



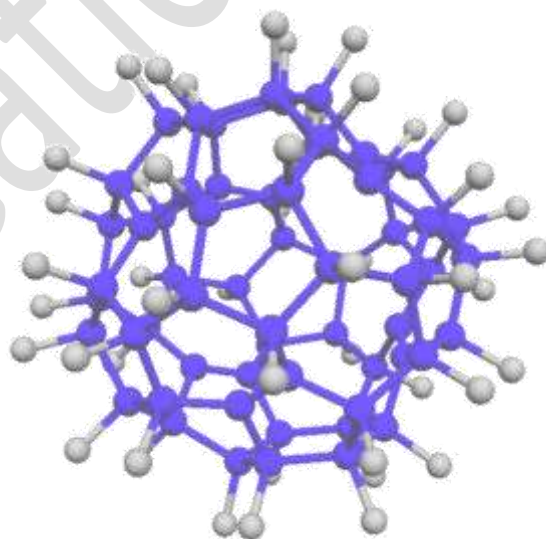
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# BIOMOLECULES

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CHAPTER: - 9



**BIOLOGY**  
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## CHAPTER: - 9

# BIOMOLECULES

**Introduction:** - Biomolecules are organic molecules that are present in and essential to the structures and functions of living organisms. These molecules play critical roles in the maintenance and metabolic processes of life. There are four main types of biomolecules:

- 1. Proteins:** These are complex molecules made up of amino acid chains. Proteins serve a wide range of functions in organisms, such as enzymatic reactions, transportation of molecules, structural support, cell signaling, and many more. Enzymes, which are specialized proteins, speed up biochemical reactions.
- 2. Nucleic Acids:** These are the genetic materials of cells and come in two forms: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA holds the genetic code or instructions for making all the proteins in the cell, while RNA acts to carry out these instructions. DNA is usually found in the nucleus of eukaryotic cells and in a region called the nucleoid in prokaryotic cells.
- 3. Carbohydrates:** These are organic molecules made up of carbon, hydrogen, and oxygen. They are the primary energy source for many living organisms. Simple sugars like glucose and fructose can be combined in various ways to form complex carbohydrates like starch and cellulose. While starches serve as energy storage for plants, cellulose provides structural support in the cell walls of plants.
- 4. Lipids:** These are hydrophobic (water-insoluble) molecules that include fats, oils, waxes, phospholipids, and steroids. Lipids are important for energy storage, insulation, and cushioning, as well as being critical components of cell membranes. Phospholipids, in particular, form the bilayer structure of cell membranes, creating a barrier and playing a role in the selective permeability of cells.

### I. HOW TO ANALYSE CHEMICAL COMPOSITION?

#### **1. Methodology for Analysis:**

- **Tissue Preparation:** Grind living tissue (e.g., vegetable, liver) in trichloroacetic acid to create a slurry.
- **Fractionation:** Strain the slurry to obtain:
  - **Acid-soluble pool (Filtrate):** Contains thousands of organic compounds.
  - **Acid-insoluble fraction (Retentate):**

## 2. Chemical Identification:

- Extract compounds from the tissue.
- Utilize separation techniques to isolate specific compounds.
- Employ analytical techniques to determine molecular formula and probable structure of isolated compounds.

## 3. Biomolecules - Definition and Classification:

- Organic and inorganic compounds derived from living tissues.
- Elemental analysis provides insights into elemental composition, such as hydrogen, oxygen, carbon, and more.
- Functional groups identified can range from aldehydes, ketones to aromatic compounds.

**A Comparison of Elements Present in Non-living and Living Matter\***

Element	% Weight of	
	Earth's crust	Human body
Hydrogen (H)	0.14	0.5
Carbon (C)	0.03	18.5
Oxygen (O)	46.6	65.0
Nitrogen (N)	very little	3.3
Sulphur (S)	0.03	0.3
Sodium (Na)	2.8	0.2
Calcium (Ca)	3.6	1.5
Magnesium (Mg)	2.1	0.1
Silicon (Si)	27.7	negligible

\* Adapted from CNR Rao, *Understanding Chemistry*, Universities Press, Hyderabad.

## II. PRIMARY AND SECONDARY METABOLITES

### 1. Introduction

- The field of chemistry is extensive, with the isolation, structural determination, and synthesis of numerous compounds from living organisms being a significant focus.
- Biomolecules encompass thousands of organic compounds such as amino acids and sugars. These biomolecules can be referred to as 'metabolites'.

### 2. Primary Metabolites

- **Definition:** Organic compounds that are crucial for the normal growth, development, and reproduction of an organism.
- **Examples:** Amino acids, sugars, nucleic acids, and certain organic acids.
- **Presence:** Noted in animal tissues.
- **Function:** They play known roles in the normal physiological processes of organisms.

### 3. Secondary Metabolites

- **Definition:** Organic compounds produced by plants, fungi, and microbes that are not directly involved in the normal growth, development, or reproduction of an organism.

- **Examples:** Alkaloids, flavonoids, rubber, essential oils, antibiotics, colored pigments, scents, gums, and spices.
- **Function:**
  - Their exact roles in their host organisms are not always well-understood.
  - They have significant value for human welfare, including in the production of rubber, drugs, spices, scents, and pigments.
  - Some of these metabolites have recognized ecological importance.

**Some Secondary Metabolites**

Pigments	Carotenoids, Anthocyanins, etc.
Alkaloids	Morphine, Codeine, etc.
Terpenoides	Monoterpenes, Diterpenes etc.
Essential oils	Lemon grass oil, etc.
Toxins	Abrin, Ricin
Lectins	Concanavalin A
Drugs	Vinblastin, curcumin, etc.
Polymeric substances	Rubber, gums, cellulose

#### 4. Distinction

- Primary metabolites are essential for basic survival and functions of an organism.
- Secondary metabolites, while not essential for basic survival, have various other roles, some of which are beneficial to humans and some that are ecologically significant.

#### 5. Future Learning

- More detailed information about the roles and functions of these metabolites will be explored in subsequent chapters and academic years.

### III. BIOMACROMOLECULES

#### 1. General Understanding

- Biomolecules, or chemical compounds found in living organisms, are of two main types based on their molecular weights.

#### 2. Micromolecules/Biomolecules

- Found in the acid soluble pool.
- Molecular weights range from 18 to around 800 daltons (Da).
- Examples aren't explicitly mentioned in the text, but these typically include smaller molecules like amino acids, nucleotides, and monosaccharides.

#### 3. Macromolecules/Biomacromolecules

- Found in the acid insoluble fraction.
- Major types: Proteins, nucleic acids, polysaccharides, and lipids.

- Except for lipids, they have molecular weights of 10,000 daltons and above.
- Mostly polymeric in nature.

#### ❖ Major Classes of Biomolecules

- Carbohydrate
- Lipid
- Protein
- Nucleic Acids

#### a) CARBOHYDRATES

- **Definition:** Organic molecules composed of carbon (C), hydrogen (H), and oxygen (O) with a general formula of  $C_m(H_2O)_n$ .
- **Primary Roles:**
  1. **Energy Source:** Primary energy source for most organisms.
  2. **Structural Components:** Found in the cell walls of plants (cellulose) and exoskeletons of insects (chitin).
- **Classification:**
  1. **Monosaccharides (Simple Sugars):**
    - Single sugar molecule.
    - **Examples:** glucose, fructose, galactose.
  2. **Disaccharides:**
    - Two monosaccharides linked together.
    - **Examples:** sucrose (glucose + fructose), lactose (glucose + galactose).
  3. **Polysaccharides:**
    - Chains of many monosaccharides.
    - **Examples:** starch, glycogen, cellulose.

#### ➤ MONOSACCHARIDES

- **Definition:** Monosaccharides, often referred to as "simple sugars", are the most basic form of carbohydrates. They consist of a single sugar molecule and cannot be hydrolyzed to yield simpler sugars.
- **General Formula:**  $C_m(H_2O)_n$ , where "m" and "n" can range from 3 to 7.
- **Key Characteristics:**
  1. **Solubility:** Typically, soluble in water due to their hydroxyl (-OH) groups.
  2. **Sweet Taste:** Many have a sweet taste, making them a key component in various natural sweeteners.

**3. Optical Activity:** Most of them are optically active, meaning they can rotate the plane of polarized light due to their asymmetric carbon atoms.

• **Major Types & Examples:**

1. **Trioses:** 3 carbon atoms.

- Example: Glyceraldehyde

2. **Tetroses:** 4 carbon atoms.

- Example: Erythrose

3. **Pentoses:** 5 carbon atoms.

- Examples: Ribose (found in RNA) and Deoxyribose (found in DNA)

4. **Hexoses:** 6 carbon atoms.

- Examples: Glucose (major energy source in cells), Galactose (found in milk), Fructose (found in fruits).

5. **Heptoses:** 7 carbon atoms.

- Less common than the other types.

• **Isomerism:**

1. Monosaccharides can exist in multiple forms called isomers that have the same molecular formula but different structures or spatial arrangements.
2. Example: Glucose and fructose are isomers with the formula  $C_6H_{12}O_6$ , but they have different structures.

• **Ring Structure:**

1. In aqueous solutions, many monosaccharides tend to form ring structures. This cyclization is due to the interaction between the carbonyl group and one of the hydroxyl groups in the molecule.

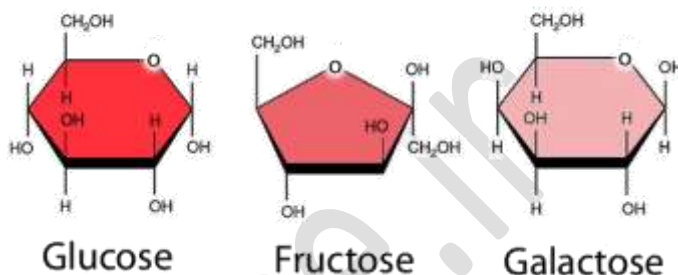
• **Function:**

1. Primary source of energy in metabolism.
2. Building blocks for disaccharides and polysaccharides.

• **Derivatives:**

1. Monosaccharides can be modified to produce other molecules such as amino sugars (e.g., glucosamine) and sugar acids (e.g., gluconic acid).

## Monosaccharides



Monosaccharides play a fundamental role in biochemistry and physiology, and understanding their structure and function is crucial for grasping more complex

carbohydrate metabolism processes. For a more comprehensive understanding, consulting advanced biochemistry or organic chemistry resources is advisable.

## ➤ DISACCHARIDES

- **Definition:** Disaccharides are carbohydrates composed of two monosaccharide molecules. The two sugar molecules are linked together by a glycosidic bond.
- **Formation:**
  - Formed when two monosaccharides undergo a dehydration synthesis (or condensation) reaction. This involves the elimination of a water molecule.
  - The bond formed between the two monosaccharide units is known as a glycosidic bond.
- **Key Characteristics:**
- **Solubility:** Generally soluble in water.
- **Taste:** Many disaccharides, like sucrose, are sweet-tasting.
- **Digestion:** Require specific enzymes to be broken down into their constituent monosaccharides.
- **Major Types & Examples:**

### 1. Sucrose:

- Composed of: Glucose + Fructose
- Found in: Sugar cane, sugar beets, and is the common table sugar.
- Enzyme for Digestion: Sucrase

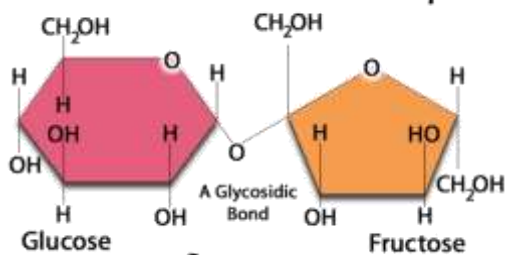
### 2. Lactose (Milk Sugar):

- Composed of: Glucose + Galactose
- Found in: Milk and dairy products.
- Enzyme for Digestion: Lactase
- Notably, some people are lactose-intolerant, meaning they lack sufficient lactase enzyme to digest lactose effectively.

### 3. Maltose:

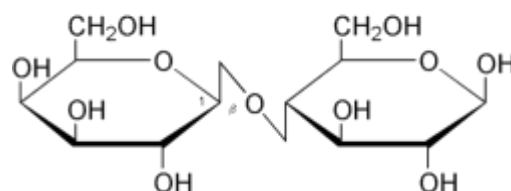
- Composed of: Glucose + Glucose
- Found in: Germinating seeds as they break down starch, and in certain fermentation processes.
- Enzyme for Digestion: Maltase

## A Disaccharide Example

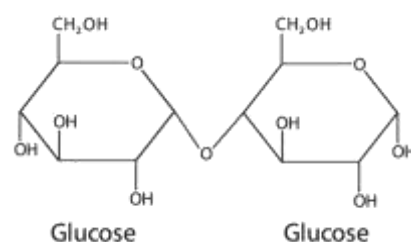


Sucrose

Lactose



## Maltose



- **Hydrolysis:**
  - The process of breaking down a disaccharide into its two monosaccharide components using water is termed hydrolysis. Specific enzymes catalyze this reaction in organisms to utilize the simpler sugars.
- **Function:**
  - Serve as a source of energy: They are broken down into their monosaccharide components, which can then be used in metabolic pathways to produce energy.
  - Serve as transport forms of sugars in plants (e.g., sucrose).

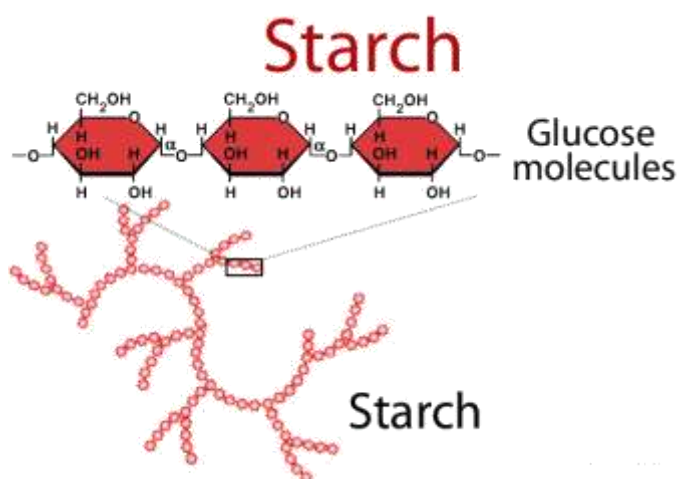
Disaccharides play a significant role in nutrition and metabolism. Understanding them aids in a better grasp of dietary needs, energy production processes, and certain health conditions like lactose intolerance.

## ➤ POLYSACCHARIDES

- **Definition:** Polysaccharides are complex carbohydrates made up of multiple monosaccharide units linked together through glycosidic bonds. They can consist of hundreds to thousands of monosaccharide units.
- **Formation:**
  - Formed by the condensation reaction of many monosaccharides, leading to the formation of glycosidic bonds and the release of water molecules.
- **Key Characteristics:**
- **Solubility:** Generally insoluble in water.
- **Taste:** Typically, not sweet, in contrast to monosaccharides and disaccharides.
- **Functionality:** Serve as energy storage molecules and structural components in plants and animals.
- **Major Types & Examples:**

### 1. Starch:

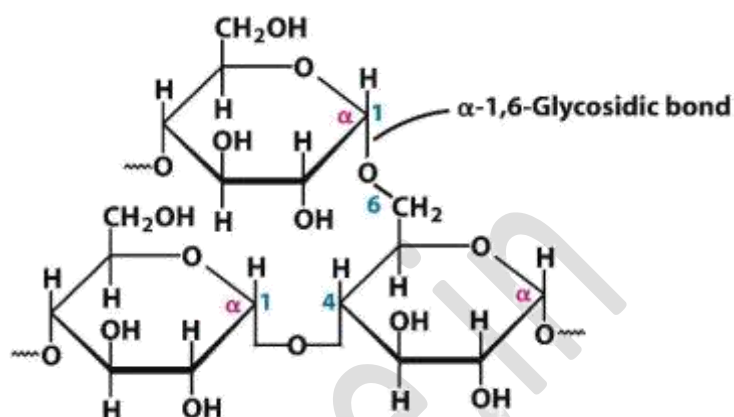
- Primary storage carbohydrate in plants.
- Comprises two components: Amylose (linear) and Amylopectin (branched).
- Found in: Roots, tubers, and seeds.



- Enzyme for Digestion: Amylase

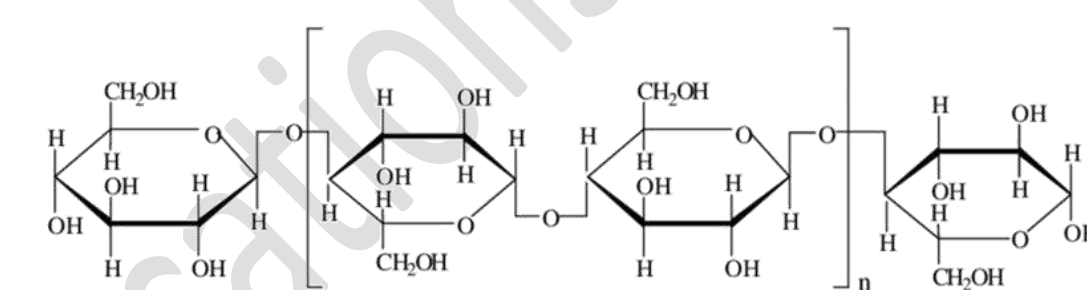
## 2. Glycogen:

- The primary storage carbohydrate in animals.
- Highly branched structure, allowing for rapid glucose release.
- Found in: Liver and muscle cells of animals.
- Often referred to as "animal starch."



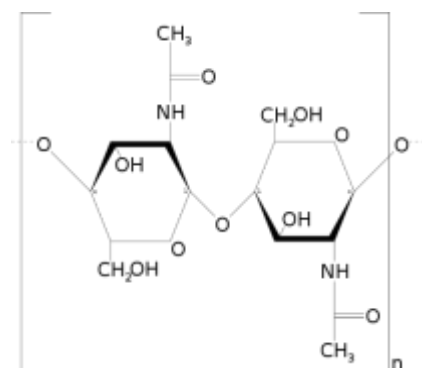
## 3. Cellulose:

- A major structural component in plant cell walls.
- Linear chain of glucose molecules.
- Unique because of its  $\beta$ -glycosidic linkages, which make it indigestible for most animals. Some animals, like ruminants, have symbiotic bacteria that can break it down.



## 4. Chitin:

- Structural polysaccharide found in the exoskeleton of arthropods (like insects and crustaceans) and cell walls of fungi.
- Made up of modified glucose units (N-acetylglucosamine).

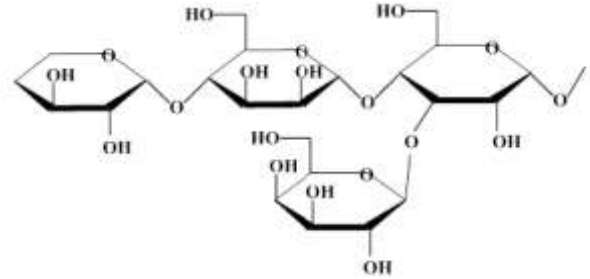


## 5. Pectin:

- Found in the cell walls of plants, especially in fruits.
- Used commercially to make jellies and jams due to its gelling properties.

## 6. Hemicellulose:

- Found in plant cell walls alongside cellulose.
- Not a single type of carbohydrate; instead, it's a mixture of different polysaccharides.



### • Functions:

- **Energy Storage:** Starch and glycogen are reservoirs of energy, ready to be broken down into simpler sugars when the organism needs energy.
- **Structural Support:** Compounds like cellulose and chitin provide structural integrity to plants and certain animals, respectively.

Polysaccharides are crucial for various biological functions in both plants and animals. Their diverse structures determine their specific roles in energy storage, structural support, and other functions.

### • Sources:

1. Found in foods like fruits, grains, vegetables, and milk products.

### • Importance in Diet:

1. Essential for providing energy.
2. Dietary fiber (indigestible polysaccharides) aids in digestion.

### • Storage:

1. **Animals:** Store carbohydrates as **glycogen** in the liver and muscles.
2. **Plants:** Store carbohydrates as **starch** in roots, stems, and leaves.

### • Structural Role:

1. **Cellulose:** Major component of plant cell walls.
2. **Chitin:** Forms the exoskeleton of arthropods.

### • Chemical Bonds:

1. Glycosidic bonds link sugar molecules together.

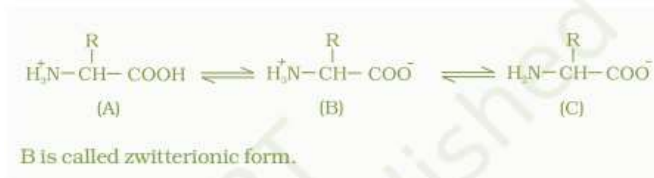
### • Homopolymers vs. Heteropolymers:

1. A homopolymer consists of only one type of monosaccharide (e.g., cellulose is a homopolymer of glucose).

- Many complex polysaccharides, including chitin, are also considered homopolymers, even if they have slightly modified sugar units.

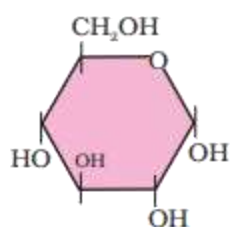
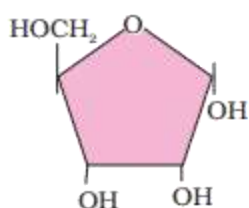
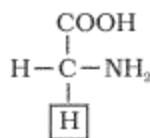
## b) Lipids:

- Water-insoluble molecules.
- Types include: -
  - Fatty Acids:** Carboxyl group attached to an R group. Can be saturated or unsaturated.
  - Glycerol:** Trihydroxy propane.
  - Phospholipids:** Contain phosphorous and a phosphorylated compound, e.g., Lecithin, crucial for cell membrane structure.
  - Complex Lipids:** Found especially in neural tissues.
- Distinction can be made based on melting points: Fats (higher melting point) vs. Oils (lower melting point).
  - Molecular weights do not exceed 800 Da.
  - They are categorized under the acid insoluble (macromolecular) fraction because:
    - Lipids are arranged into cell membranes and other structures.
    - When tissues are ground, these structures break and form vesicles that aren't water soluble.
    - As a result, lipid vesicles become part of the acid insoluble fraction.
  - Hence, lipids are not strictly macromolecules.

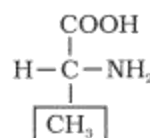


Average Composition of Cells

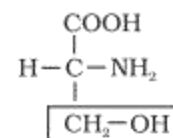
Component	% of the total cellular mass
Water	70-90
Proteins	10-15
Carbohydrates	3
Lipids	2
Nucleic acids	5-7
Ions	1

 $C_6H_{12}O_6$  (Glucose) $C_5H_{10}O_5$  (Ribose)**Sugars (Carbohydrates)**

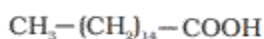
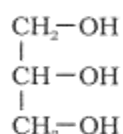
Glycine



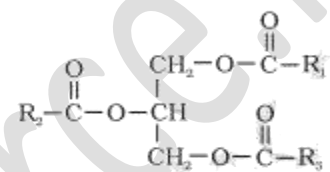
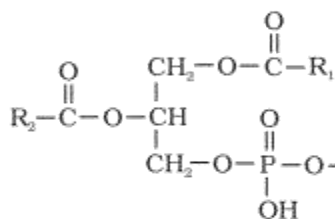
Alanine



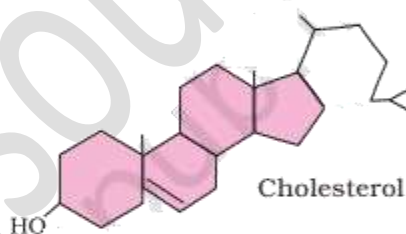
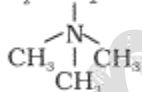
Serine

**Amino acids**Fatty acid  
(Palmitic acid)

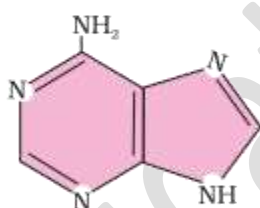
Glycerol

Triglyceride ( $R_1$ ,  $R_2$   
and  $R_3$  are fatty acids)

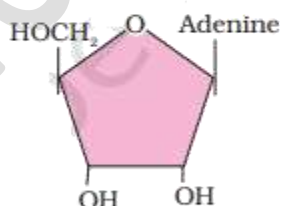
Phospholipid (Lecithin)



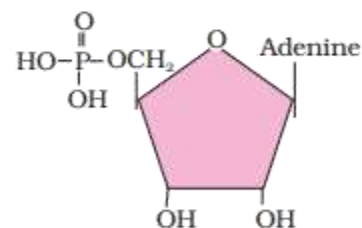
Cholesterol

**Fats and oils (lipids)**

Adenine (Purine)



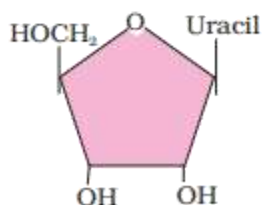
Adenosine



Adenylic acid



Uracil (Pyrimidine)



Uridine

**Nitrogen bases****Nucleosides****Nucleotide**

Diagrammatic representation of small molecular weight organic compounds in living tissues

## c) PROTEINS

### 1. Definition and Structure

- **Proteins:** They are polypeptides, which are linear chains of amino acids. These chains are held together by peptide bonds.

### 2. Protein Composition

- **Heteropolymer:** Proteins are considered heteropolymers because they are composed of 20 different types of amino acids (e.g., alanine, cysteine, proline, tryptophan, lysine, etc.).
- **Homopolymer:** A polymer made up of only one type of monomer repeating multiple times.

**Some Proteins and their Functions**

Protein	Functions
Collagen	Intercellular ground substance
Trypsin	Enzyme
Insulin	Hormone
Antibody	Fights infectious agents
Receptor	Sensory reception (smell, taste, hormone, etc.)
GLUT-4	Enables glucose transport into cells

### 3. Amino Acids: Essential vs. Non-Essential

- **Essential Amino Acids:** These are amino acids that the human body cannot synthesize. As a result, they must be obtained through the diet. Dietary proteins supply these essential amino acids.
- **Non-Essential Amino Acids:** These amino acids can be synthesized by our bodies; hence they don't have to be solely sourced from food.

#### Amino Acids:

- Defined as organic compounds containing both an amino group and an acidic group on the  $\alpha$ -carbon.
- 20 primary types are constituents of proteins, each with distinct R groups.
- Examples include:
  - **Glycine:** R group is hydrogen.
  - **Alanine:** R group is a methyl group.
  - **Serine:** R group is hydroxy methyl.
- Classification based on properties:
  - Acidic (e.g., glutamic acid)
  - Basic (e.g., lysine)
  - Neutral (e.g., valine)
  - Aromatic (e.g., tyrosine, phenylalanine, tryptophan)

**A List of Representative Inorganic Constituents of Living Tissues**

Component	Formula
Sodium	Na <sup>+</sup>
Potassium	K <sup>+</sup>
Calcium	Ca <sup>++</sup>
Magnesium	Mg <sup>++</sup>
Water	H <sub>2</sub> O
Compounds	NaCl, CaCO <sub>3</sub> , PO <sub>4</sub> <sup>3-</sup> , SO <sub>4</sub> <sup>2-</sup>

#### 4. Functions of Proteins

- **Transport:** Some proteins transport nutrients across cell membranes.
- **Defense:** Certain proteins defend against infectious organisms.
- **Hormonal:** Some proteins act as hormones and help regulate physiological functions.
- **Enzymatic:** Many proteins are enzymes that speed up biochemical reactions.

#### 5. Notable Proteins

- **Collagen:** The most abundant protein in the animal world. It provides structure and support in many tissues, especially in the skin, bones, and connective tissues.
- **Ribulose biphosphate Carboxylase-Oxygenase (RuBisCO):** Recognized as the most abundant protein in the biosphere. It plays a crucial role in the process of photosynthesis, facilitating the conversion of carbon dioxide and atmospheric oxygen.

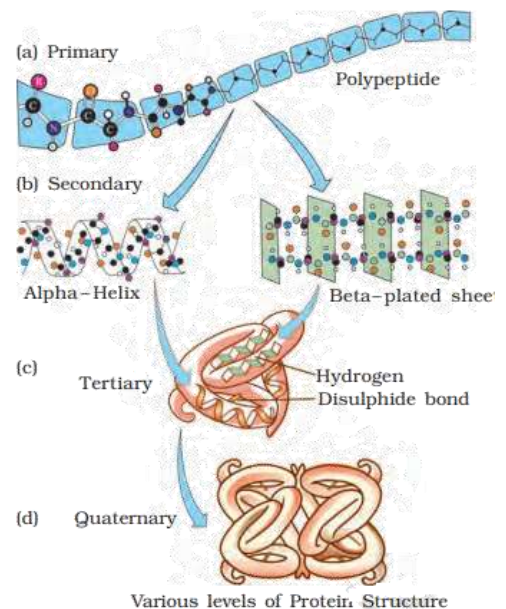
### STRUCTURE OF PROTEINS

#### 1. Introduction:

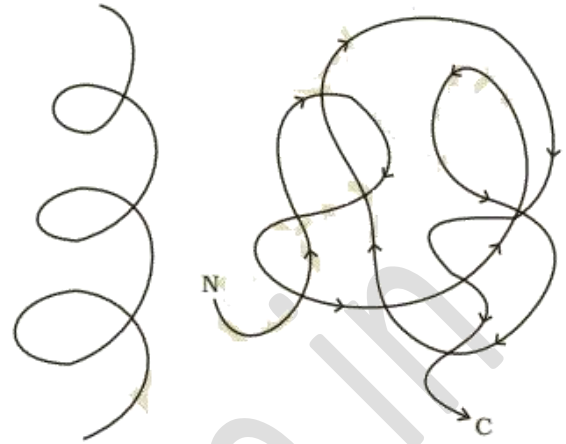
- Proteins are heteropolymers made up of amino acids.
- The structure of a protein is vital for its function and understanding how proteins carry out their roles in the cell.

#### 2. Levels of Protein Structure:

- **Primary Structure:** Refers to the linear sequence of amino acids in the protein. This positional information, from the first to the last amino acid, defines the protein's primary structure. The first amino acid is referred to as the N-terminal, while the last one is called the C-terminal.
- **Secondary Structure:** This involves local folding patterns within a protein. Common secondary structures include the  $\alpha$ -helix (right-handed helices only in proteins) and  $\beta$ -pleated sheets. These structures arise due to hydrogen bonds between the amino acids' backbone atoms.



- **Tertiary Structure:** This represents the three-dimensional shape or conformation of a polypeptide chain. It arises due to interactions between the side chains of the amino acids, including hydrophobic interactions, ionic bonds, hydrogen bonds, and disulfide bridges. The tertiary structure is essential for a protein's biological activity.
- **Quaternary Structure:** Found in proteins with multiple polypeptide subunits. It refers to the arrangement and interaction of these subunits. For instance, human hemoglobin is made of 4 subunits - two  $\alpha$  and two  $\beta$  types, giving it a quaternary structure.



Cartoon showing : (a) A secondary structure and (b) A tertiary structure of proteins

### 3. Analogy:

- A protein can be thought of as a thread. While primary structure is the sequence of this thread, secondary structures are local folding (like helices). In the tertiary structure, the thread folds upon itself into a more compact shape. In proteins with a quaternary structure, multiple such folded threads (or subunits) come together in a specific arrangement.

### 4. Importance:

- The precise structure at each level determines a protein's function. Changes or mutations in the amino acid sequence can lead to alterations in the protein's structure and function, sometimes resulting in diseases or disorders.

## d) NUCLEIC ACIDS

### 1. Definition and Importance:

- Nucleic acids are macromolecules found in the acid-insoluble fraction of living tissues.
- They are polynucleotides, playing a fundamental role in the genetics and function of living organisms.
- Alongside polysaccharides and polypeptides, nucleic acids form the primary macromolecular fraction of living tissues or cells.

### 2. Building Blocks:

- The basic unit of nucleic acids is the **nucleotide**.
- A nucleotide comprises three distinct chemical components:
  1. **Heterocyclic Compound:** This is the nitrogenous base of the nucleotide, which could be adenine, guanine, uracil, cytosine, or thymine.
  2. **Monosaccharide:** A sugar molecule that could either be ribose (a pentose sugar) or 2'-deoxyribose.
  3. **Phosphate Group:** Derived from phosphoric acid.

### 3. Nitrogenous Bases:

- **Purines:** Adenine (A) and Guanine (G) are the two primary purines in nucleic acids. They have a double-ring structure.
- **Pyrimidines:** Cytosine (C), Thymine (T), and Uracil (U) are the three primary pyrimidines in nucleic acids, having a single-ring structure.
- Adenine pairs with Thymine (in DNA) or Uracil (in RNA), and Guanine pairs with Cytosine through hydrogen bonds.

### 4. Types of Nucleic Acids:

- **Deoxyribonucleic Acid (DNA):** Contains the sugar 2'-deoxyribose and serves as the primary genetic material in cells. It is typically a double-stranded helix. Thymine is the pyrimidine base exclusive to DNA.
- **Ribonucleic Acid (RNA):** Contains the sugar ribose and plays various roles in the cell, including acting as a messenger (mRNA), a builder of proteins (rRNA and tRNA), and various other specialized functions. It is typically single-stranded. Uracil is the pyrimidine base exclusive to RNA.

## **IV. NATURE OF BOND LINKING MONOMERS IN A POLYMER**

### 1. Polypeptides/Proteins:

- **Peptide Bond:** This bond is formed between amino acids in a protein. Specifically, the carboxyl (-COOH) group of one amino acid reacts with the amino (-NH<sub>2</sub>) group of the adjacent amino acid. This reaction is a dehydration synthesis, meaning water is removed.



## **V. DYNAMIC STATE OF BODY CONSTITUENTS – CONCEPT OF METABOLISM**

### **1. Introduction**

- Living organisms, regardless of their complexity, contain thousands of organic compounds or biomolecules.
- These biomolecules are present in specific concentrations, denoted as mols/cell, mols/litre, etc.

### **2. Turnover of Biomolecules**

- A significant discovery was the turnover of biomolecules: they constantly transform into other biomolecules and are made from others.
- The constant making and breaking of these molecules via chemical reactions is termed metabolism.

### **3. Metabolic Reactions**

- Metabolic reactions lead to the transformation of biomolecules.
- **Examples:** a. Removal of CO<sub>2</sub> from amino acids converts an amino acid into an amine.  
b. Removal of an amino group in a nucleotide base.  
c. Hydrolysis of a glycosidic bond in a disaccharide.
- There are thousands of such reactions in living organisms.

### **4. Metabolic Pathways**

- Metabolic reactions often do not occur in isolation.
- Metabolites convert into each other through linked reactions forming metabolic pathways.
- These pathways can be: a. Linear b. Circular
- Pathways intersect each other, creating "traffic junctions".
- The flow of metabolites through these pathways is termed the dynamic state of body constituents.

### **5. Smooth Traffic of Metabolism**

- The flow of metabolites, like automobile traffic, has a specific rate and direction.
- In healthy conditions, this metabolic traffic operates flawlessly, without mishaps.

### **6. Catalyzed Reactions**

- Every metabolic reaction in living systems is catalyzed.
- There's no occurrence of an uncatalyzed metabolic conversion.

- Even physical processes, like CO<sub>2</sub> dissolving in water, are catalyzed reactions within living systems.

## 7. Role of Enzymes

- Catalysts that accelerate the rate of metabolic reactions are proteins.
- These proteins are called enzymes.

**Summary:** Living organisms are composed of thousands of biomolecules that are constantly in a state of turnover, converting from one form to another through metabolic reactions. These reactions are interconnected in pathways that allow for the smooth, catalyzed flow of metabolites, all facilitated by proteins called enzymes.

# VI. METABOLIC BASIS FOR LIVING

## 1. Introduction to Metabolic Pathways

- Metabolic pathways are a series of chemical reactions that transform biomolecules from one form to another.
- They can either lead to the formation of a more complex structure from a simpler one or vice versa.

## 2. Types of Metabolic Pathways

- **Anabolic Pathways (Biosynthetic)**
  - a. Create complex structures from simpler ones.
  - b. **Example:** Acetic acid becomes cholesterol.
  - c. Consume energy.
  - d. E.g., The synthesis of proteins from amino acids requires energy.

### **Catabolic Pathways (Degradation)**

- a. Break down complex structures into simpler ones.
- b. **Example:** Glucose becomes lactic acid in skeletal muscles.
- c. Result in the release of energy.
- d. A well-known catabolic pathway is glycolysis, where glucose is broken down into lactic acid through 10 metabolic steps.

## 3. Energy Management in Living Organisms

- Organisms can capture the energy released during catabolic reactions and store it as chemical bonds.
- This stored energy is later used for various activities like biosynthesis, osmotic work, or mechanical work.

#### 4. The Energy Currency: ATP

- Adenosine triphosphate (ATP) is a chemical compound that acts as the primary energy currency in living organisms.
- The bond energy in ATP is what living systems use to perform various tasks.

#### 5. Questions on Energy in Living Systems

- How organisms derive and store energy?
- What strategies have they evolved for energy management?
- In what form is the energy stored?
- How is this stored energy converted into useful work?

#### 6. Bioenergetics

- A sub-discipline called 'Bioenergetics' addresses these questions about energy in living systems.
- It delves into the principles and mechanisms governing energy flow and conversion in biological systems.

**Summary:** At the core of life are metabolic pathways that either build up (anabolic) or break down (catabolic) molecules. These pathways are responsible for energy management in living organisms, with ATP acting as the primary energy currency. The study of energy in biological systems, or bioenergetics, further explores how organisms manage and utilize this energy.

### VII. THE LIVING STATE

#### 1. Biomolecules and Metabolites

- Living organisms consist of tens of thousands of chemical compounds known as biomolecules or metabolites.
- These compounds are present in unique concentrations, characteristic of each one.
- For instance:
  - Blood glucose concentration in a healthy individual: 4.2 mmol/L – 6.1 mmol/L.
  - Hormone concentration: nanograms/mL.

#### 2. Steady-State

- A defining feature of biological systems is the existence of all living organisms in a steady-state.

- This means the concentrations of biomolecules remain constant, even though these molecules are in a constant state of metabolic flux.

### 3. Equilibrium vs. Non-Equilibrium

- Chemical or physical processes naturally progress towards a state of equilibrium.
- However, the steady-state in living organisms is a non-equilibrium state.
- In physics, a system at equilibrium cannot do work.

### 4. Living State: A Continuous Challenge

- Since organisms need to perform work continuously, they cannot attain equilibrium.
- Therefore, the living state is a non-equilibrium steady-state that allows organisms to execute work.
- The living process constantly strives to avoid equilibrium.
- This active state is sustained through energy input.

### 5. Role of Metabolism

- Metabolism facilitates the production of energy, which maintains the non-equilibrium steady-state.
- This energy helps in preventing the organism from reaching equilibrium, ensuring that the organism remains "alive" and functional.

### 6. The Synonymous Relationship

- The living state and metabolism are deeply intertwined.
- Without metabolism, there can't be a living state. Conversely, the existence of the living state indicates ongoing metabolism.

**Summary:** Life is a continuous, non-equilibrium steady-state marked by specific concentrations of biomolecules. Even though these molecules are in constant metabolic flux, their concentrations remain steady. Living organisms are always performing work, which requires them to stay out of equilibrium. This non-equilibrium state is maintained by metabolism, which provides the necessary energy input. Thus, the living state and metabolism are inextricably linked. Without metabolism, life ceases to exist.

## VIII. ENZYMES

### 1. Nature and Composition

- The majority of enzymes are proteins.
- Some nucleic acids can also function like enzymes; these are termed "ribozymes."

## 2. Structural Layers of Enzymes

- **Primary Structure:** Represents the sequence of amino acids in the protein.
- **Secondary Structure:** Refers to the local sub-sequences of proteins, often characterized by repeating patterns, such as alpha-helices or beta-sheets.
- **Tertiary Structure:** Represents the overall 3D structure of the enzyme, showcasing how the protein folds upon itself.

## 3. Active Site

- As a protein folds, it forms various pockets and crevices.
- Among these pockets, one specific region is termed the "active site."
- The active site of an enzyme is where substrates bind, and the actual catalysis takes place. It is essentially a crevice that perfectly accommodates the substrate, enabling enzymes to increase reaction rates.

## 4. Difference from Inorganic Catalysts

- Inorganic catalysts tend to be efficient at high temperatures and pressures.
- Contrarily, most enzymes lose their functionality and denature at high temperatures (typically above 40°C).

## 5. Thermophilic Enzymes

- However, there are exceptions: enzymes derived from thermophilic organisms (organisms that thrive in extremely high temperatures, like in hot vents and Sulphur springs).
- These enzymes are unique as they are stable and retain their catalytic ability even at high temperatures, sometimes up to 80°-90°C.
- Their thermal stability makes them particularly valuable for certain industrial applications.

**Summary:** Enzymes, predominantly proteins, act as catalysts in biological reactions. They have a unique structure, with a distinct active site, allowing them to effectively interact with substrates. While most enzymes are sensitive to high temperatures, those derived from thermophilic organisms can function at much higher temperatures.

### **(a) Chemical Reactions**

#### **Understanding Chemical Reactions:**

- **Physical Change:** Change in shape or state without bond-breaking, such as melting ice into water or water evaporating into vapor.

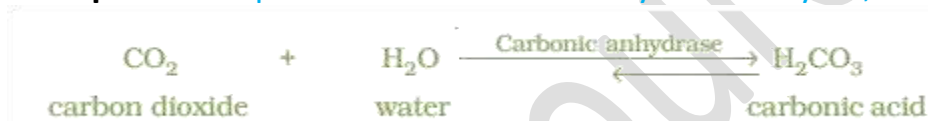
- **Chemical Reaction:** Transformation involving breaking and forming bonds.
  - **Example (Inorganic):**  $\text{Ba(OH)}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{BaSO}_4 + 2\text{H}_2\text{O}$
  - **Example (Organic):** Hydrolysis of starch into glucose.

## 2. Rate of Reactions:

- Rate refers to the amount of product formed per unit time.
  - **Rate =  $\delta P / \delta t$**
- Rates of reactions can be influenced by various factors, most notably temperature. Typically, a rate can double or decrease by half with every 10°C change.

## 3. Power of Enzymes:

- Enzymes increase the rate of reactions significantly compared to uncatalyzed reactions.
  - **Example:** In the presence of carbonic anhydrase enzyme, the reaction



occurs 10 million times faster than without the enzyme.

## 4. Enzymatic Diversity:

- There are thousands of enzymes, each specialized in catalyzing a specific reaction or set of reactions.

## 5. Metabolic Pathways:

- A series of chemical reactions, each catalyzed by an enzyme, is termed a metabolic pathway.
  - **Example:** Glucose converting into pyruvic acid involves ten enzyme-catalyzed reactions.
  - Depending on conditions and presence of specific enzymes, metabolic pathways can lead to different end products:
    - **In skeletal muscles (anaerobic):** lactic acid
    - **Under aerobic conditions:** pyruvic acid
    - **In yeast (fermentation):** ethanol

**Summary:** Chemical reactions can be either physical changes or chemical transformations. The rate of these reactions can be significantly influenced by enzymes, specialized proteins that accelerate reactions. Enzymes are incredibly diverse, each catering to specific reactions, and when these reactions occur in sequence, it forms what's known as a metabolic pathway. Depending on the

conditions and available enzymes, these pathways can produce various end products.

**(b) How do Enzymes bring about such High Rates of Chemical Conversions?**

**1. Active Site and Substrate Interaction:**

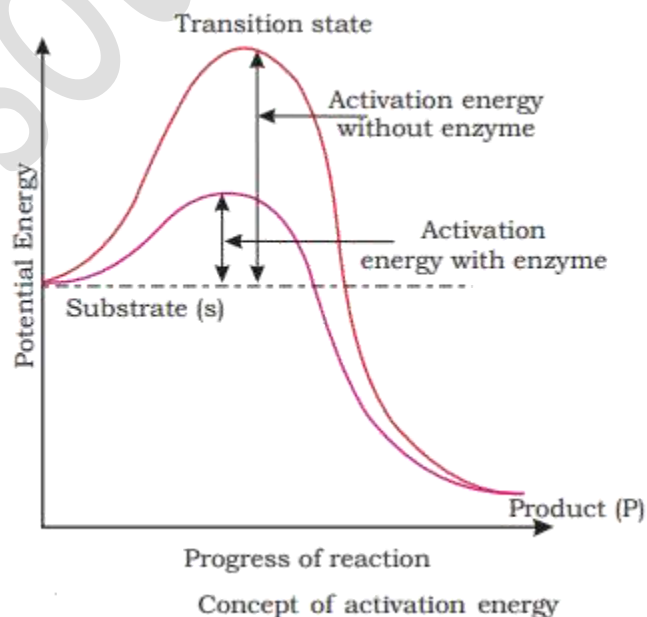
- Enzymes have a three-dimensional structure with a specific region called the 'active site'.
- The molecule that undergoes transformation due to the enzyme's action is the 'substrate'.
- The substrate binds to the enzyme's active site, leading to the formation of an enzyme-substrate (ES) complex.

**2. Transition State:**

- During the enzyme's action, the substrate undergoes a temporary change to form a 'transition state structure'.
- This state is not stable and is an intermediate phase between the substrate and the product.
- The substrate's structure is transformed into the structure of the product via this transition state.

**3. Energy and Reaction Progress:**

- All molecules possess a certain amount of potential energy.
- For a reaction to proceed from substrate (S) to product (P), the substrate has to cross an energy barrier, reaching the transition state.



**4. Activation Energy:**

- Illustrated graphically, the energy profile of a reaction would show the energy levels of the substrate and product on the y-axis and the progress of the reaction on the x-axis.
- The difference in energy between the substrate and the highest point (transition state) is termed 'activation energy'.
- Whether a reaction is exothermic (releases energy) or endothermic (requires energy), this activation energy needs to be surpassed for the reaction to proceed.

## 5. Role of Enzymes:

- Enzymes facilitate reactions by reducing the activation energy required.
- They make the transition from 'S' to 'P' easier by lowering the energy barrier, hence accelerating the reaction.

**In Summary:** Enzymes work by binding substrates at their active sites and stabilizing the transition state, making it easier for the reaction to proceed. They achieve this by lowering the activation energy required for the transformation, ensuring that biochemical reactions occur efficiently within living organisms.

### **(c) Nature of Enzyme Action**

Enzymes play a pivotal role in biological reactions, ensuring they proceed efficiently. The action of enzymes involves a series of specific steps:

#### 1. Formation of the Enzyme-Substrate Complex:

- Each enzyme has a specific region called the "active site," where the substrate binds.
- Enzyme (E) and Substrate (S) interact to form the enzyme-substrate complex (ES).



#### 2. Induced Fit Model:

- Upon substrate binding, the enzyme might change its shape to fit more snugly around the substrate. This change enhances the enzyme's catalytic activity and is often referred to as the 'induced fit' model.

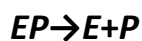
#### 3. Catalysis and Formation of the Enzyme-Product Complex:

- Once the substrate is tightly bound, the enzyme facilitates the breaking and/or making of chemical bonds, transforming the substrate into the product.
- This leads to the formation of an enzyme-product complex (EP).



#### 4. Release of Product:

- After the reaction, the product (P) is released from the enzyme.
- The enzyme remains unchanged after the reaction and can participate in subsequent reactions.



#### 5. Resetting the Enzyme:

- The enzyme, now free, returns to its initial state and is available to bind with another substrate molecule, repeating the catalytic cycle.

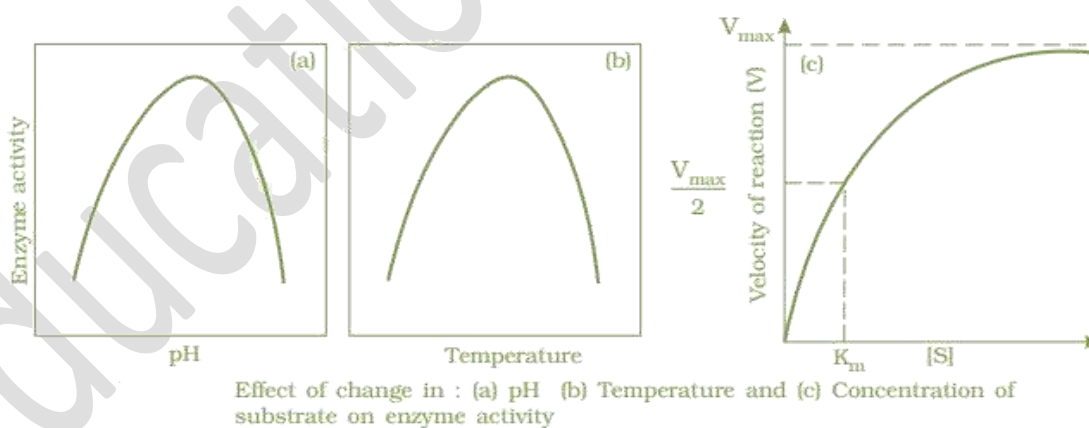


**Summary:** The enzymatic process is a cycle of substrate binding, shape adaptation, catalysis, and product release. The enzyme remains unchanged throughout, ready to participate in subsequent reactions, exemplifying its catalytic nature. This process ensures that biological reactions occur rapidly and efficiently, allowing cells to perform vital functions.

### **(d) Factors Affecting Enzyme Activity**

#### **1. Temperature and pH:**

- Each enzyme has an optimal temperature and pH at which it functions best. At this optimum, the enzyme exhibits its maximum activity.
- Temperature:** Enzyme activity typically increases with temperature until it reaches its optimum. Beyond this point, the enzyme activity starts to decrease. At low temperatures, enzymes remain inactive. At high temperatures, enzymes can become denatured, losing their structure and function.
- pH:** Similarly, enzymes have an optimal pH at which they are most active. Activity declines when the pH deviates from this optimum.



#### **2. Concentration of Substrate:**

- Initially, as the concentration of the substrate increases, the rate of reaction also increases.
- However, after a certain point, even if the substrate concentration increases, the rate of the reaction does not. This plateau happens when all enzyme molecules are occupied with substrate molecules, reaching a maximum velocity (V<sub>max</sub>).

Further increase in substrate concentration won't affect the rate because there are no free enzymes available.

### 3. Inhibition and Inhibitors:

- Certain chemicals can bind to enzymes and reduce their activity. These are called inhibitors.
- When an inhibitor deactivates an enzyme, it is termed inhibition.

### 4. Types of Inhibitors:

- **Competitive Inhibitors:** These resemble the substrate's structure and compete with the substrate for binding at the active site. Since they block the substrate from binding, they reduce enzyme activity. An example is the inhibition of succinic dehydrogenase by malonate.
- There are also non-competitive inhibitors, which bind to other parts of an enzyme causing it to change shape and making it less effective.

### 5. Medical and Therapeutic Importance:

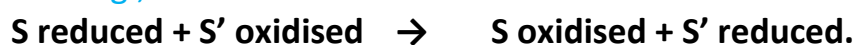
- Competitive inhibitors have therapeutic importance. Since they can block enzyme activity, they can be used in controlling bacterial pathogens.

**Summary:** Enzyme activity is influenced by several factors such as temperature, pH, substrate concentration, and the presence of inhibitors. Understanding these factors is crucial in various fields, including medicine, where inhibitors can be used as therapeutic agents.

### **(e) Classification and Nomenclature of Enzymes**

Thousands of enzymes have been discovered, isolated and studied. Most of these enzymes have been classified into different groups based on the type of reactions they catalyse. Enzymes are divided into 6 classes each with 4-13 subclasses and named accordingly by a four-digit number.

**Oxidoreductases/dehydrogenases:** Enzymes which catalyse oxidation-reduction between two substrates S and S' e.g.,



**Transferases:** Enzymes catalysing a transfer of a group, G (other than hydrogen) between a pair of substrate S and S' e.g.,



**Hydrolases:** Enzymes catalysing hydrolysis of ester, ether, peptide, glycosidic, C-C, C-halide or P-N bonds.

**Lyases:** Enzymes that catalyse removal of groups from substrates by mechanisms other than hydrolysis leaving double bonds.



**Isomerases:** Includes all enzymes catalyzing inter-conversion of optical, geometric or positional isomers.

**Ligases:** Enzymes catalyzing the linking together of 2 compounds, e.g., enzymes which catalyze joining of C-O, C-S, C-N, P-O etc. bonds.

### (f) Co-factors

#### 1. Definition:

- Enzymes, which are largely made up of polypeptide chains, often need non-protein components known as co-factors to become catalytically active. The protein part of such enzymes is referred to as the apoenzyme.

#### 2. Types of Co-factors:

- Prosthetic Groups:** - These are organic compounds that are tightly and permanently attached to the apoenzyme. - They play a crucial role in enzyme activity and are part of the enzyme's active site. - *Example:* Haem in peroxidase and catalase enzymes is a prosthetic group. These enzymes catalyze the decomposition of hydrogen peroxide into water and oxygen.
- Co-enzymes:** - Unlike prosthetic groups, co-enzymes bind to the apoenzyme temporarily, typically during the catalysis process. - They can function as co-factors for various enzyme-catalyzed reactions. - Many co-enzymes are derived from vitamins. - *Example:* Nicotinamide adenine dinucleotide (NAD) and NADP are co-enzymes derived from the vitamin niacin.
- Metal Ions:** - Certain enzymes need specific metal ions for their catalytic activity. - These ions often interact with the active site and the substrate to facilitate the reaction. - *Example:* Zinc acts as a co-factor for the enzyme carboxypeptidase, aiding in its proteolytic activity.

### 3. Importance of Co-factors:

- The presence of co-factors is essential for many enzymes to exhibit their catalytic activity. When a co-factor is removed, the enzyme often loses its catalytic property, emphasizing the critical role co-factors play in enzyme function.

**Summary:** Co-factors are crucial non-protein components that aid enzymes in their catalytic functions. These can be permanent (as in prosthetic groups) or temporary (as in co-enzymes). Some enzymes also require specific metal ions to function effectively. The presence of these co-factors is often essential for the enzyme to carry out its intended reactions.

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