bioenergy Production**: Anaerobic digestion converts organic waste into biogas, offering a renewable energy source. Materials like agricultural residues, food waste, and animal manure can be digested, reducing reliance on fossil fuels and promoting sustainable bioenergy production.

Photosynthesis:

Photosynthesis is the process by which green plants, algae, and some bacteria convert light energy, usually from the sun, into chemical energy stored in glucose molecules. This process occurs in chloroplasts, utilizing carbon dioxide and water, and producing oxygen as a byproduct. It is crucial for the sustenance of most life forms on Earth, forming the foundation of the food chain.

Equation:

The word equation for photosynthesis is:

Carbon dioxide + Water + Light energy → Glucose + Oxygen

The balanced chemical equation for photosynthesis is:

$6CO_2 + 6H_2O$ + light energy → $C_6H_{12}O_6 + 6O_2$

Factors limiting Rate of Photosynthesis:

Several factors can limit the rate of photosynthesis:

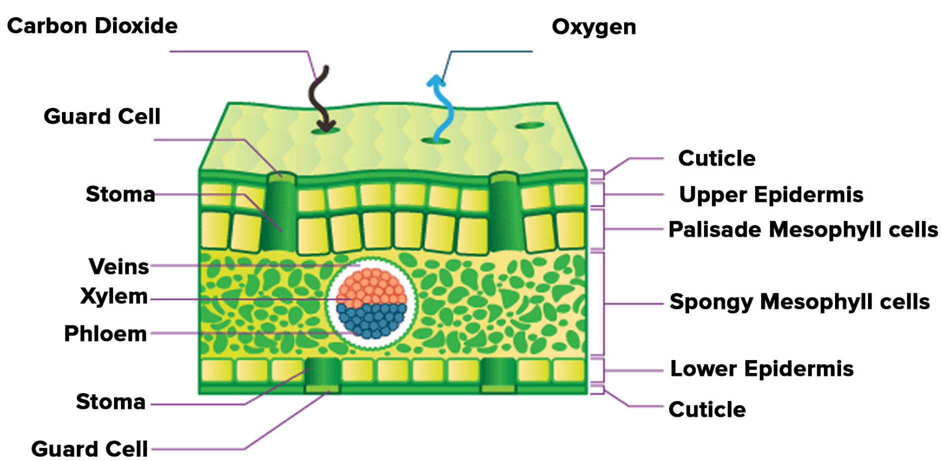
1. **Light Intensity**: Insufficient light can limit the rate of photosynthesis, as it's the primary energy source driving the process. Beyond a certain point, however, increasing light intensity won't further increase the rate, as other factors become limiting.
2. **Carbon Dioxide Concentration**: CO_2 is a raw material for photosynthesis, and if its concentration is low, the rate of photosynthesis decreases. In many cases, CO_2 availability is the limiting factor, especially in environments with high temperatures.
3. **Temperature**: Photosynthesis is sensitive to temperature. Enzymes involved in the process work optimally within a certain temperature range. Extreme temperatures can denature enzymes, slowing down or halting photosynthesis.
4. **Water Availability**: Water is essential for photosynthesis, serving as a solvent and a reactant in the light-dependent reactions. Insufficient water availability can cause stomata closure, reducing CO_2 intake, and hence limiting photosynthesis.
5. **Nutrient Availability**: Plants require various nutrients like nitrogen, phosphorus, and potassium, among others, for optimal growth and photosynthesis. Deficiencies in these nutrients can limit the rate of photosynthesis.
6. **Oxygen Concentration**: High concentrations of oxygen can inhibit photosynthesis, particularly in certain environments or under conditions of

poor ventilation.

7. **pH Levels**: The pH of the environment can influence the activity of enzymes involved in photosynthesis. Extremes in pH can inhibit enzyme function, thus limiting photosynthetic activity.

These factors interact in complex ways, and the rate of photosynthesis is often determined by the most limiting factor at any given time. Understanding and managing these factors are crucial for optimizing plant growth and agricultural productivity.

Cross-Section of a Leaf:



Graphs to show Limiting Factors of Photosynthesis:

Light Intensity:

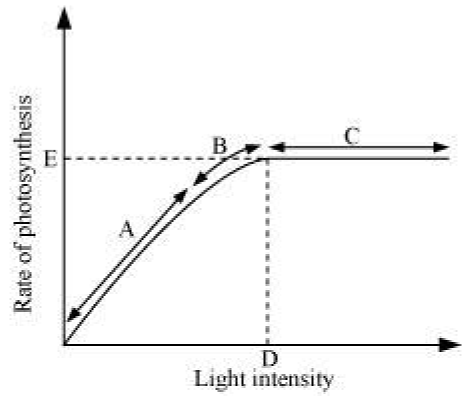
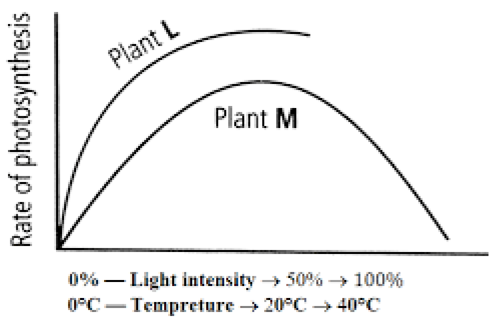


Figure 13.10

Temperature:



Investigation of Photosynthesis Experiments:

Link:https://stewartschoolctc.in/wp-content/uploads/Practical-Biology-10.pdf

Enzymes:

Key Terms:

1. **Catalyst**:
   A catalyst is a substance that speeds up the rate of a chemical reaction by

providing an alternative reaction pathway with a lower activation energy. Catalysts remain unchanged at the end of the reaction and can be reused. In biology, enzymes are examples of catalysts that facilitate biochemical reactions essential for life processes.

2. **Kinetic Energy**:
   Kinetic energy is the energy an object possesses due to its motion. It is dependent on the object's mass and velocity. In biological systems, kinetic energy is important for various processes, including the movement of molecules within cells and the transmission of nerve impulses.
3. **Limiting Factor**:
   A limiting factor is a variable that constrains or restricts the rate or extent of a process or reaction. In biological contexts, limiting factors can include environmental factors such as temperature, availability of nutrients, or other resources necessary for growth and metabolism.
4. **Energy Transfer**:
   Energy transfer refers to the movement of energy from one system or object to another. In biological systems, energy transfer occurs through various processes such as photosynthesis, cellular respiration, and metabolic pathways. These processes involve the conversion of energy from one form to another.
5. **Yield**:
   Yield refers to the amount or quantity of a product obtained from a reaction or process. In the context of energy transfer, yield can refer to the efficiency of energy conversion from one form to another. For example, the yield of ATP (adenosine triphosphate) from the breakdown of glucose during cellular respiration indicates the efficiency of energy transfer in producing usable energy for the cell.
6. **Active Site**:
   The active site is a specific region on the surface of an enzyme or other protein molecule where a substrate molecule binds and undergoes a chemical reaction. The active site possesses a complementary shape and chemical environment to the substrate, facilitating the catalytic conversion of the substrate into a product. The specificity of the active site enables enzymes to catalyze specific biochemical reactions.

Structure and Function of Enzymes:

1. **Active Site**:
   Function: This is where the substrate binds to the enzyme, allowing the enzyme to catalyze the chemical reaction by bringing the substrate molecules together and facilitating their interaction.

2. **Substrate**:
   Function: The molecule upon which the enzyme acts. It binds to the enzyme's active site, and the enzyme catalyzes its conversion into products.

3. **Cofactors and Coenzymes**:
   Function: These molecules assist the enzyme in catalyzing reactions. Cofactors are usually inorganic ions or organic molecules that are necessary for the enzyme's activity. Coenzymes are organic molecules, often derived from vitamins, that facilitate enzyme function by carrying chemical groups between enzymes.

4. **Allosteric Sites**:
   Function: These are sites on the enzyme where molecules other than the substrate can bind. Binding at allosteric sites can regulate the enzyme's activity by altering its shape, either activating or inhibiting its function.

5. **Active Site Residues**:
   Function: Specific amino acids within the active site directly participate in catalyzing the reaction. They may form temporary bonds with the substrate or stabilize reaction intermediates, ultimately facilitating the conversion of substrate into products.

Lock and Key Theory:

1. **Lock (Enzyme)**:
   Enzymes have a specific shape, just like a key. This shape is called the active site. Each enzyme is designed to fit only one specific type of molecule, its substrate, just like a key is designed to fit into a specific lock.

2. **Key (Substrate)**:
   The molecule that an enzyme works on is called the substrate. It has a shape that matches the active site of the enzyme, just like a key fits into a lock.

3. **How It Works**:
   When the substrate comes into contact with the enzyme, it fits perfectly into the enzyme's active site, just like a key fitting into a lock. This is like the "key" turning in the "lock." Once the substrate is in place, the enzyme helps to speed up the chemical reaction, converting the substrate into a product.
4. **Specificity**:
   Just as each key fits into a specific lock, each enzyme works only with a specific substrate. This specificity ensures that enzymes catalyze only the reactions they are meant to catalyze.

In summary, the lock and key theory helps us understand how enzymes interact with their substrates in a highly specific and efficient manner, much like how keys interact with locks.

Induced Model and Scignificance:

The induced fit model of enzyme-substrate interaction expands upon the traditional lock and key theory by introducing the concept of dynamic adjustments. In this model, enzymes and substrates are not static entities but rather undergo conformational changes upon binding.

Initially, the active site of the enzyme may not perfectly match the shape of the substrate. However, when the substrate binds, it induces a structural rearrangement in the enzyme, leading to a tighter fit and optimal alignment of chemical groups for catalysis. This dynamic adjustment allows for greater specificity and efficiency in catalyzing the reaction.

Furthermore, the induced fit model accounts for the flexibility of enzymes to accommodate substrates of slightly different shapes, enhancing their versatility in catalyzing various reactions. Overall, the induced fit model provides a more comprehensive understanding of enzyme-substrate interactions by incorporating the dynamic nature of these molecular interactions.

Enzyme and Substrate, Product and Enzyme-Substrate Complex:

1. **Enzyme**:
   An enzyme is a type of protein that acts as a biological catalyst, speeding up chemical reactions in living organisms. Enzymes are highly specific, each one catalyzing a particular reaction or group of closely related reactions.
2. **Substrate**:
   A substrate is a molecule upon which an enzyme acts. It binds to the active site of the enzyme, where the catalytic reaction takes place. Substrates are transformed into products during the enzymatic reaction.
3. **Product**:
   A product is the molecule or molecules formed as a result of an enzymatic reaction. It is the outcome of the transformation of substrates catalyzed by the enzyme. Products are different from substrates and may have different chemical properties.
4. **Enzyme-Substrate Complex**:
   An enzyme-substrate complex is a temporary molecular structure formed when the enzyme binds to its substrate(s) at the active site. This complex facilitates the catalytic conversion of substrates into products. The enzyme-substrate complex is an intermediate stage in the enzymatic reaction, leading to the formation of products. After the reaction is complete, the products are released, and the enzyme returns to its original state, ready to catalyze another reaction.

In summary, enzymes are proteins that catalyze chemical reactions, substrates are the molecules upon which enzymes act, products are the molecules formed as a result of enzymatic reactions, and the enzyme-substrate complex is the temporary structure formed when the enzyme binds to its substrate(s) during the catalytic process.

Limiting Factors of Enzyme Activity:

1. **Substrate Concentration**:

- Enzyme activity increases with substrate concentration until all enzyme active sites are saturated. Further increases in substrate concentration do not increase the rate of reaction.

2. **Enzyme Concentration**:
    - Limited enzyme concentration can limit the rate of reaction, as there may not be enough enzyme molecules available to bind with substrates.
3. **Temperature**:
    - Enzymes have an optimal temperature at which they work most effectively. Increasing temperature usually increases the rate of reaction, but excessively high temperatures can denature enzymes.
4. **pH Level**:
    - Enzymes have an optimal pH at which they work most effectively. Deviation from this pH can disrupt enzyme-substrate interactions and reduce enzyme activity.
5. **Inhibitors**:
    - Inhibitors can bind to enzymes and decrease their activity. Competitive inhibitors compete with the substrate for binding to the enzyme's active site, while non-competitive inhibitors bind to other parts of the enzyme, altering its shape and reducing its activity.

Enzyme Action in the Human Body:

1. **Digestion**:
   Enzymes play a crucial role in breaking down large molecules into smaller, absorbable components during the process of digestion. For example, amylase breaks down carbohydrates into sugars, proteases break down proteins into amino acids, and lipases break down fats into fatty acids and glycerol. These smaller molecules can then be absorbed by the body for energy and other essential functions.
2. **Metabolism**:
   Enzymes are involved in various metabolic pathways that regulate the

synthesis and breakdown of molecules within cells. For instance, enzymes like hexokinase and phosphofructokinase are involved in glycolysis, the breakdown of glucose to produce energy. Additionally, enzymes such as ATP synthase play a key role in ATP production, the primary energy currency of cells.

3. **Immune Response**:
   Enzymes are also involved in the body's immune response. For example, lysozyme is an enzyme found in tears, saliva, and mucus that helps protect against bacterial infections by breaking down bacterial cell walls. Additionally, enzymes such as catalase and superoxide dismutase help neutralize harmful reactive oxygen species (ROS) produced during immune responses, thereby protecting cells from oxidative damage.