SELF-ASSESSMENT Chapter # 04

Total Mark: 30

Q.1 Encircle the correct option. (1 x 6 = 06)

i. **Which characteristic of water molecules is responsible for most of the unique properties of water?**
(a) Small in size (b) Held together by covalent bonds
(c) Can easily separate from one another (d) Stick together

ii. **Which of the following is NOT a protein?**
(a) Haemoglobin (b) Cholesterol (c) Pepsin (d) Antibody

iii. **What compound would be manufactured difficultly when soil has a shortage of phosphorous?**
(a) DNA (b) Fatty acids (c) Proteins (d) Cellulose

iv. **Which group is found in all fatty acids?**
(a) PO_4 (b) SO_4 (c) C – N (d) COOH

v. **Haemoglobin has:**
(a) Primary structure (b) Secondary structure (c) Tertiary structure (d) Quaternary structure

vi. **Which process produces peptide bonds?**
(a) Digestion (b) Dehydration synthesis (c) Hydrolysis (d) Enzyme deactivation

Q.2 Write short answers of the following questions. (2 x 8 = 16)

i. Draw a sketch of hydrolysis reactions.
ii. Draw the ring structure of glucose and fructose.
iii. Draw the sketch of amino acid.
iv. Draw the sketch of acylglycerol, phospholipid and terpene.
v. Illustrate the formation of phosphodiester bond.
vi. State the central dogma of gene expression.
vii. How do steroids differ structurally and functionally from other lipids?
viii. What roles do transfer RNA (tRNA) play in protein synthesis?

Q.3 Extensive Questions. (4 x 2 = 8)

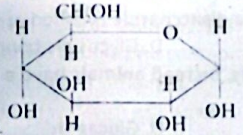
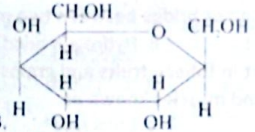
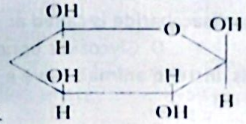
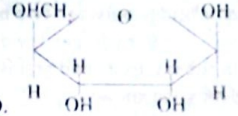
(a) Explain how the solvent properties of water make it the medium of life.
(b) Justify the significance of the sequence of amino acids through the example of sickle cell haemoglobin.

ENTRANCE TEST MCQs (UHS)

1. **Monosaccharides are major components of:**
A. DNA, ATP, Ribose bisphasphate and cysteine B. DNA, NAD and Insulin
C. DNA, NADP, ATP and ribulose bisphosphate D. DNA, RNA and myosin

2. **Myosin is a _____ type of protein:**
A. Intermediate B. Globular C. Simple D. Fibrous

3. **The compounds which on hydrolysis yield polyhydroxy aldehyde or ketone sub-units are:**
A. Lipids B. Polynucleotides C. Proteins D. Carbohydrates

4. **Which one of the following is the formula structure of D (α) glucose?**
A. 
B. 
C. 
D. 

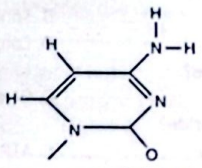
5. **Secondary structure of protein is found in:**
A. Trypsin B. Insulin C. Keratin D. Glucagon

6. **Phosphodiester bond is:**
A. P – O – C – P – O – C B. C – O – P – O – C C. C – O – P D. C – C – O – P

7. **_____ are the specific structures related to monosaccharides:**
A. Glycosidic bond B. Maltose C. Keto group D. Fructose

8. **_____ are the major sites for the storage of glycogen in animal's body:**
A. Muscles and liver B. Around belly and hips C. Around thighs and belly D. Liver and kidneys

9. **If in lipid there is a higher proportion of unsaturated fatty acids then it will be:**
A. Oil B. Phenols C. Waxes D. Fat

10. **Following is the structure of _____:**

A. Uracil B. Guanine C. Thymine D. Cytosine

11. **Which of the following holds the alpha helix of protein in its place?**
A. R group B. Amino group C. Disulphide bond D. Hydrogen bond

12. **A complete turn of the double helix of DNA comprises of:**
A. 34 nm B. 3.4 mm C. 3.4 angstrom D. 34 micrometer

13. **Which lipid is totally hydrophobic or insoluble?**
A. Triglycerides B. Waxes C. Phospholipids D. Terpenoids

14. **In plants, which sugar is transported from source to sink through sieve tubes?**
A. Fructose B. Glucose C. Sucrose D. Starch

- **Blood Cells + Nerve Cells:** The chemical reactions going on in red blood cells are very different from those going on within a nerve cell because red blood cells and nerve cells contain different sets of enzymes.
- **Synthesis of Enzymes:** All enzymes are synthesized inside cells by ribosomes. After their synthesis, either they stay and work inside cell or they are secreted out to work at other sites.

➢ **Distribution of Enzymes in Cells:**

- **Enzymes for Glycolysis:** Inside cell, many enzymes are dissolved in cytoplasm; for example, the enzymes of **glycolysis.**
- **Enzymes For Calvin & Krebs Cycle:** Many are tightly bound to membranes of certain organelles, for example, the enzyme of **Calvin cycle and Krebs cycle.**
- **Enzymes for Pastein Synthesis:** Some enzymes are integral part of ribosomes; for example, the enzymes of protein synthesis.

Reaction with & without Enzymes:
- A reaction that is catalysed by an enzyme and is completed in **30 minutes**, would take one year to get completed without being catalysed by enzyme. Thus, we can say that without enzymes there would have been no life at all.

Q. Describe the structure of enzyme, explaining the role and component parts of the active site of an enzyme. (Exercise L.Q.1)

➲ Active Site of Enzyme

- Enzymes are **three-dimensional** globular proteins. They are made of **polypeptide chains** that are coiled upon themselves. There is a small cleft or depression on the surface of globular enzyme molecule.
- **Active Site:** It consists of only a **few amino acids**. This site is known as **active site**. It is the location at which catalysis occurs.
- **Shape of Active Site:** The shape of active site of each enzyme is very specific. So, only a certain substrate molecule can fit into it. It is **three-dimensional** and bears a specific charge.
- **Sub-sites of Active Site:** Active site has two distinct regions:
  (i) Binding Site **(ii) Catalytic Site**
- Substrate molecule fits into binding site by weak **chemical forces**, such as hydrogen bonds.
- Catalytic site catalyses the reaction and substrate is transformed into products.

Importance of Enzyme's Location
- Some enzymes may prove harmful if become active at wrong place. For example; pepsin is a protein digesting enzyme.
- It can destroy **protein-made structures** present inside cells where it is synthesized. That is why it is produced in inactive form (pepsinogen) and is secreted out of cells. When it reaches its target site of action, it is activated (pepsin).

COFACTORS AND COENZYMES

- Many enzymes use additional chemical components to aid in catalysis.
- **Co-factor:** The additional non-protein components of enzymes are called cofactors.

Q. Differentiate among the three types of co-factors, by giving examples. (Exercise L.Q.2)

- **Types of Co-factor:** There are three kinds of cofactor:
  (i) Metal Ions **(ii) Prosthetic groups** **(iii) Coenzymes**

(i) Metal Ions:
- Many enzymes use metal ions, such as Ca^{+2}, Mg^{+2}, Mn^{+2}, Cu^{+2}, and Zn^{+2} as their cofactors. These metal ions change the non-functional active sites of enzymes into functional sites.
- The attachment of a cofactor also changes the shape of enzyme and allows it to combine with substrate (Figure).

- **Apoenzyme:** The protein part of enzyme is called apoenzyme.
- Holoenzyme complete enzyme including co-factor is called holoenzyme.

Check Understanding!
2. What is the active site of an enzyme and how does it function?

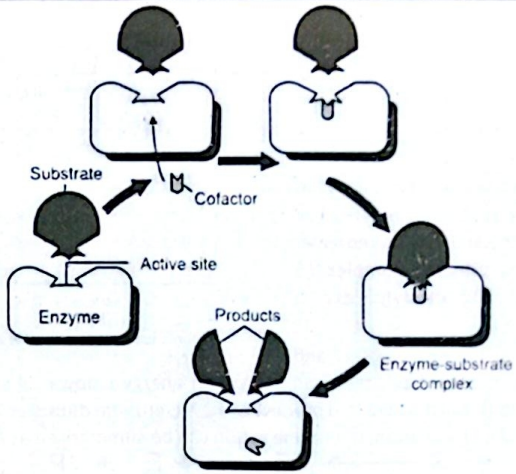


Figure: Cofactor, changing the shape of active site

(ii) Prosthetic Group:
- The cofactors which form covalent bonds with enzyme and are known as prosthetic groups.
- **Example:** Prosthetic group may be an organic compound e.g., **hematin.**

(iii) Coenzyme:
- The cofactor which is a **non-protein** organic molecule and is loosely attached with enzyme, is called a coenzyme.
- Coenzymes participate in enzyme-catalysed reactions, often by transporting electrons (hydrogen atoms), from one enzyme to another.
- **Examples:** Many vitamins (e.g., niacin and riboflavin) function as coenzymes. Some are part of coenzymes.

- Many trace elements such as molybdenum and manganese, which are necessary for our health, are used by enzymes as cofactors.

➢ **NAD^+/Most Important Coenzyme:**

- The most important coenzyme in cell is the hydrogen acceptor **nicotinamide adenine dinucleotide (NAD^+).**
- When NAD^+ acquires a hydrogen atom from an enzyme, it reduces to NADH.
- The electron of hydrogen atom contains energy that NADH molecule carries.
- **Example:** When food is oxidized in cell, **enzymes draw** electrons from food molecules and transfer them to NAD^+, which reduces to NADH.

Check Understanding!
3. In the Lock and Key model, enzyme specificity is due to:
A) Enzyme flexibility
B) Substrate breaking
C) Perfect shape match
D) Product release

MECHANISM OF ENZYME ACTION

Q. Define activation energy and explain through graph how an enzyme speeds up a reaction by lowering activation energy. (Exercise L.Q.4)

- The speed of a chemical **reaction depends** on the amount of **activation energy** required to initiate it.
- **Activation Energy:** The energy which works to destabilize the existing **chemical bonds.**
- Enzymes bring reactants together in correct orientation or stress particular chemical bonds of reactants. Thus, they lower the activation energy required for new bonds to form and speed up the rate of reactions (Figure). Reactions proceed much faster than their **normal speed.**

- **Mechanism of Enzymes Action:** The presence of enzymes does not affect the nature or **properties** of end products. For example, **sucrose (substrate)** will always be hydrolysed into **glucose** and **fructose (products)** whether sucrase (enzyme) is present or not.
- **Specificity of Enzyme:** Due to its specificity, an enzyme recognizes a specific substrate. The substrate binds with the active site of enzyme. In this way, an **enzyme-substrate complex** (ES complex) is formed and **catalytic site** is activated.

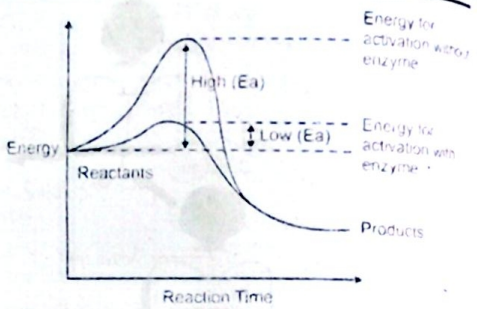


Figure: Enzymes lower the activation energy

- The atoms of catalytic site stress and **destabilize particular bonds of substrate.** So, activation energy is lowered. This action initiates the **reaction and substrate** is transformed into products. After it, enzyme **detaches itself** from the products in an unaltered state. The mechanism of enzyme action can be summarised as follows:

$$E + S \longrightarrow ES \longrightarrow E + P$$

Enzyme Substrate Enzyme-substrate complex Enzyme Product

➢ **Feedback Inhibition of Enzymes:**

- In complex metabolic pathways e.g., respiration, photosynthesis, protein synthesis etc., many enzymes act in a sequence and regulate the **steps of pathway.** The successive enzymes controlling these steps are present together along with their cofactors. The products from **one enzyme's** catalysis serve as substrate for the enzyme of **next step** and are transformed into next products. The series goes on and finally end products are formed that inhibit (through feedback) the first enzyme, the complex metabolic pathway is called feedback inhibition.

➲ Models for Mechanism of Action of Enzymes

(i) Lock-and-Key Model

- **Proposed By:** A German chemist Emil Fischer in 1894.
- According to this model, "As a **specific key** can open only a specific lock in the same manner a specific enzyme can transform only **one specific substrate** into products".

Check Understanding!
4. How does the Induced Fit model differ from the Lock and Key model?

➢ **Draw Back of Lock & Key Model:**

- **Rigid Active Site:** This model postulates that active site is a **rigid structure** and there is no modification or flexibility in it before, during or after the enzyme action (Figure).
- **Conclusive Line:** Later studies did not support lock-and-key model in all reactions.

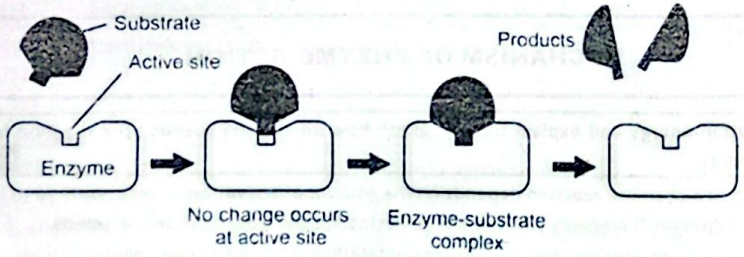


Figure : Enzymes lower theactivation energy

Q. Explain the mechanism of enzyme action through Induced Fit Model, comparing it with Lock and Key Model. (Exercise L.Q.5)

(ii) Induced Fit Model

- On the basis of new evidence, an American biochemist **Daniel Koshland** (1958) presented induced fit model.
- According to this model, **"When a substrate combines with the binding site of an enzyme, it induces changes in enzyme structure. These changes enable the enzyme to perform its catalytic activity more effectively."**
- **Postulates:** Active site is not a rigid structure and is capable of going under modification and flexibility, before the enzyme action (catalysis) starts (Figure).

Check Understanding!
5. Which statement is true for competitive inhibition?
A) Inhibitor binds away from active site
B) Substrate binds permanently
C) Inhibitor resembles substrate
D) Enzyme is denatured

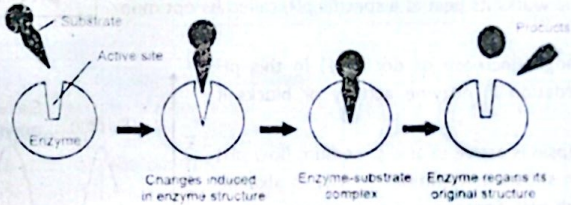


Figure: Induced-fit model of enzyme action

FACTORS AFFECTING THE RATE OF ENZYME ACTION

Q. Describe the effect of temperature on the rate of enzyme action. (Exercise L.Q.5)
Q. Compare the optimum temperatures of enzymes of human and thermophilic bacteria. (Exercise L.Q.6)

- Enzymes are very sensitive to the environment in which they work.
- **Dependence of Enzyme Activity:** The activity of an enzyme is affected by any **change** that alters its **chemistry and its three dimensional shape.**
- Some of the factors that can affect the rate of enzyme action are being discussed next.

(1) Temperature

- The shape of a protein is determined by the **hydrogen bonds** and hydrophobic interactions that hold its polypeptide chains in particular position. Both the hydrogen bonds and hydrophobic interactions are easily disrupted by slight changes in **temperature.**
- **Optimum Temperature:** The temperate at which enzyme works at its maximum rate is called optimum temperature. The optimum temperature for human **enzymes is 37°C.**

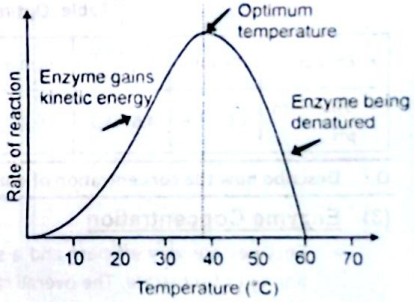


Figure : Effect of temperature on enzyme activity

➢ **Effect of Temperature Below Optimum:**

- When temperature falls below optimum temperature, the **bonds that determine** enzymes shape become less flexible. They do not permit the induced change in active sites that is necessary for enzyme action and so reaction rate is slow.

➢ **Effect of Temperature Above Optimum:**

- When temperature is raised up to a certain limit, the heat adds in **activation energy** and so reactions are accelerated. Heat also provides kinetic energy to substrate and enzyme molecules. It causes them to move rapidly. Thus, they collide more frequently and reaction rate is increased.

- **Why increase in temperature also increase in reaction rate?**
- When temperature is raised well **above optimum temperature**, the heat energy increases the vibrations of atoms of enzyme molecules.
- When vibrations become too violent, bonds cannot hold polypeptide chains in the proper position and globular structure of enzyme is lost. This phenomenon is known as **denaturation of enzyme**. It results in a rapid decrease in the rate of enzyme action and it may be blocked completely.

- **Thermophilic Bacteria:** Which live in hot springs. They have proteins with stronger bonding between their polypeptide arms and can function at temperature of 70°C or higher.

(2) pH

- **Optimum pH:** All enzymes work at their maximum rate at a narrow range of pH is called optimum temperature.
- Every enzyme works its best at a specific pH, called its optimum pH.
- A slight change (increase or decrease) in this pH causes retardation in enzyme activity or blocks it completely.
- **Example:** Pepsin is active in acidic medium (low pH) while trypsin shows its optimum activity in alkaline medium (high pH). Some enzymes like papain from green papaya work both in acidic and alkaline media.
- In the globular structure of an enzyme, polypeptide chains are held by bonds between oppositely charged amino acids, such as **glutamic acid (-) and lysine (+).** These bonds are sensitive to hydrogen ion concentration.
- **Any change in pH** can change the ionization of amino acids at active site. Moreover, it may affect the ionization of substrate.
- **Extreme change in pH** can break the bonds in enzymes, resulting in enzyme denaturation.

Check Understanding!
6. Define competitive inhibition with an example.

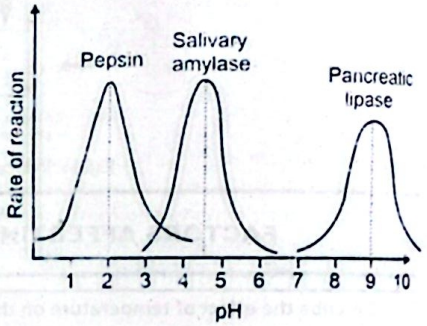


Figure : Optimum pH of some enzyme and effect of change of pH on enzyme activity

Table: Optimum pH of important human enzymes

Enzyme	Pepsin	Salivary amylase	Sucrase	Pancreatic amylase	Catalase	Urease	Trypsin	Pancreatic lipase	Arginase
Optimum pH	1.5 – 1.6	4.6 – 5.2	6.2	6.7 – 7.0	7.0	7.0	7.8 – 8.7	8.0	10.0

Q. Describe how the concentration of enzyme affects the rate of enzyme action. (Exercise L.Q.7)

(3) Enzyme Concentration

- Enzymes are very efficient and a small number of **enzyme molecules** can catalyse reactions of large amount of substrate. The overall rate of **enzyme-controlled** reactions depends directly on the amount of enzyme present at a specific time (if substrate concentration is unlimited).
- **As Enzyme Concentration Increases:** When enzyme concentration increases, there are more enzyme molecules and **more active sites.** So, more substrate molecules bind with new active sites and are transformed into products.
- If enzyme concentration goes on increasing but **substrate concentration** remains the same, no more substrate molecules will attach with enzymes. So, the rate of reaction stays constant and does not increase further (Fig.).

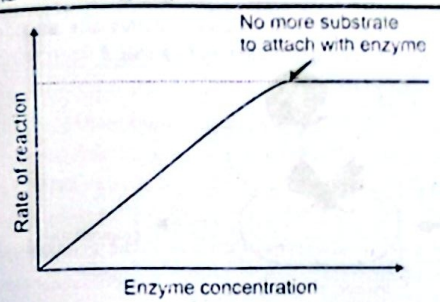


Figure : Effect of enzyme concentration on enzyme activity

Check Understanding!
7. What do hydrolases do?
A) Add water to break bonds
B) Remove water
C) Form peptide bonds
D) Oxidize sugars

Q. Explain the effect of substrate concentration on the rate of enzyme action. (Exercise L.Q.8)

(4) Substrate Concentration

- If there are enzyme molecules with **vacant active sites**, an increase in substrate concentration will increase the rate of reaction.
- If enzyme concentration is kept constant and the amount of substrate is increased, a point is reached where any further increase in substrate does not increase the rate of **reaction** any more.

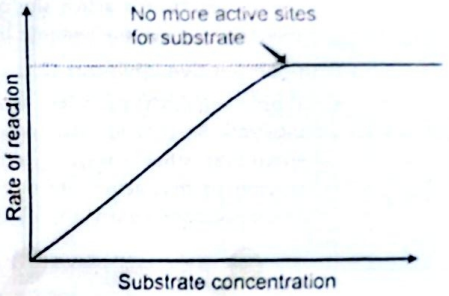


Figure : Effect of substrate concentration on enzyme activity

At Lower Substrate Concentration:

- When enzyme molecules are free (at low substrate concentration) new substrate molecules bind with the available active sites and so more products are formed in the given time i.e., rate of enzyme action is increased.

At Higher Substrate Concertation:

- But when all active sites of enzymes are occupied (at high substrate concentration), any more substrate molecules do not find free active sites and so reaction rate does not increase (Fig.)

ENZYME INHIBITION

Q. Categorize inhibitors into competitive and non-competitive inhibitors. (Exercise L.Q.10)

- **Enzyme Inhibitor:** A chemical that interferes and blocks an enzyme's activity is called an **inhibitor.**
- **Enzyme Inhibition:** The phenomenon in which inhibitors attach with enzymes but are not transformed into **products** and thus block active sites temporarily or permanently is known as **enzyme inhibition.**
- The final products of complex enzymatic reactions also act as the inhibitors of the enzyme of the first step.

- Inhibitors are often used as drugs, but they can also act as poisons. An example of an enzyme inhibitor being used as a drug is aspirin. It inhibits the enzymes that produce prostaglandin (that causes inflammation). Thus, aspirin suppresses pain and inflammation.
- The poison cyanide is an irreversible enzyme inhibitor that combines with copper and iron in the active site of enzyme cytochrome oxidase and blocks cellular respiration.

Types of Inhibitors

- Two general classes of inhibitors are recognized.

(I) Competitive Inhibitors:

- A competitive inhibitor resembles the enzyme's substrate. It competes with substrate for the same binding site on enzyme.

- When competitive inhibitor is selected by binding site, it blocks active site and does not p substrate from attaching. Thus, it prevents enzyme from acting (Figure).

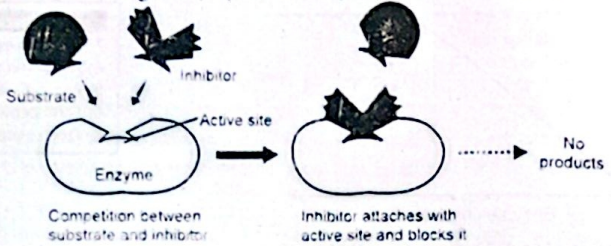


Figure: Competitive inhibition of an enzyme

- **Example:** The enzyme **succinic dehydrogenase** catalyses the oxidation of succinic acid to fumaric acid. **Malonic acid** has structural similarity with substrate (succinic acid). So, both of them compete for active site of enzyme. Malonic acid is selected by active site and thus blocks it.

Check Understanding!
8. How does substrate concentrat affect the rate of enzyme activity?

(ii) Non-competitive inhibitor:

- These inhibitors have no real structural similarity to substrate. So, they do not enter active site. Instead, they bind enzyme at other places. Their binding alter the shape of enzyme so that active site does not fit substrate and so enzyme is inhibited (Figure).

- Competitive inhibitors are used a antibiotics to kill bacteria. The inhibitor molecules are similar structure to bacterial enzymes whi are necessary for their life.
- The inhibitors bind and inhibit t enzymes of bacteria.

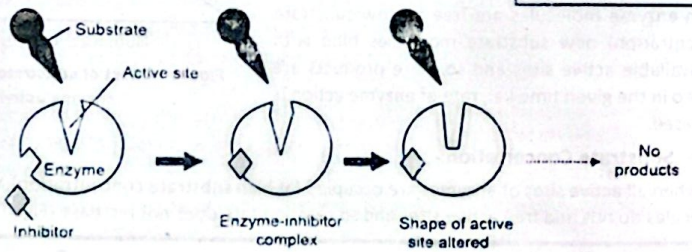


Figure: Non-competitive inhibition of an enzyme

- **Example:** Two substrates i.e., succinic acid and CoA react to form succinyl CoA. This reaction catalysed by enzyme **succinyl-CoA synthetase**. After its formation, the product i.e., succinyl CoA act as a **non-competitive** inhibitor and binds with enzyme. Thus, enzyme is inhibited and no mo succinyl-CoA is produced.

Reversible and Irreversible Inhibitors:

- **Irreversible Inhibitors:** The inhibitors which make covalent bonds with enzyme. Such inhibitors cann be released by dilution or dialysis or by increasing the concentration of substrate.
- **Example:** Penicillin permanently disables the enzyme responsible for building bacterial cell walls.
- **Reversible Inhibitors:** The inhibitors which make weak bonds (e.g., hydrogen bonds) with enzyme. Such inhibitors can be released and the inhibition caused by them can be neutralized by increasing the concentration of substrate.

Check Understanding!
9. What is a coenzyme?
A) Inactive enzyme B) Protein subunit
C) Organic cofactor D) Substrate mimic

- **Example:** Malonate is a reversible inhibitor. It temporarily slows down the reaction by blocking th enzyme succinate dehydrogenase, which is involved in cellular respiration. This inhibition can b reversed when malonate is removed.

Q. Describe enzymatic inhibition, its types and its significance. (Exercise L.Q.9)

Significance of Enzyme Inhibition

Enzyme inhibition is crucial in various biological processes.

i. **Regulation of Metabolic Pathway:** Enzyme inhibition plays a vital role in regulating **metabolic pathways**. By inhibiting specific enzymes, the rate of a metabolic reaction can be controlled.
ii. **Use as Medicines:** Many drugs work as inhibitors. For example, **antibiotics inhibit** the enzymes of bacteria, while cancer drugs may inhibit enzymes involved in cell division.
iii. **Use to Manage Medical Condition:** Enzyme inhibitors are used to manage various medical conditions. For example, some inhibitors of enzymes involved in blood clotting are used as anticoagulants.
iv. **Use to Treat Poisoning:** Some toxins and poisons inhibit important enzymes in the body. Understanding how these inhibitors affect enzymes can be critical in treating cases of poisoning.
v. **Use in Pharmaceutical Research:** Enzyme inhibitors serve as valuable tools in pharmaceutical research. They are used to study the function of specific enzymes, and potential drugs.
vi. **To Study Enzyme Kinetics:** Enzyme inhibition is an important part of studying enzyme kinetics. It helps to understand the factors that influence enzyme activity.

Q. Explain feedback inhibition. (Exercise L.Q.11)

Feedback Inhibition of Enzymes: (Regulation of Product Concentration)

- We know that in **metabolic pathways**, the product of one reaction becomes the substrate for next reaction. At the end of pathway, a desired product is **synthesized.**
- In order to regulate the concentration of that product, pathway needs to be **shut down**. This is done through **feedback inhibition**.
- In this process the final product of pathway acts as inhibitor. It reacts with some initial enzyme and changes its conformation. That enzyme can no longer bind to its substrate. So, pathway closes and no more product is prepared (Figure).
- **Example:** When a cell has a greater number of ATP than its requirement, ATP itself acts as a noncompetitive inhibitor and blocks the enzyme that catalyses **ATP synthesis.**

- **Feedback inhibition**: A phenomenon where the end product of a process controls the process itself, oftentimes limiting the production of more products.

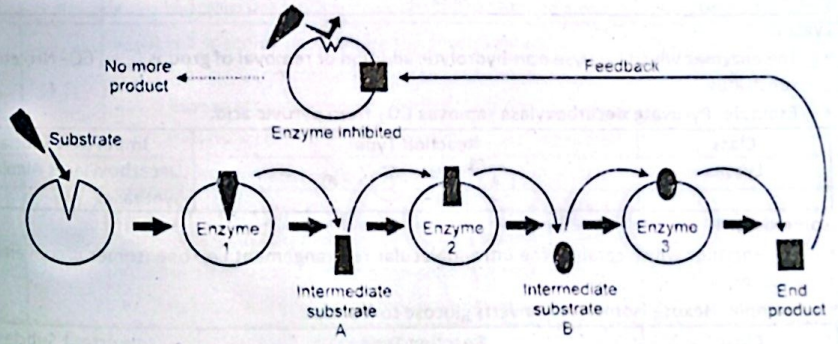


Figure: Feedback inhibition of enzyme action

CLASSIFICATION OF ENZYMES

Q. Classify enzymes on the basis of the reactions catalysed. Exercise L.Q.9

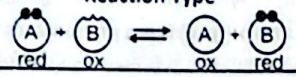
(1) Classification on the Basis of Reactions

According to the general type of reaction, enzymes are classified into **six classes.**

i. Oxidoreductases:

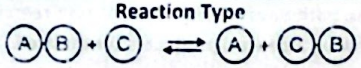
- The enzymes which catalyse the **oxidation / reduction** of their substrates.
- They **add or remove H^+ ions** or electrons from substrates.
- **Example:** Cytochrome oxidase catalyses the oxidation of cytochrome.

Check Understanding?
10. Explain how enzymes reduce activation energy of reactions

Class	Reaction Type	Important Subclass:
Oxidoreductases		Dehydrogenases Oxidases Reductases

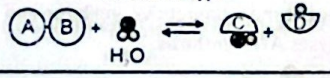
ii. Transferases:

- The enzymes of this class catalyse the **transfer of a specific functional group** (e.g., methyl, acyl, amino, or phosphate) from **one substrate to another.**
- **Example:** Hexokinase transfers phosphate group from ATP to glucose.

Class	Reaction Type	Important Subclass
Transferases		Phospho-transferases Amino-transferases Acyl-transferases

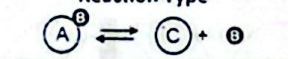
iii. Hydrolases:

- The enzymes which catalyse **hydrolysis reactions** are called hydrolases.
- They break their **substrates** into monomers by adding water.
- **Example:** Lipase, amylase, peptidase, and other digestive enzymes catalyse the hydrolysis of the molecules.

Class	Reaction Type	Important Subclass
Hydrases		Peptidases Lipases Glycodsidases

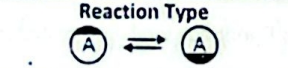
iv. Lyases:

- The enzymes which catalyse **non-hydrolytic addition or removal of groups** (e.g., CO_2, NH_3 etc.) from substrates.
- **Example: Pyruvate decarboxylase removes CO_2 from pyruvic acid.**

Class	Reaction Type	Important Subclass
Lyases		Decarboxylases Aldolases Synthases

v. Isomerases:

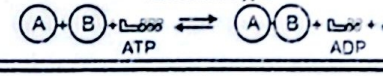
- The enzymes which catalyse the **intra-molecular rearrangement** i.e., one isomer is converted into another.
- **Example: Hexose isomerase converts glucose to fructose.**

Class	Reaction Type	Important Subclass
Isomerases		Epimerases Mutases cis trans isomerases

vi. Ligases:

- The enzymes which catalyse the reactions in which **two molecules join** by forming new C - C, C - N, C - O or C - S bonds, using energy from ATP.

- **Example:** Polymerase enzymes join monomers by using ATP.

Class	Reaction Type	Important Subclass
Ligases		C-C ligases C-O ligases C-N ligases

Q. Give examples of enzymes naming according to substrates. Exercise L.Q.13

(2) Classification on the Basis of Substrates

Enzymes are also classified into following groups on the basis of their substrates.

i. Proteases:

- A group of enzymes which catalyse the **breakdown of proteins** are called protease.
- **Example:** Pepsin and trypsin enzymes catalyse the breakdown of large polypeptides into smaller polypeptides. Similarly, aminopeptidases further breakdown small polypeptides into dipeptides and erypsin breaks dipeptides into amino acids.

ii. Lipases:

- The enzymes which **act upon lipids and catalyse** their breakdown.
- **Example:** Pancreatic lipase hydrolyses lipids into fatty acids and glycerol.

iii. Carbohydrases:

- The enzymes which act upon **bigger carbohydrates** and break them into smaller units.
- **Example:** Amylase acts upon starch or glycogen and breaks them into maltose. Cellulase breaks cellulose into cellobiose (a disaccharide) or glucose.
- Similarly, maltase breaks down maltose into glucose, sucrasebreaks sucrose into glucose and fructose, and lactase breaks lactose into glucose and galactose.

iv. Nucleases:

- The enzymes which **act upon nucleic acids** and catalyse their breakdown.
- **Example:** RNAase, DNAase, ATPase are responsible for the breakdown of RNA, DNA and ATP respectively.

Check Understanding (Solutions)

Sr. #	Option	Explanation
1.	B	• The active site has a specific shape that fits the substrate, enabling catalysis.
2.	S.Q	• It is a specific region where the substrate binds. • Its shape is complementary to the substrate. • It lowers activation energy for the reaction. • Catalysis occurs here, converting substrate to product.
3.	C	• The model states enzyme and substrate fit exactly like a key in a lock.
4.	S.Q	• Enzyme changes shape upon substrate binding. • Provides tighter binding and better catalysis. • Explains flexibility of enzyme-substrate interactions. • More accurate for many modern enzymes.
5.	C	• Competitive inhibitors mimic substrate and block active sites.
6.	S.Q	• Inhibitor resembles substrate and binds active site. • Prevents substrate from binding • Can be reversed by adding more substrate. • **Example:** Sulfa drugs inhibit bacterial folic acid synthesis.

7.	A	• Hydrolases catalyze hydrolysis reactions using water.
8.	S.Q	• At low substrate levels, the reaction rate increases sharply. • As more substrate is added, enzyme active sites become saturated. • Beyond saturation, adding more substrate has no effect. • This leads to a plateau in the reaction rate.
9.	C	• Coenzymes like NAD^+ help in enzymatic reactions.
10.	S.Q	• Enzymes stabilize the transition state of the reaction. • They bring substrates into optimal orientation. • Provide an alternative reaction pathway with lower energy. • **Result:** faster reactions at body temperature.

Exercise

Exercise — MULTIPLE CHOICE QUESTIONS (MCQs) — Section 01

1. **What roles does nicotinamide adenine dinucleotide play in oxidative pathways?**
(a) Enzyme (b) Coenzyme (c) Prosthetic group (d) Inhibitor

2. **The enzymes that catalyse the reactions in which two molecules are joined together by synthesis of new bonds, using energy from ATP, are placed in group:**
(a) Hydrolase (b) Ligase (c) Lyase (d) Transferase

3. **Which of the following is an example of hydrolases?**
(a) Lipase (b) Glycogen phosphorylase
(c) Pyruvate decarboxylase (d) Cytochrome oxidase

4. **Which of the following statements about enzymes is correct?**
(a) They increase the activation energy of a reaction.
(b) They are consumed during the reaction.
(c) They are specific in terms of the reactions they catalyse.
(d) They always work optimally at high temperatures.

5. **Enzyme *B* requires Zn^{2+} to catalyse the conversion of substrate *X*. The zinc is best identified as a(n).**
(a) Coenzyme (b) Activator (c) Substrate (d) Product

6. **If an enzyme solution is saturated with substrate, the most effective way to obtain an even faster yield of products would be**
(a) Add more of the enzymes (b) Add more substrate
(c) Add an allosteric inhibitor (d) Add a non-competitive inhibitor

7. **How does a non-competitive inhibitor decrease the rate of an enzyme-catalysed reaction?**
(a) By binding the active site of the enzyme
(b) By changing the shape of the enzyme
(c) By changing the free energy change of the reaction
(d) By acting as a coenzyme for the reaction

8. **Which enzyme class is responsible for catalysing the addition of water to a substrate molecule?**
(a) Ligase (b) Lyase (c) Hydrolase (d) Isomerase

Answer Key with Explanations

Sr.No.	Option	Answer	Explanations
1.	(b)	Coenzyme	• NAD+ (nicotinamide adenine dinucleotide) acts as a coenzyme in redox reactions by accepting and donating electrons.
2.	(b)	Ligase	• Ligases catalyze the joining of two molecules with the input of energy from ATP.
3.	(a)	Lipase	• Lipase enzyme because it breaks down lipids (fats) by adding water molecules — a classic hydrolysis reaction.
4.	(c)	They are specific in terms of the reactions they catalyse	• Enzymes act on specific substrates due to their active site configuration.
5.	(b)	Activator	• Zinc acts as a cofactor that activates enzyme B, making it an activator.
6.	(a)	Add more of the enzymes	• When substrate is in excess, adding more enzymes increases the reaction rate.
7.	(b)	By changing the shape of the enzyme	• Non-competitive inhibitors bind elsewhere on the enzyme and alter its shape, reducing activity.
8.	(c)	Hydrolase	• Hydrolases catalyze the addition of water to break chemical bonds in molecules.

Exercise — SHORT ANSWER QUESTIONS — Section 02

Q.1 Define enzyme and co-factor.

Ans.
- **Enzyme:** A biological catalyst made of globular proteins that speeds up chemical reactions without being consumed.
- Enzymes are highly specific to the reactions they catalyze.
- **Co-factor:** A non-protein chemical that helps an enzyme function.
- Co-factors can be metal ions (like Mg^{2+}, Zn^{2+}) or organic molecules.
- Some enzymes are inactive without co-factors.
- They assist in substrate binding or in the catalytic process.

Q.2 Differentiate between co-enzyme and prosthetic group.

Ans.

Co-enzyme	Prosthetic Group
• Organic molecule that temporarily binds with the enzyme. • Loosely attached and separates after the reaction. • **Examples:** NAD^+, FAD	• Tightly or permanently bound to the enzyme. • Remains attached during the enzyme's life. • **Example:** Heme group in cytochromes.

Q.3 What do you mean by hydrolases? Give two examples.

Ans. **Hydrolases:**
- Hydrolases are enzymes that **catalyze** the breaking of bonds **using water.**
- They are involved in digestion and other metabolic processes.
- These enzymes break down complex molecules into simpler ones.
- Common hydrolase reactions include hydrolysis of proteins, fats, and carbohydrates.

Examples:

- Amylase – breaks starch into sugars.
- Lipase – breaks fats into fatty acids and glycerol.

Q.4 What is meant by activation energy?

Ans. Activation Energy:

- Activation energy is the minimum energy required to start a **chemical reaction.**
- It is needed to break bonds in the reactants.
- Enzymes lower the activation energy, speeding up the reaction.
- Lower activation energy means the reaction happens more easily.
- This is a key factor in enzyme efficiency and specificity.

Q.5 Define feedback inhibition.

Ans. Feedback Inhibition:

- Feedback inhibition is when the end product of a pathway inhibits an early enzyme in the same pathway.
- It prevents the cell from making more of a substance than needed.
- It is a self-regulating mechanism to maintain balance.
- Once the product accumulates, it binds to the enzyme and halts further production.
- It is a type of negative feedback control in metabolism.

Q.6 Give examples of competitive and non-competitive inhibitors.

Ans.

Competitive Inhibitors	Non-competitive Inhibitors
• Compete with the substrate for the enzyme's active site due to structural similarity.	• Bind to a site other than the active site & have no structural similarity.
• Reduce enzyme activity by blocking substrate binding.	• Change the shape of the enzyme, reducing its function.
• **Example:** Malonate inhibiting succinate dehydrogenase.	• **Example:** Heavy metals like lead or mercury

Q.7 What is optimum pH? Give optimum pH of three human enzymes.

Ans. Optimum pH:

- Optimum pH is the specific pH at which an enzyme shows maximum activity.
- A change in pH can denature the enzyme or reduce its efficiency.
- Enzymes work best at their specific pH range.
- Examples of enzymes with their optimum pH.
- **Pepsin:** pH 1.5–2 (works in the stomach).
- **Trypsin:** pH 7.5–8.5 (works in the small intestine).
- **Salivary amylase:** pH 6.7–7.0 (works in the mouth).

Exercise — LONG ANSWER QUESTIONS — Section 03

Q.1 Describe the structure of enzyme, explaining the role and component parts of the active site of an enzyme.

Ans. See Page No. (158)

Q.2 Differentiate among the three types of co-factors, by giving examples.

Ans. See Page No. (158)

Q.3 Explain the mechanism of enzyme action through Induced Fit Model, comparing it with Lock and Key Model.

Ans. See Page No. (161)

Q.4 Define activation energy and explain through graph how an enzyme speeds up a reaction by lowering activation energy.

Ans. See Page No. (159)

Q.5 Describe the effect of temperature on the rate of enzyme action.

Ans. See Page No. (161)

Q.6 Compare the optimum temperatures of enzymes of human and thermophilic bacteria.

Ans. See Page No. (161)

Q.7 Describe how the concentration of enzyme affects the rate of enzyme action.

Ans. See Page No. (162)

Q.8 Explain the effect of substrate concentration on the rate of enzyme action.

Ans. See Page No. (163)

Q.9 Describe enzymatic inhibition, its types and its significance.

Ans. See Page No. (165)

Q.10 Categorize inhibitors into competitive and non-competitive inhibitors.

Ans. See Page No. (164)

Q.11 Explain feedback inhibition.

Ans. See Page No. (166)

Q.12 Classify enzymes on the basis of the reactions catalysed.

Ans. See Page No. (166)

Q.13 Give examples of enzymes naming according to substrates.

Ans. See Page No. (167)

Exercise — INQUISITIVE ANSWER QUESTIONS

Q.1 Does physical exercise involve anabolic processes, catabolic processes, or both? Give evidence for your answer.

Ans.

- **Catabolic = Breaking things down:** During exercise, the body breaks food like sugar and fat to make energy.
- **Anabolic = Building things up:** After exercise, the body builds and repairs muscles.
- **Both happen during exercise:** The body uses energy (catabolic) and also starts muscle repair (anabolic).
- **Example:** When you lift weights, your muscles get tiny tears (catabolic), then the body fixes them and makes them stronger (anabolic).
- **Conclusion:** So, exercise uses both breaking down (for energy) and building up (for muscle repair and growth).

Q.2 If a chemical reaction could occur without an enzyme, why is it important to have one?

Ans.

- **Speed of Reaction:** Enzymes greatly accelerate the rate of chemical reactions — often by millions of times — making them fast enough to support life.
- **Mild Conditions:** Enzymes allow reactions to occur at body temperature and normal pH, instead of requiring extreme heat or pressure.
- **Specificity:** Enzymes are highly specific; they target only the correct substrate, reducing unwanted or harmful side reactions.
- **Energy Efficiency:** Enzymes lower the activation energy needed to start reactions, saving cellular energy.
- **Regulation:** Enzyme activity can be regulated or inhibited, allowing the cell to control when and how much of a product is made.
- **Reversibility and Reusability:** Enzymes are not consumed in reactions, so they can be reused, making biochemical processes efficient and sustainable.

Q.3 Construct and interpret graphs based on data about the effect of temperature, enzyme concentration and substrate concentration on the rate of enzyme action.

Ans. i. **Temperature vs Enzyme Activity:**
- Enzyme activity increases as temperature rises, due to faster particle movement.
- Maximum activity is reached at the optimum temperature.
- Beyond this point, enzyme activity drops sharply because enzymes denature.

ii. **Enzyme Concentration vs Enzyme Activity**
- More enzymes mean more active sites, so the reaction rate increases.
- The rate levels off when the substrate becomes the limiting factor.
- Adding more enzymes after saturation has no effect.

iii. **Substrate Concentration vs Enzyme Activity**
- Higher substrate concentration increases enzyme activity at first.
- Activity plateaus when all enzyme active sites are full.
- This is known as the saturation point.

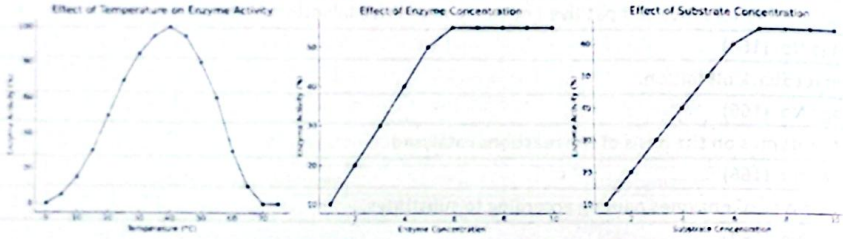


Figure: Graphs showing the effect of temperature, enzyme concentration, and substrate concentration on enzyme activity.

Q.4 Identify the competitive and non-competitive inhibitors from a list of chemicals used in daily life.

Ans.

Competitive Inhibitors	Non-competitive Inhibitors
• **Sulfa drugs (e.g., sulfanilamide):** Used as antibiotic to stop bacterial growth. • **Statins (e.g., atorvastatin):** Lower cholesterol in heart patients. • **Aspirin (low dose):** Pain relief, reduces inflammation. • **Ibuprofen:** Over-the-counter painkiller. • **Sildenafil (Viagra):** Treats erectile dysfunction. • **Ethanol (in methanol poisoning):** Competes with methanol for breakdown.	• **Cyanide:** Extremely toxic, blocks cellular respiration • **Lead (Pb^{2+}):** Environmental toxin, affects enzymes in children. • **Fluoride:** Used in toothpaste to prevent tooth decay. • **Mercury (Hg^{2+}):** Toxic heavy metal, disrupts protein function. • **Carbon monoxide (CO):** Binds to hemoglobin & mitochondrial enzymes. • **DDT (pesticide):** Inhibits nervous system enzymes in insects. • **Penicillin (some actions):** Though mostly irreversible, can act non-competitively too.

ADDITIONAL MCQs

Q.1 Which of the following best describes the role of an enzyme's active site in the context of the Induced Fit Model?
A) It remains rigid regardless of substrate type
B) It undergoes conformational changes to bind the substrate tightly
C) It acts only on non-polar substrates
D) It is unaffected by environmental conditions

Q.2 Coenzymes differ from prosthetic groups in that coenzymes:
A) Are permanently bound to the enzyme
B) Are always metallic ions
C) Are loosely bound and often derived from vitamins
D) Cannot assist in redox reactions

Q.3 Which statement best explains why enzymes are classified as biological catalysts?
A) They increase the activation energy
B) They speed up reactions without being consumed
C) They always change the product of a reaction
D) They permanently alter substrate structure

Q.4 The enzyme pepsin functions optimally at a low pH because:
A) It is found in the liver
B) It is adapted to the acidic environment of the stomach
C) It is activated by neutralizing agents
D) It only works in the presence of bile

Q.5 Which of the following inhibition types involves a molecule binding at a site other than the active site, changing the enzyme's shape?
A) Competitive inhibition
B) Non-competitive inhibition
C) Feedback inhibition
D) Catalytic inhibition

Q.6 A sudden increase in temperature above optimal levels can denature an enzyme primarily by:
A) Disrupting its genetic coding
B) Increasing the number of substrates
C) Breaking hydrogen bonds and altering 3D structure
D) Enhancing allosteric activation

Q.7 What effect does increasing enzyme concentration have on the rate of reaction when the substrate is not limiting?
A) No effect
B) Increases linearly
C) Decreases due to feedback inhibition
D) Stops the reaction

Q.8 Which statement about activation energy is accurate in the presence of an enzyme?
A) Enzymes eliminate activation energy completely
B) Enzymes lower the activation energy needed
C) Enzymes increase activation energy in unfavorable reactions
D) Activation energy remains constant

Q.9 Which type of cofactor is most likely to be a metal ion such as Mg^{2+} or Fe^{2+}?
A) Prosthetic group
B) Inorganic ion
C) Coenzyme
D) Active site

Q.10 Which enzyme would be most effective in alkaline conditions, such as in the small intestine?
A) Pepsin
B) Papain
C) Trypsin
D) Catalase

Q.11 What characterizes competitive inhibitors in enzyme-catalyzed reactions?
A) They attach irreversibly to the enzyme
B) They structurally resemble the substrate
C) They bind to an allosteric site
D) They enhance enzyme-substrate binding

Q.12 Feedback inhibition is a regulatory mechanism in which:
A) The enzyme enhances its own activity
B) The substrate inhibits product formation
C) A non-specific inhibitor is used
D) The end product inhibits an earlier enzyme in the pathway

Q.13 The function of ligases is to:

A) Join two molecules using ATP B) Oxidize biological molecules
C) Break peptide bonds D) Transfer phosphate groups

Q.14 The enzyme amylase primarily acts on:

A) Proteins B) Starches C) Lipids D) Amino acids

ANSWER KEY

1. B)	2. C)	3. B)	4. B)	5. B)	6. C)	7. B)	8. B)	9. B)	10. C)	11. B)	12. D)
13. A)	14. B)										

ADDITIONAL SHORT ANSWER QUESTIONS

Q.1 Define co-factor. What is its function?

Ans. Cofactor:

- Non-protein part of an enzyme known as a co-factor.

Importance/Functions: (Need of Cofactor For Enzymes)

- Co-factor is essential for the proper functioning of an enzyme.
- Co-factor acts as a bridge between enzyme and its substrate.
- Sometimes the co-factor provides a **source of chemical energy,** helping to drive reactions which would otherwise be difficult or impossible.

Q.2 Differentiate between cofactor and activator.

Ans.

Characteristics	Cofactor	Activator
• Role in Enzyme Function	• A non-protein molecule that binds to an enzyme, essential for its catalytic activity. Cofactors provide chemical groups or electrons, facilitating the enzyme-catalyzed reaction.	• A molecule that increases enzyme activity by binding to a specific site, often inducing conformational changes. Activators enhance enzyme function without directly participating in the catalytic reaction.
• Binding and Duration	• Typically binds tightly to the enzyme, often through covalent bonds, and remains associated throughout the catalytic cycle.	• Binds reversibly to the enzyme, often through non-covalent interactions, and dissociates after enhancing enzyme activity.

Q.3 Give differences between prosthetic group and activator.

Ans. Prosthetic Group:

- It is a **co-factor which is covalently** bonded with the enzyme.
- Without **prosthetic group,** holoenzyme becomes an apoenzyme.
- Prosthetic group may be organic or inorganic.
- **Example:** Heme group of haemoglobin.

Activator:

- An activator is also a **non-protein part** of the enzyme, which is actually a detachable co-factor.
- It is a **co-factor which is in the form of inorganic metal ion** required for the proper functioning of the enzyme.
- **Example:** Some enzymes use metal ions **as co-factor is known as activator** if it is an inorganic ion.
- **Examples:** Mg^{2+}, Fe^{2+}, Cu^{2+}, Zn^{2+}

Co-Enzyme:

- When **non-protein** part is loosely attached to the protein part of enzyme is known as co-enzyme.
- Many co-enzymes are either **vitamins** or derivatives of **vitamins** e.g. NAD^+, $NADP^+$.
- **Examples:** NAD^+ (Nicotinamide adenine dinucleotide). $NADP^+$ – Nicotinamide adenine dinucleotide Phosphate, Ubiquinone etc.

Q.4 Why in human body vitamins are required in small quantity?

Ans. Human Body Requires Vitamins In Small Quantity:

(i) **High Potency:** Vitamins are highly potent molecules that catalyze specific biochemical reactions. Even small amounts can facilitate numerous reactions.

(ii) **Efficient Utilization:** The human body has efficient mechanisms to recycle and reuse vitamins, minimizing waste and optimizing utilization.

(iii) **Precise Regulation:** Vitamins play critical roles in regulating enzyme activity and metabolic pathways, requiring precise amounts to maintain optimal function and prevent imbalance.

Q.5 Differentiate between Holoenzyme and Apoenzyme.

Ans.

Apoenzyme: (Protein Part – Non - Protein Part)	Holoenzyme: (Protein Part + Non - Protein Part)
• Enzyme **without non-protein** part is called apoenzyme.	• Complete enzyme **including co-factor is known as holoenzyme.**
• It is inactive form of enzyme.	• It is active form of enzyme.

Q.6 Why without enzymes life is impossible?

Ans. Importance of Enzymes in Life/Life is impossible without enzymes:

(i) **Metabolic Reactions:** Enzymes facilitate and accelerate biochemical reactions essential for life, such as:

- Nutrient digestion and absorption.
- Energy production (glycolysis, Krebs cycle).
- DNA replication and repair.
- Protein synthesis.
- Without enzymes, these reactions would occur too slowly or inefficiently, making life unsustainable.

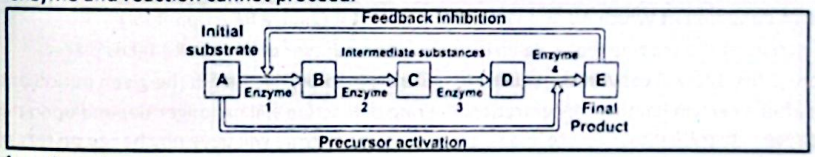
(ii) **Energy Efficiency and Specificity:** Enzymes provide energy efficiency and specificity to biochemical reactions:

- Lowering activation energy requirements.
- Catalyzing specific reactions without unwanted byproducts.
- Regulating reaction rates and pathways.
- Without enzymes, cells would waste energy and resources, leading to cellular dysfunction and ultimately, death.
- These reasons highlight the crucial role enzymes play in maintaining life.

Q.7 Define feedback inhibition of enzymes with diagram.

Ans. Feedback Inhibition of Enzymes:

- A type of inhibition in which enzyme's activity is inhibited or blocked, by the enzyme's own product, when enzymes work in a chain. In this process enzyme's final product blocks the active site of first enzyme and reaction cannot proceed.



Explanation of Feedback Inhibitions:

- In certain cases enzymes act in a **series of chemical reactions** in a particular order to complete a metabolic pathway such as **respiration or photosynthesis.**
- The successive enzymes containing these reactions are normally present together in a precise order of reaction such that substrate molecules transferred **from one enzyme** to another forming a **enzyme to enzyme chain.**
- In this way, the products from one step in the **pathway are transferred to the enzyme** catalyzing the next step.
- **Examples:** Glycolysis, krebs cycle.

Q.8 How does enzyme accelerate the rate of metabolic reaction?

Ans. Acceleration of Metabolic Reaction By Enzymes:

- Enzymes generally **lower the activation energy** by reducing the **energy needed for reactants to** co together and react.
- **Enzymes accelerate** the metabolic reactions by lowering the activation energy in the following ways
- Enzymes **bring reactants** together so they **don't have to expend** energy moving about until they co at random.
- Enzymes bind both reactant molecules **(called the substrate),** tightly and specifically, at a site on t enzyme molecule called the **active site.**
- By binding reactants at the active site, enzymes also make the **position of reactants correctly,** so th do not have to **overcome intermolecular** forces that would otherwise push them apart.
- This allows the molecules to interact with less energy.
- Enzyme may also allow reactions to **occur by different pathways that** have lower **activation energy** t these ways enzymes accelerate the metabolic reactions.

Q.9 What is lock and key model of enzyme action?

Ans. Lock and Key Model:

- **Emil Fischer** (1890) proposed this model.
- According to this model, as one specific key can open only a specific lock, similarly a specific enzyme ca transforms only one substrate into products.

According to Lock and Key Model: (Reason that lock and Key Model is Not Supported in all Reactions)

- Active site is a rigid structure, it means no modification or **flexibility** in the active site before during after the enzyme action occurs.
- Active site is used only as a template.
- Thus later studies did not support this **model in all reactions.**

Q.10 What is induced fit model of enzyme action? Who proposed it?

Ans. Induced Fit Model (Hands and Glove Model):

- **Koshland** (1959) proposed induce fit model of enzymes.

According to Induced Fit model: (Need to Change in Enzymes Structure)

- When a substrate combines with an enzyme, it **induces changes in the enzyme structure.**
- The change in structure enables the **enzyme to perform** its catalytic activity **more effectively.**
- According to this model enzymes are **not rigid and inflexible,** but are capable of considerable interna **movement.**

Q.11 If more enzymes are added in a system its rate of reaction remains unchanged, why?

Ans. Reason: (A Condition At Which Addition of Enzyme does Not Change Reaction Rate)

- By increasing the enzyme molecule an increase in the number of active site takes place.
- More active site will **convert the substrate** molecule in to product (s), in the given period of time.
- But after a **certain limiting concentration,** the rate of reaction will no longer depend upon this increas **because substrate molecule are less** so any addition of enzyme will have **no change on rate of reaction**

Q.12 What are inhibitors?

Ans. Inhibitors:

- An inhibitor is a chemical substance that blocks or retards the rate of enzyme catalysis by occupying th active sites of an enzyme.
- It reacts with enzyme but is **not transformed into product(s).**
- Inhibitors block the active site temporarily or permanently.
- **Examples:** Poisons like cyanide, antibodies, **anti-metabolites, pesticides and** some drugs.

- Inhibitors can be divided into two types.
  (i) Irreversible inhibitors (ii) Reversible inhibitors

Poisons as Inhibitors:

- Poisons act as inhibitors, because they bind covalently to the enzymes, and block the activity of enzymes, thus poisons act as inhibitors.

Q.13 How inhibitors inhibit enzymes.

Ans. Inhibitors Inhibit Enzymes:

(i) **Blocking the Active Site:** Inhibitors bind to the active site of the enzyme, preventing the substrate from binding and being converted into product. This blocks the enzyme's catalytic activity.

Types:

- Competitive inhibitors (e.g., aspirin, methotrexate),
- Irreversible inhibitors (e.g., cyanide, nerve agents)

(ii) **Altering Enzyme Conformation:** Inhibitors bind to other sites on the enzyme, causing a conformational change that:

- Reduces substrate affinity. • Disrupts catalytic activity. • Changes enzyme stability.

Types:

- Non-competitive inhibitors (e.g., cyanide, allosteric inhibitors)
- Allosteric inhibitors (e.g., some antibiotics).

Q.14 Differentiate between reversible and irreversible inhibitor.

Ans.

Irreversible inhibitors (Way of Inhibition of Enzyme's Activity)	Reversible Inhibitors
• They **check the rate of reactions** by occupying the active sites or **destroying** the globular structure. • They occupy the **active sites by forming covalent bonds** or they may physically block the active sites.	• They **form weak linkage** with the **enzyme.** **Neutralization of Effects:** • Their **effect can be neutralized** completely or partly by an increase in the **concentration** of the substrate. • **Reversible Inhibitors** are divided into two major types: **(a)** Competitive inhibitor **(b)** Non-competitive inhibitor

Q.15 How do allosteric sites influence enzyme regulation?

Ans.

- Molecules bind to allosteric sites (not active site).
- This changes the enzyme's shape and activity.
- Can either activate or inhibit the enzyme.
- Plays a role in feedback inhibition and metabolic control.

◈◈◈◈◈

SELF-ASSESSMENT Chapter # 05

Total Mark: 30

Q.1 Encircle the correct option. (1 x 6 = 06)

i. **Which of the following inhibition types involves a molecule binding at a site other than the active site, changing the enzyme's shape?**
(a) Competitive inhibition (b) Non-competitive inhibition
(c) Feedback inhibition (d) Catalytic inhibition

ii. **Which enzyme would be most effective in alkaline conditions, such as in the small intestine?**
(a) Pepsin (b) Papain (c) Trypsin (d) Catalase

iii. **The function of ligases is to:**
(a) Join two molecules using ATP (b) Oxidize biological molecules
(c) Break peptide bonds (d) Transfer phosphate groups

iv. **The enzymes that catalyse the reactions in which two molecules are joined together by synthesis of new bonds, using energy from ATP, are placed in group;**
(a) Hydrolase (b) Ligase (c) Lyase d) Transferase

v. **If an enzyme solution is saturated with substrate, the most effective way to obtain an even faster yield of products would be**
(a) Add more of the enzymes (b) Add more substrate
(c) Add an allosteric inhibitor (d) Add a non-competitive inhibitor

vi. **Which enzyme class is responsible for catalysing the addition of water to a substrate molecule?**
(a) Ligase (b) Lyase (c) Hydrolase (d) Isomerase

Q.2 Write short answers of the following questions. (2 x 8 = 16)

i. Why is the active site often conserved across species for homologous enzymes?
ii. How does the absence of a co-factor affect enzyme activity?
iii. Explain the role of acid-base catalysis in enzyme mechanisms.
iv. Differentiate between co-enzyme and prosthetic group.
v. What is meant by activation energy?
vi. What is optimum pH? Give optimum pH of three human enzymes.
vii. Explain non-competitive inhibition.
viii. Why does enzyme activity drop after reaching an optimal temperature?

Q.3 Extensive Questions. (4 x 2 = 8)

(a) Describe the effect of temperature on the rate of enzyme action.
(b) Classify enzymes on the basis of the reactions catalysed.

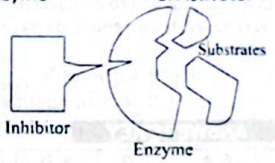
ENTRANCE TEST MCQs (UHS)

1. Some enzymes require helper which is a non-protein part for its efficient functioning; that is called:
A. Accerator B. Prosthetic group C. Cofactor D. Apoenzyme

2. Pepsin, protein digesting enzyme acts best at pH:
A. 3.00 B. 2.00 C. 4.5 D. 6.00

3. Which one of the following is an example of competitive inhibitor?
A. Glucose B. Succinic acid C. Fumerate D. Melonate

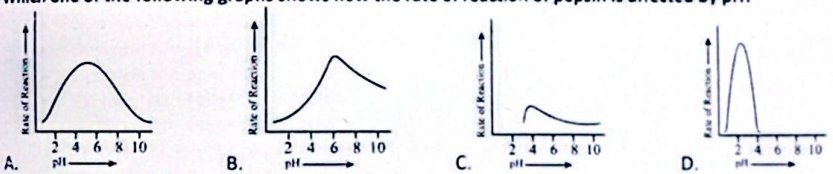
4. An enzyme required Mg^{++} to catalyze the substrate. The Mg^{++} is best identified as:
A. Prosthetic group B. Co-enzyme C. Activator D. Inhibitor



5. This figure represents _____ inhibitor.
A. Non-competitive B. Irreversible C. Competitive D. Isosteric

6. According to _____ model the active site of enzyme is modified as the substrate interacts with enzyme:
A. Induced fit B. Emil Fischer C. Lock and key D. Fluid mosaic

7. Which one of the following graphs shows how the rate of reaction of pepsin is affected by pH?



A. B. C. D.

8. All enzymes are:
A. Fibrous proteins B. Lipoproteins
C. Low molecular weight proteins D. Globular proteins

9. The reactants on which enzyme works are:
A. Products B. Substrates C. Metabolites D. Catabolites

10. Which one of the following comprises of inorganic ions?
A. Coenzymes B. Prosthetic group C. Activators D. Apoenzyme

11. Which one of the followings is a non-cellular infectious entity?
A. Mycoplasma B. Herpes virus C. Escherichia coli D. Diplococcus

12. If molecule can bind to another site of the enzyme rather than the true active site, it is referred as:
A. Competitive inhibitors C. Non competitive inhibitors
B. Allosteric inhibition D. Irreversible inhibition

13. A non-protein part essential for proper and essential functioning of enzyme is called:
A. Additional factor B. Efficient co factor C. Co factor D. Extra factor

14. The temperature that promotes the maximum activity of enzyme is referred as:
A. Fixed temperature B. Controlled temperature
C. Optimum temperature D. Active temperature

15. The type of energy reduced by the enzymes for biological reactions to occur is called the:
A. Light energy B. Active energy C. Activation energy D. Heat energy

16. What is common in both competitive and non-competitive inhibition?
A. Irreversible inhibition B. Reversible inhibition
C. Feedback Inhibition D. Non-reversible inhibition

17. A student of chemical engineering mistakenly engulfed the toxic compound "A" which was a potent inhibitor of certain enzyme. He was immediately brought to hospital where Dr. injected intravenously substrate "B" to minimize the toxic effect of compound A. His life was saved from serious damages. The treatment method shows that compound A was a _____ inhibitor:
A. Temperature sensitive B. Irreversible
C. Competitive reversible D. Non-competitive reversible

18. The type of energy reduced by the enzymes for biological reactions to occur is called the:
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19. What is common in both competitive and non-competitive inhibition?
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20. A student of chemical engineering mistakenly engulfed the toxic compound "A" which was a potent inhibitor of certain enzyme. He was immediately brought to hospital where Dr. injected intravenously substrate "B" to minimize the toxic effect of compound A. His life was saved from serious damages. The treatment method shows that compound A was a _____ inhibitor:
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C. Competitive reversible D. Non-competitive reversible

ANSWERS KEY

1. C	2. B	3. D	4. C	5. A	6. A	7. D	8. D	9. B	10. C	11. B	12 C
13. C	14. C	15. C	16. B	17. C	18. C	19. B	20. C				

Chapter 06

BIOENERGETICS

Student Learning Outcomes (SLOs)

After studying this chapter, the students will be able to:

- Explain the role of light, carbon dioxide and water in photosynthesis.
- Identify the two general kinds of photosynthetic pigments (carotenoids and chlorophylls).
- Describe the roles of photosynthetic pigments in the absorption and conversion of light energy.
- Differentiate between the absorption spectra of chlorophyll 'a' and 'b'.
- Draw the molecular structure of chlorophyll.
- Describe the arrangements of photosynthetic pigments in the form of photosystem-I and II.
- Describe the events of non-cyclic photophosphorylation and outline the cyclic photophosphorylation.
- Draw the Z-scheme for explaining the events the light dependent reactions.
- Explain the Calvin cycle.
- Develop a flow chart for explaining the events of light reactions.
- Describe the features of ATP that make it suitable as the universal energy currency.
- Describe the synthesis and breakdown of ATP.
- Describe the four stages in aerobic respiration in eukaryotic cells:
- Explain the process of anaerobic respiration in terms of glycolysis and conversion of pyruvate into lactic acid or ethanol.
- Outline the events of glycolysis (naming the reactants and products of each step)
- Describe the link reaction, including the role of coenzyme A.
- Outline the Krebs cycle (naming the reactants and products of each step).
- Describe the role of NAD and FAD in cellular respiration.
- Explain that passage of electrons through electron transport chain highlighting the oxidation and reduction reactions (details of carriers are not required).
- Describe chemiosmosis and relate it to electron transport chain.
- Explain why the energy yield from respiration in aerobic conditions is much greater than the energy yield from respiration in anaerobic conditions.

- Every living organism, from the **smallest bacterium** to the **largest whale**, is driven by energy. This energy fuels their growth, reproduction, and daily survival, making it a fundamental aspect of life.

- Nearly all the energy used by **living organisms** on Earth comes from photosynthesis.
- Plants, algae, and certain bacteria capture sunlight and convert it into chemical energy, forming the base of the food chain.

Q.1 Where does the energy for organisms come from?

Q.2 How is energy harnessed and utilized by cells to perform countless activities essential for life?

- The answer of the above question 1 and 2 lies in the **fascinating** field of **bioenergetics.**
- **Bioenergetics:** The study of how energy flows through living systems is called **bioenergetics.**
- It explores the processes through which cells store and expend energy.
- The processes of photosynthesis and respiration help to understand some of the principles of bioenergetics.
- Photosynthesis acts as an **energy-capturing** while respiration as an **energy-releasing process.**

ATP: The Energy Currency of Cells

- Cells use a special energy currency for their reactions. This currency is actually a nucleotide called **adenosine triphosphate (ATP)** when cells store energy, they make ATP. When cells need energy, they break ATP.
- **Components of ATP:** A molecule of ATP has three subunits:
  (a) Adenine, (a nitrogen containing base)
  (b) Ribose (a five-carbon sugar)
  (c) Three phosphate groups.

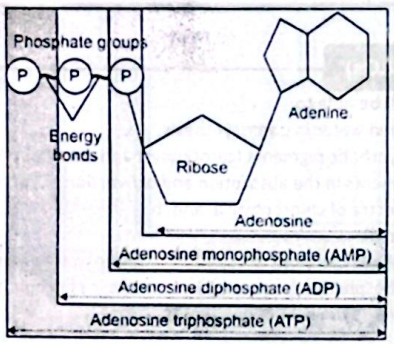


Figure: Molecular structure of ATP

Check Understanding!

1. **Which structural feature of ATP makes it a suitable molecule for energy transfer in cells?**
   A. The sugar-ribose backbone
   B. The adenine nitrogen base
   C. The presence of three phosphate groups with unstable bonds
   D. Its water-soluble nature

- ATP was discovered in 1929 by Karl **Lohmann.**
- In 1941, the Nobel prize winner, Fritz Lipmann proposed that ATP is the main energy-transfer molecule in the cell.

- **High Energy Phosphate:** The covalent bonds between two phosphates are **high-energy bonds**. When one of **these bonds** is broken, inorganic phosphate (Pi) separates and energy is released. The breaking of one phosphate bond releases about **7.3 kcal** (7,300 calories) per **mole of ATP.**

$$ATP + H_2O \rightarrow ADP + P_i + \text{energy (7.3 kcal/mole)}$$

- In common energy reactions only the outer P – P high-energy bond breaks. When this happens, ATP becomes ADP (adenosine diphosphate) and one Pi is released.
- In some cases, ADP is further broken down to **AMP (adenosine monophosphate) and Pi:**

$$ADP + H_2O \rightarrow AMP + P_i + \text{energy (7.3 kcal/mole)}$$

- Cells get energy from the oxidation of food. They store this energy by combining ADP with Pi to form ATP. So, we can summarize that ATP is made during energy-releasing processes and it is broken down during energy-consuming processes.
- In this way ATP transfers energy between metabolic reactions.

PHOTOSYNTHESIS

- The use of **light energy** that is absorbed and converted into **chemical energy** by photosynthetic pigments is called **photosynthesis.** Photosynthesis in plants can be summarized as:

$$6CO_2 + 12H_2O + \text{Light} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

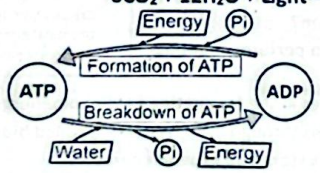


Figure: ATP-ADP Cycle

Recalling

- Photosynthesis is the process in which the energy-poor inorganic compounds of carbon (i.e., CO_2) are reduced to energy-rich carbohydrates.

- Carbon dioxide, **water and light** are the reactants while glucose and oxygen are the products.
- Water appears on both sides of the equation because water is used as reactant in some reactions and released as product in others. However, there is no net yield of water.

Compensation Point

- Photosynthesis uses the **products of respiration** and respiration uses the products of photosynthesis.
- Photosynthesis occurs only during day time but respiration goes on day and night.
- **During darkness,** leaves and other parts respire and utilize oxygen and release carbon dioxide.
- **At dawn and dusk,** when light intensity is low, the rate of photosynthesis and respiration may be equal for a short time. Thus, the oxygen released from photosynthesis is just equal to the amount required for cellular respiration. Also, the carbon dioxide released by respiration is just equal to the amount required by photosynthesizing cells. At this moment there is no net gas exchange between leaves and atmosphere. This is termed as compensation point.
- **At noon,** when the light intensity increases, the rate of photosynthesis also increases. At this time, there is more requirement of carbon dioxide.
- Respiration alone cannot supply this carbon dioxide. Similarly, the oxygen produced during photosynthesis is more than the need of the respiring cells.
- So, the result is the **net release** of oxygen becomes equal to the uptake of carbon dioxide, which is called **compensation point.**

Role of Light In Photosynthesis:

- Light plays a crucial role in photosynthesis, providing the **energy required** to drive the chemical reactions that transform simple molecules into complex organic compounds.
- Light energy is **absorbed** by chlorophyll. The absorbed light energy is **converted into chemical energy,** which is in turn stored in organic compounds in the form of **C-H bond energy**. It happens like this.

- Plants convert only about 1-2% of the solar energy they receive into chemical energy during photosynthesis.
- Despite this **seemingly low efficiency,** this conversion is enough to sustain almost all life on Earth.

Action Spectrum

Check Understanding!

2. **Describe the role of light in photosynthesis.**

- **Definition:** A graph which shows the **relative effectiveness** of different wavelength of light on the rate of photosynthesis is called **action spectrum.**
- Photosynthetic pigments absorb different wavelengths of light at different rates. Moreover, the different wavelengths are also differently effective in photosynthesis.
- **To Obtain Action Spectrum:** For getting action spectrum of light, a plant is illuminated with different colours of light one by one. While providing each colour, the rate of photosynthesis is measured by measuring the amount of oxygen emitted from leaves. The data is plotted in a graph called action spectrum.
- **First Action Spectrum:** The first action spectrum was made by a German biologist, **T. W. Engelmann** In 1883. He worked on the photosynthetic pigments of **Spirogyra,** when the cells of a filament of **Spirogyra** were illuminated with different wavelengths of light, maximum photosynthesis occurred in the cells which received blue and red spectrum of light and so **maximum oxygen** was emitted from these cells.

Role of Carbon Dioxide In Photosynthesis:

- Sugar is formed by the **reduction of CO_2** by using ATP and NADPH. In this way, **CO_2** acts as the source of carbon for **making sugars.**
- Carbon dioxide enters the **leaves through stomata** and gets dissolved in water absorbed by the cell walls of mesophyll cells. Stomata are found in large numbers in leaves.
- The entry of **CO_2** into the leaves is dependent upon the opening of stomata.

Q. Describe how the role of water in photosynthesis can be explained through experiment. Exercise LO 1

Role of Water In Photosynthesis:

- Water is the **source of hydrogen**, for the reduction of CO_2 to synthesize sugar during photosynthesis.
- Oxygen released during photosynthesis comes from water, and so water is an important source of atmospheric oxygen which most organisms need for aerobic respiration and thus for obtaining energy to live.

- About 10% of **total photosynthesis** is carried out by terrestrial plants, the rest occurs in **oceans, lakes** and **ponds**.
- Aquatic photosynthetic organisms use dissolved CO_2, bicarbonates and soluble carbonates as carbon source.
- Land photosynthetic **organisms** use atmospheric CO_2 as carbon source.

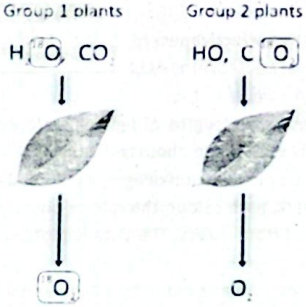
Van Neil's Hypothesis: (O_2 Comes From Water Not From CO_2)

- In 1930s, **Van Neil** hypothesized that plant splits water as a source of **hydrogen**, releasing oxygen as a by-product.
- **Confirmation of Van Neil's Hypothesis:** Neil's hypothesis was later confirmed by scientists during 1940s.
- An experiment was conducted in which isotopic **tracer (^{18}O)** of oxygen was used.
- In laboratory, scientists prepared water with **heavy-oxygen** i.e., $H_2{}^{18}O$. They also prepared carbon dioxide with heavy oxygen i.e., $C^{18}O_2$
- Experimental green plants in one group were given water $H_2{}^{18}O$ and normal carbon dioxide i.e., $C^{16}O_2$. Plants in the second group were given $C^{18}O_2$ and normal water i.e., $H_2{}^{16}O$.
- Both plants were given an environment to conduct photosynthesis.
- **O_2 Releases From H_2O:** Oxygen **released during** photosynthesis of both plants was collected and tested. It was found that plants of first group **produced ^{18}O** but the plants of second group produced **normal oxygen (^{16}O).**

- **Neil's hypothesis** was based on the investigations on photosynthetic bacteria that make carbohydrate from carbon dioxide, but do not release oxygen.

Check Understanding!

3. According to Van Niel's hypothesis, the oxygen released during photosynthesis comes from:
A. Carbon dioxide B. Glucose
C. Water D. Air



NADP — Oxidized form
NADPH — Reduced form

Group 1

$$6CO_2 + 12H_2{}^{18}O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6{}^{18}O_2$$

Group 2

$$6C^{18}O_2 + 12H_2O \longrightarrow C_6H_{12}{}^{18}O_6 + 6H_2{}^{18}O + 6O_2$$

Figure: Experiment to prove that water is the source of oxygenreleased in photosynthesis

- **Final Result:** In photosynthesis water is split to release hydrogen. This hydrogen reduces the coenzyme **nicotinamide adenine dinucleotide phosphate (NADP)** to NADPH. The reduced coenzyme i.e., NADPH serves as the "reducing power" for the reduction of CO_2 to form sugar.

Q. What are photosynthetic pigments and what role they play in the absorption and conversion of light energy? Exercise LO 1

Role of Photosynthetic Pigments In Photosynthesis:

- Photosynthetic **pigments** are present in thylakoid membranes.
- These pigments capture light energy necessary for photosynthesis. Some of the pigments are **chlorophyll a, chlorophyll b, xanthophylls, carotenes.**
- Different pigments absorb light of different wavelengths (colours).
- **Photon:** Light behaves like a stream of particles called **photons.** Pigment molecules absorb one photon at a time.
- When a pigment molecule absorbs a photon, its electrons move to **higher energy level**, so, it becomes energy-rich or excited.

- Short **wavelength** photons (blue) have a higher energy than long wavelength (red) photons.
- More energetic photons (shorter wavelength) promote electrons to higher energy levels.

Check Understanding!

4. Why is chlorophyll a considered the primary pigment in photosynthesis?

Chlorophylls:

- Chlorophyll is a lipid molecule. Chlorophylls are of different kinds.
- Chlorophyll ***a***, ***b***, ***c*** **and** ***d*** are found in plants and algae.
- **Bacteriochlorophylls:** While the chlorophylls which are found in photosynthetic bacteria and are known as **bacteriochlorophylls.**

Structure of Chlorophyll Molecule:

- A molecule of chlorophyll consists of two parts:
  (a) A hydrophilic head (b) A hydrophobic tail

(a) Head of Chlorophyll:

- The head is made of a porphyrin ring, which further consists of four pyrrole rings (5 -sided N -containing compounds).
- The **four pyrrole** rings are held together by a magnesium atom in the centre.
- **Chlorophyll "a" + Chlorophyll "b":** In chlorophyll-a, the second pyrrole ring has methyl (CH_3) group while in chlorophyll-b, it has aldehyde (CHO) group at the same spot.
- The porphyrin ring of chlorophyll absorbs light.

(b) Tail of Chlorophyll:

- The tail is made of long hydrocarbon chain. It anchors the molecule in the thylakoid membrane.
- **Maximum Absorption Chlorophyll:** Chlorophylls absorb mainly **violet-blue (VB)** and **orange-red (OR)** wavelengths of light.
- **Least Absorption:** Green wavelengths are least absorbed by chlorophylls and are transmitted or reflected.

- Carotenoids, such as beta-carotene, play dual role in photosynthesis.
- They **capture light** energy in the blue and green regions of the spectrum and protect the photosynthetic apparatus from damage by excess light.

Accessory Pigments:

- **Definition:** The pigments which are not directly involve in photosynthesis are called **accessory pigments.**
- Accessory pigments include all the pigments, other than chlorophylla, which can gather light for photosynthesis.
- **Chlorophyll b** is an accessory pigment and others are **carotenoids** (carotenes and xanthophylls) and phycobilins. **Chlorophyll b** and carotenoids are found in plants while **phycobilins** are found in the red algae and cyanobacteria.
- When accessory pigments absorb light, they pass on the energy towards chlorophyll a. It is generally believed that the order of transfer of energy in plants is;

Carotenoids → Chlorophyll b → Chlorophyll a

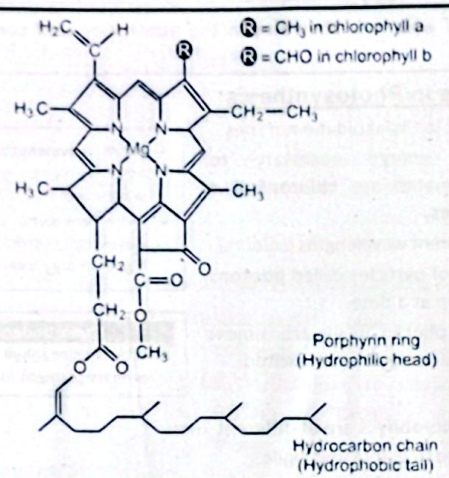


Figure: Molecular structure of chlorophyll a and chlorophyll b

- Some wavelengths not absorbed by chlorophyll-a are very effectively absorbed by chlorophyll-b and viceversa.
- Such differences increase the range of light absorbed by both chlorophylls.

Check Understanding!

5. Which component is shared by both Photosystem I and II and is essential for initiating the light reactions?
A) Plastoquinone
B) Reaction center with chlorophyll a
C) Oxygen-evolving complex
D) ATP synthase

Q. How are the absorption spectra of chlorophyll 'a' and 'b' different? (Exercise Q.4)

➢ **Absorption Spectrum:**

- A graph showing different wavelengths of light absorbed by a pigment, is called absorption spectrum of the pigment.
- **Maximum Absorption By Chlorophyll:** Absorption spectrum of chlorophylls indicates that absorption of **blue light (430 nm) and red light (670 nm)** is maximum. Absorption peaks of carotenoids are different from those of chlorophylls (Fig).
- Action spectrum of photosynthesis also shows that blue and red parts lights are the most effective. This means that the **action spectrum** of photosynthesis coincides with the absorption spectrum of photosynthetic pigments.

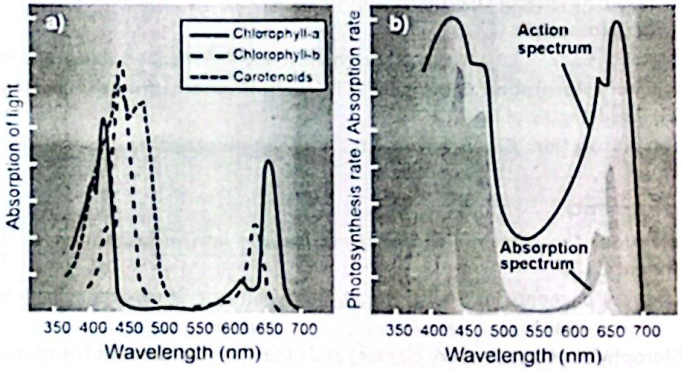


Figure: (a) -Absorption spectrum; (b) - Action spectrum

Q. Describe and illustrate how photosynthetic pigments are organized in thylakoid membrane? (Exercise Q.4)

➲ Organization of Photosynthetic Pigments: (Photosystems)

- The photosynthetic pigments organized into clusters are called photosystems. The photosystems are embedded in thylakoid membranes of chloroplasts.
- For efficient absorption and utilization of solar energy photosystems are very important

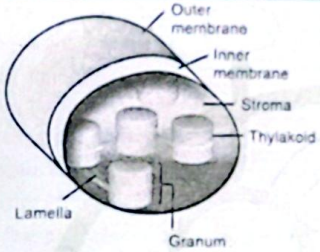


Figure: Structure of Chloroplast

Check Understanding!

6. What is the function of the DNA-protein complexes in chloroplast photosystems?

➢ **Components of Photosystem:**

- Photosystems contain photosynthetic pigments and the carriers of electron transport chain. Each photosystem consists of:
  (a) A light gathering 'antenna complex' **(b) A 'reaction centre'**

(a) Antenna Complex:

- Antenna complex has many pigment molecules which **capture** light energy and pass the excitation energy (in the form of high-energy electrons) to the reaction centre.

(b) Reaction Center:

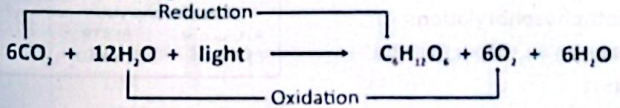
- The reaction centre has one or more molecules of chlorophyll-a, which pass the high-energy electrons to a primary electron acceptor. The electron acceptor passes them on to the series of electron carriers, collectively called electron transport chain.

➢ **Types of Photosystem:**

- In chloroplast, there are **two photosystems**:
  (a) Photosystem-I (PS-I) **(b) Photosystem-II (PS-II)**
- These are named so in order of their discovery. PS-I has P700 chlorophyll-a molecule in its reaction centre and it absorbs maximum light of 700 nm.
- The reaction centre of PS-II has P680 chlorophyll-a, which absorbs best the light of 680 nm.

➲ Mechanism of Photosynthesis

- Photosynthesis is a **redox (oxidation-reduction)** process. In which water is oxidized & CO_2 is reduced.
- As indicated in the **photosynthesis** equation below, when water molecules are **split apart**, they are actually **oxidized** (they lose electrons and hydrogen ions) and yield oxygen.
- Meanwhile, CO_2 is reduced to sugar as electrons and hydrogen ions are added to it. In this way oxidation and reduction go hand in hand.



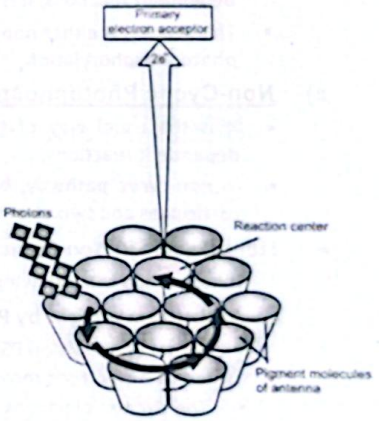


Figure: Photosystem

- **Photosynthesis** is not a simple, single-step process. Rather, it is a complex metabolic **pathway** consisting of a series of reactions.
  (1) The **light-dependent reactions** which take place on the thylakoid membranes of the grana
  (2) The **light-independent reactions** which take place in the stroma of the chloroplasts. Figure shows the summary of these reactions.

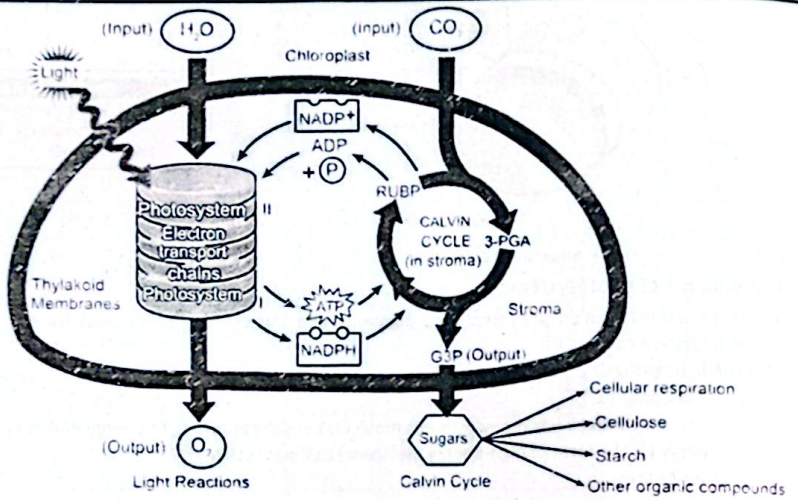


Figure: Overview of photosynthesis

Q. What are the events that capture light and convert it into chemical energy during light dependent reactions? Exercise L.Q.5

(1) Light- Dependent Reactions:

- Key Events in the Light-Dependent Reactions of Photosynthesis:
  - (i) Absorption of light energy by photosynthetic pigments,
  - (ii) Excitation of electrons by that energy,
  - (iii) Formation of ATP and NADPH.
- The formation of ATP is the most important step of **light-dependent** reactions. It is called photophosphorylation
- This process is either **non-cyclic photophosphorylation** or **cyclic photophosphorylation.**

- **During light dependent reactions,** light energy is absorbed and converted into chemical energy, which is in the form of reducing and assimilating powers i.e., NADPH and ATP.
- **Light independent reactions** use NADPH and ATP for the reduction CO_2 and thus store chemical energy in the form of C-H bond energy.

a) Non-Cyclic Photophosphorylation:

- It is the usual way of the **production of ATPs** during light-dependent reactions.
- In **non-cyclic pathway, both photosystems** i.e., PS-I and PS-II participate and two electron chains are involved (Fig.).

Check Understanding!

7. What is the ultimate source of electrons that flow through the non-cyclic photophosphorylation pathway?
A) Glucose B) ATP
C) Water D) NADPH

➢ **Steps Involve in Non-Cyclic Photophosphorylation:**

It happens in the following way.

i. Absorption of light by PS-II:

- When light falls on PS-II, the energy level of chlorophyll **molecules** of its antenna centre rises. Two excited electrons move from them and pass to different chlorophyll molecules.
- The excited electrons reach **P680 chlorophyll** present in the reaction centre. Due to energy boost of P680 chlorophyll, its two excited electrons pass to the **primary electron** acceptor of photosystem-II.
- Due to it, an electron "hole" is created in p680 chlorophyll, which has become a strong oxidizing agent.

- The oxygen produced during photolysis is the main source of atmospheric oxygen.

ii. Photolysis of Water:

- The electron "hole" in chlorophyll molecule is filled by the electrons from water.
- When water molecule reacts with oxidized chlorophyll in PS-II, it breaks into two hydrogen ions, an oxygen atom (which immediately combines with another oxygen to form O_2, and two electrons. These two electrons fill the "hole" in P680 chlorophyll.
- The water **splitting step** of photosynthesis is called **photolysis**

iii. Electron flow from PS-II to PS-I:

Check Understanding!

8. Compare Photosystem I and Photosystem II.

- In step 1, the photoexcited electrons of P680 chlorophyll were received by primary electron acceptor of PS-II.
- Now, these electrons pass to PS-I via an electron transport chain of PS-II. This chain consists of electron carriers called plastoquinone (PQ), cytochrome complex, and plastocyanin (PC).
- As electrons move down the chain, their energy goes on decreasing and is used by thylakoid membrane to produce ATP through the process of chemiosmosis.

iv. Absorption of light by PS-I:

- In the next step light energy is absorbed by PS-I. The energy level of its chlorophyll molecules boosts to very hight level. The excited electrons of P700 chlorophyll of the reaction centre pass to the primary electron acceptor of PS-I.
- The electrons coming from PS-II fill the electron "hole" of P700 chlorophyll of PS-I.

v. Electron flow from PS-I to $NADP^+$:

- The primary electron acceptor of PS-I passes the photoexcited electrons to a second electron transport chain.
- These electrons are received by ferredoxin (FD). An enzyme NADP reductase transfers these electrons from FD to $NADP^+$. When $NADP^+$ gets two electrons and an H^+ ion, it is reduced to NADPH. This reaction stores the high-energy electrons in NADPH.

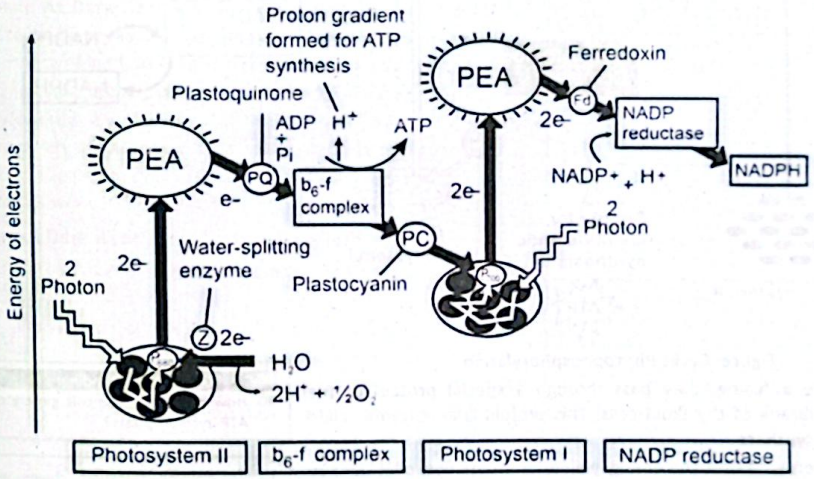


Figure: Light-dependent reactions (noncyclic photophosphorylation)

- So, the light energy gets converted into chemical energy (ATP and NADPH).
- The zigzag path taken by electrons through PS-II and PS-II and electron transport chains, is called **Z-scheme.**

Q. Illustrate the cyclic photophosphorylation. [Exercise L.Q.5]

b) Cyclic Photophosphorylation:

- Under certain conditions when system lack **ATPs photoexcited** electrons of PS-I take an alternative path called cyclic electron flow. This path uses PS-I but not PS-II.
- These electrons cycle back from primary electron acceptor of PS-I to P700 chlorophyll via the electron transport chain.
- There is no production of NADPH and no release of oxygen. Cyclic flow however generates ATP (Fig.). It happens when Calvin cycle slows down and NADPH accumulates in chloroplast.

Check Understanding!
9. Which of the following occurs only in Photosystem II and not in Photosystem I?
A) Electron excitation
B) $NADP^+$ reduction
C) ATP formation
D) Photolysis of water

➲ Chemiosmosis

- During light-dependent reactions when electrons are **transferred** to the series of carriers of electron transport chain, it results in oxidation and reduction reactions.
- A carrier is oxidized when it loses electrons and next carrier is reduced when it gets electrons. Electrons lose energy during this carrier-to-carrier transport. Chemiosmosis is the **mechanism** in which thylakoid membranes couple these redox reactions with the **synthesis of ATPs.**
- **How does chemiosmosis use the energy released from electrons to synthesize ATP?**
- Actually, this energy is spent for the active transport of H^+ ions from the **stroma** of chloroplast to its inner compartment (lumen). In this way many **H^+ ions** are deposited in the lumen. This H^+ ion gradient in lumen has potential energy. The **H^+ Ions** diffuse back from lumen in **stroma** (from higher concentration in lumen to lower concentration).

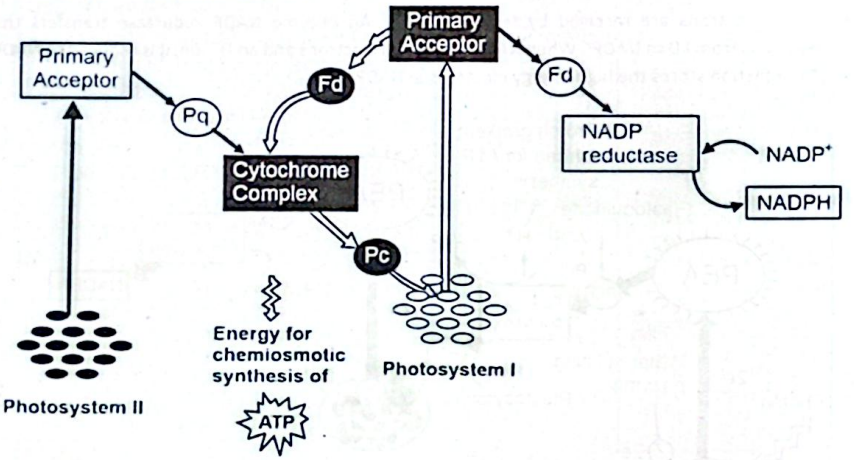


Figure: Cyclic Photophosphorylation

- While diffusing, they pass through a **special protein** of the membrane of thylakoid cells. This protein is an enzyme called **ATP synthase**.
- This enzyme uses the energy yielded from the flow of H^+ ions to make a bond between ADP and inorganic phosphate (Pi). So, ADP is **converted into ATP** and energy is packed in it (Fig).

Check Understanding!
10. How does chemiosmosis generate ATP in chloroplasts?

- The electron transport chains in mitochondria and chloroplasts generate ATP by the same mechanism of chemiosmosis.

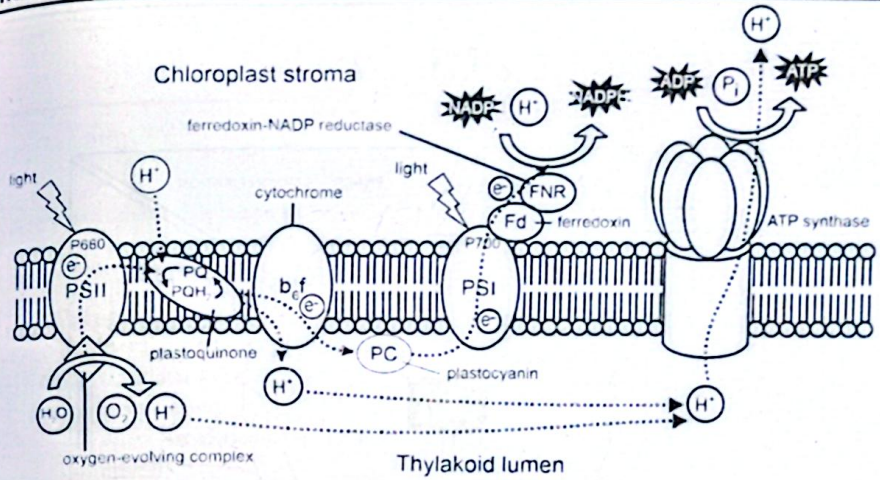


Figure: Electron transport chain and chemiosmosis in chloroplast

Q. Describe light independent reactions of photosynthesis in terms of paragraph and illustrate in terms of Calvin cycle. [Exercise L.Q.7]

(2) Light-Independent Reactions: (Dark Reactions, CO_2 Fixation)

- Light-independent reactions are a series of reactions which happen in the stroma of chloroplast and can occur **with or without light**.
- These reactions use carbon from CO_2, energy **from ATP**, and **hydrogen** ions from NADPH to construct energy-rich sugar molecules.
- **Name As Dark Reaction:** These are also called dark reactions because these reactions **can occur** in the absence as well as in the presence of light, as long as ATP and NADPH are available (Fig.).
- **Name As Calvin Cycle:** The details of dark reactions were discovered by Melvin Calvin and his colleagues at the University of California. That is why, the dark reactions are also called the **Calvin cycle**. Calvin was awarded Nobel Prize in 1961 for this work.

Check Understanding!
11. Which statement best describes the stroma coupling factor?
A) Splits water
B) Absorbs light
C) Synthesizes ATP
D) Transfers electrons

Phase I of Dark Reactions: Carbon Fixation:

- Carbon fixation refers to the **initial incorporation** of CO_2 into organic material.
- **Formation of RuBP:** An enzyme known as **ribulose biphosphate carboxylase** (or Rubisco; probably the most abundant protein on Earth) combines three molecules of CO_2 with three molecules of a **five-carbon sugar** named ribulose biphosphate (RuBP).
- **Synthesis of 3-PGA:** RuBP results in the formation of six molecules of a three-carbon compound called 3-phosphoglyceric acid (3-PGA) or 3-phosphoglycerate.

- **Name As C-3 Pathway:** Since the product of **initial carbon** fixation is a **three-carbon** compound, the Calvin cycle is also known as C-3 pathway.

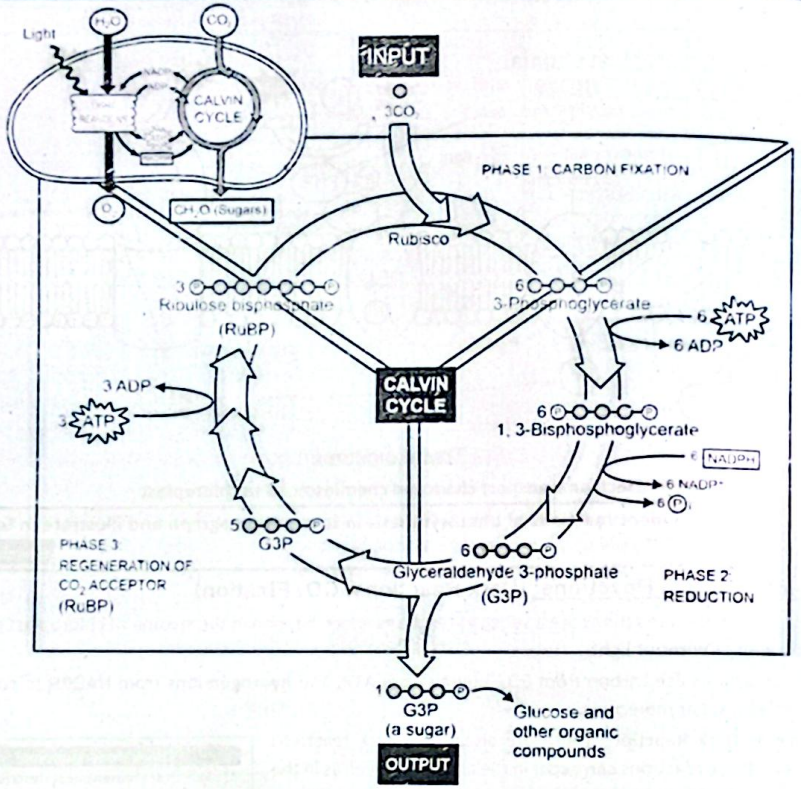


Figure: The Calvin cycle

➢ Phase-II of Dark Reactions: (Reduction)

- **Synthesis of 1,3-bisphosphoglyceric Acid:** In this phase, **six phosphate** groups are taken from six ATPs and added to molecules of **3PGA**. In this way, each 3-PGA changes into 1,3biphsophoglyceric acid.
- **Reduction of 1,3-bisphosphoglyceric PGA into G3D:** Each 1,3-biphsophoglyceric acid is then reduced to Glyceraldehyde 3-phosphate (G3P). NADPH provides hydrogen for this reduction. During this step, phosphate groups are also detached from 1,3-biphsophoglyceric acid.
- In this way, **six molecules** of G3P are produced, out of which one molecule leaves the cycle. It combines with another G3P and makes glucose, which may be then converted to other carbohydrates.

> • G3P is the same three-carbon sugar which is formed in glycolysis (first phase of cellular respiration) by the splitting of glucose.

Check Understanding!

12. What is carbon fixation in the Calvin cycle?

➢ Phase-III of Dark Reaction: (Regeneration of RuBp)

- Through a series of reactions, five molecules of G3P are converted into three molecules of Ribulose phosphate (RuP).
- One phosphate group is added to each RuP to make three molecules of RuBP by using three ATPs of light reactions. These RuBP receive CO_2 again, and the cycle continues.

CELLULAR RESPIRATION

- Cellular respiration is the **universal process** by which organisms **break down complex** carbon containing compounds (e.g., glucose) to get useable energy. Cellular respiration can be summarized as:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Energy$$

- You can see that **the arrangement** of atoms in glucose has more stored energy while there is much less energy in the arrangement of atoms in CO_2 and H_2O. The reason is that there are many C – H bonds in glucose but there are no such bonds in CO_2 and H_2O.
- The basic events in cellular respiration in all cells are much similar. Almost all cells in all organisms use glucose as energy source. That is why, glucose is known as respiratory fuel.

> • The exchange of CO_2 and O_2 between the organism and its environment is called external respiration or breathing.
> • Cellular respiration is the process by which energy is made available to cells in a step-by-step oxidation of food in the cells.

➢ Types of Cellular Respiration:

- There are two main types of cellular respiration:
  - i. Anaerobic respiration (fermentation) takes place in the absence of oxygen
  - ii. Aerobic respiration takes place in the presence of oxygen.
- In the first step of both these types, glucose is split into two molecules of pyruvic acid ($C_3H_4O_3$) in a process called glycolysis. The next reactions of pyruvic acid are different in anaerobic and aerobic respiration.

Q. What happens with glucose in anaerobic respiration and how different organisms modify the end products? (Exercise Q.5)

➲ Mechanism of Anaerobic Respiration

- Anaerobic respiration happens in many microorganisms and in some cells of higher plants. It also happens in the muscle cells of vertebrates.
- In anaerobic respiration, glucose is not completely oxidized. This type of respiration yields relatively small amount of energy from glucose molecule. As a result of anaerobic respiration, one glucose molecule yields only two ATPs (only about 2% of the energy present in glucose). The energy in two ATPs is equivalent to 14.6 kcal.
- Anaerobic respiration consists of glycolysis followed by the reduction of pyruvic acid by NADH to either lactic acid or alcohol and CO_2 i.e., it may again be classified as;

Check Understanding!

13. Why is the Calvin cycle called a "cycle"?

A) It occurs only once
B) It produces oxygen repeatedly
C) It regenerates RuBP to start again
D) It breaks down glucose continuously

> • Many of the reactions that occur in your cells also occur in the cells of frog, mice, planaria, mushrooms and radishes.

a. Alcoholic Fermentation:

In primitive prokaryotic cells (bacteria) and in some eukaryotic cells such as yeast, pyruvic acid is further broken down by alcoholic fermentation into alcohol (C_2H_5OH) and CO_2.

$$2(\underset{\text{Pyruvic acid}}{C_3H_4O_3}) \xrightarrow{4H} 2(\underset{\text{Ethyl alcohol}}{C_2H_6O_1})$$

b. Lactic acid Fermentation:

In lactic acid fermentation, each pyruvic acid molecule is converted into lactic acid $C_2H_6O_3$ in the absence of oxygen gas.

$$2(\underset{\text{Pyruvic acid}}{C_3H_4O_3}) \longrightarrow 2(\underset{\text{Ethyl alcohol}}{C_2H_5OH}) + 2CO_2$$

- This form of anaerobic respiration occurs in muscle cells of **humans and other animals.**
- It happens during extreme physical activities, when oxygen cannot be transported to the cells as rapidly as it is needed.
- Many bacteria also use lactic acid fermentation to get energy.

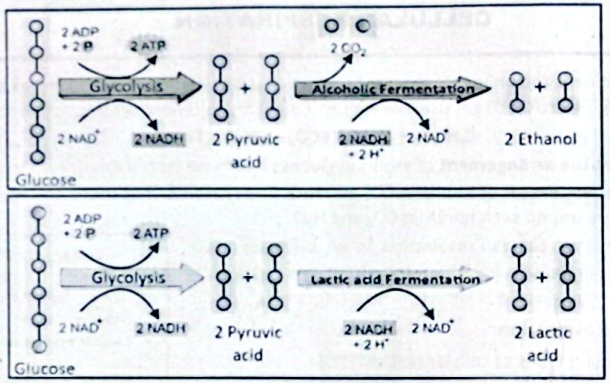


Figure: Alcoholic fermentation and lactic acid fermentation

Mechanism of Aerobic Respiration

- The complete breakdown of glucose molecule occurs only in aerobic respiration.
- During aerobic respiration, glucose is broken down to pyruvic acid which is then completely oxidized to CO_2 and water and all the energy stored in its C – H bonds, is released.
- Cellular respiration is a continuous process, but for study purposes we can divide it into four main stages.
  - **i. Glycolysis**
  - **ii. Pyruvic acid oxidation**
  - **iii. Krebs cycle or citric acid cycle**
  - **iv. Electron transport chain and Chemiosmosis**
- Glycolysis occurs in the cytosol and oxygen is not essential for this stage. The other three stages occur within mitochondria where the presence of oxygen is essential (Fig).

- When life evolved on planet Earth free O_2 was not available. So, only anaerobic respiration was possible.
- But with the evolution of photosynthesis on Earth, molecular oxygen accumulated slowly in the atmosphere. The presence of free oxygen made evolution of aerobic respiration possible.

Check Understanding!

14. What is anaerobic respiration and when does it occur?

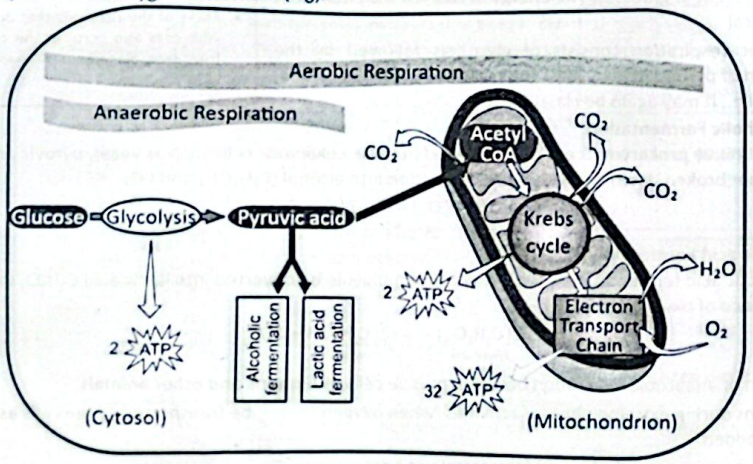


Figure: Overview of cellular respiration

Q. How is glucose broken down to pyruvic acid in glycolysis? (Exercise L.Q.9)

Stage (i): Glycolysis

- Glycolysis is the breakdown of glucose into **two molecules** of pyruvic acid.
- Glycolysis takes place in both types of respiration i.e., anaerobic and aerobic.
- The breakdown of glucose takes place in a series of steps, each catalysed by a specific enzyme (Fig). All these enzymes are found dissolved in the cytosol.
- In addition to the enzymes, ATP and coenzyme NAD^+ (nicotinamide adenine dinucleotide) are also essential. **Glycolysis involves following reactions.**

Check Understanding!

15. What is the primary ATP-generating step in aerobic respiration?

A) Glycolysis
B) Pyruvate oxidation
C) Krebs cycle
D) Electron transport chain

Steps Involve in Glycolysis:

(a) Preparatory Phase

- It involves the expenditure of energy and the breakdown of glucose. It consists of the following steps:
  - **i.** A phosphate group is transferred from ATP to glucose. As a result, **glucose changes into of glucose 6 -phosphate.**
  - **ii.** Glucose 6-phosphate is converted into its isomer called **fructose 6-phosphate.**
  - **iii.** Another ATP molecule transfers a second phosphate group to fructose 6-phosphate. So, it becomes fructose 1, 6-biphosphate.
  - **iv.** Fructose 1,6 -biphosphate is highly reactive and breaks into two molecules of three-carbon intermediates i.e., glyceraldehyde 3-phosphate (G3P) and dihydroxy acetone phosphate (DAP). These are inter-converted and result in two molecules of G3P.

(b) Oxidative Phase:

- It involves the **removal of hydrogen** from G3P and packing of released energy in the form of ATP. It consists of the following steps:

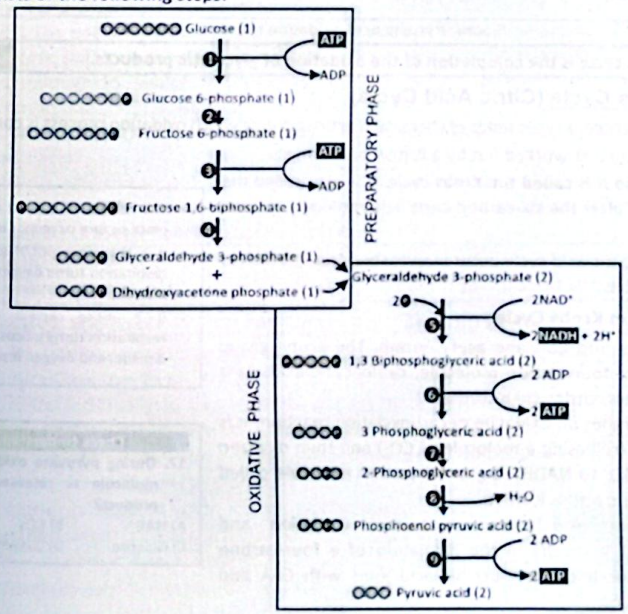


Figure: Steps in glycolysis