# BIOCHEMISTRY

## Carbohydrates

Carbohydrates are the most abundant class of organic compounds on Earth. They are macromolecules composed of carbon, hydrogen, and oxygen, in which each carbon atom is bonded to at least one oxygen atom. Every carbohydrate molecule contains either an aldehyde or keto group along with several hydroxyl groups.

Their general formula is $\mathbf{C_x(H_2O)_y}$, which suggests that carbohydrates are hydrates of carbon (with some exceptions). Plants synthesize carbohydrates through the process of photosynthesis:

$$6CO_2(g) + 6H_2O(l) \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6(aq) + 6O_2(g)$$

The glucose formed during photosynthesis is converted into **starch** and **cellulose** in plants.

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### Functions of Carbohydrates

1. **Provide energy:** Carbohydrates are the main source of energy for living cells.
2. **Structural role:** They form important structural materials such as cellulose in plants and chitin in animals.
3. **Support growth and development:** Carbohydrates play a role in the synthesis of essential biomolecules and energy storage.

Because of their complex and branched structures, carbohydrates can be easily stored and hydrolyzed into smaller glucose molecules that serve as an immediate energy source.

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### Classification of Carbohydrates

Carbohydrates are classified into three main groups:

1. Monosaccharides
2. Oligosaccharides
3. Polysaccharides

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#### 1. Monosaccharides

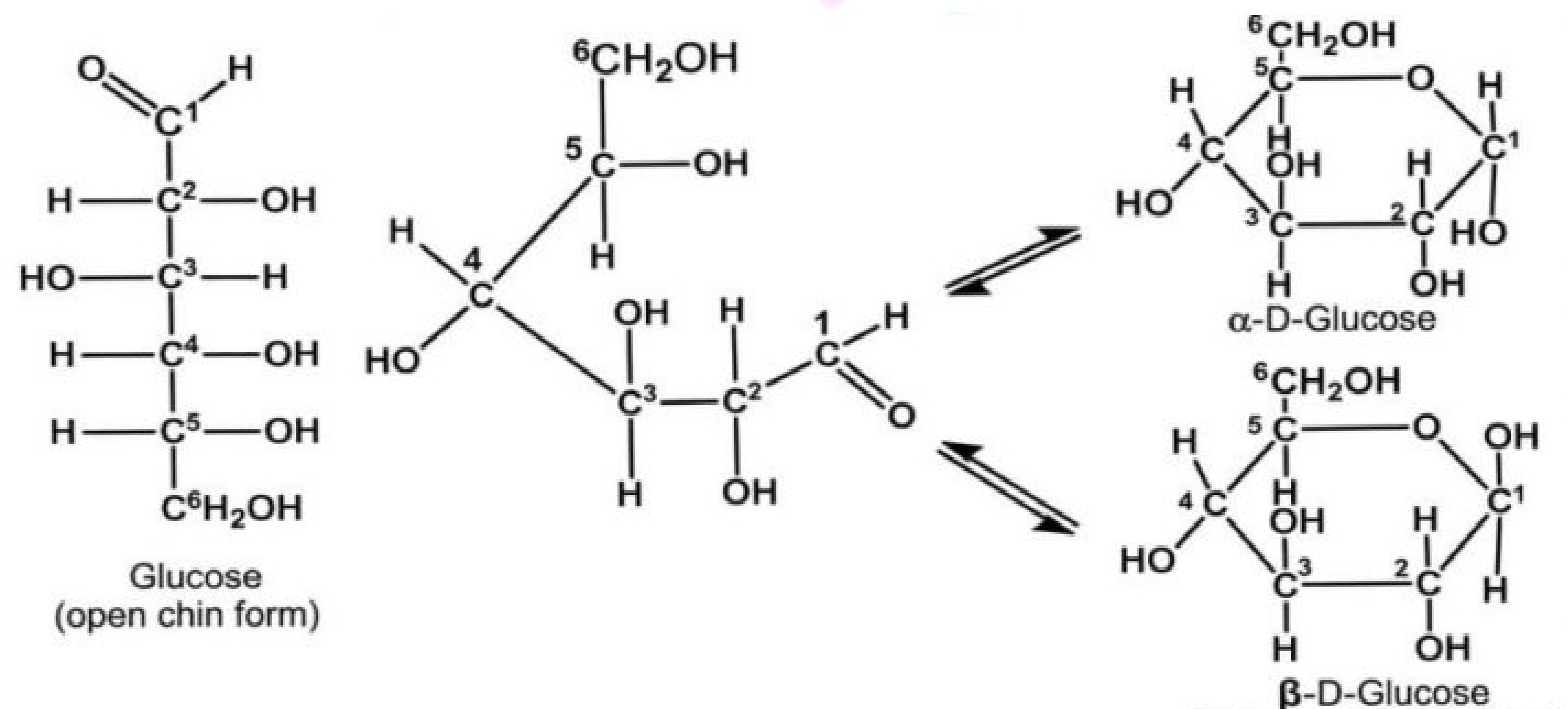
Monosaccharides are the simplest carbohydrates that **cannot be hydrolyzed** into smaller sugar units. Their general formula is **$(CH_2O)_n$**, where *n* ranges from 3 to 6. Based on the number of carbon atoms, they are classified as:

- **Trioses (3C)**
- **Tetroses (4C)**
- **Pentoses (5C)**
- **Hexoses (6C)**

The most common monosaccharides are **glucose** and **fructose**, both having the molecular formula **$C_6H_{12}O_6$.**

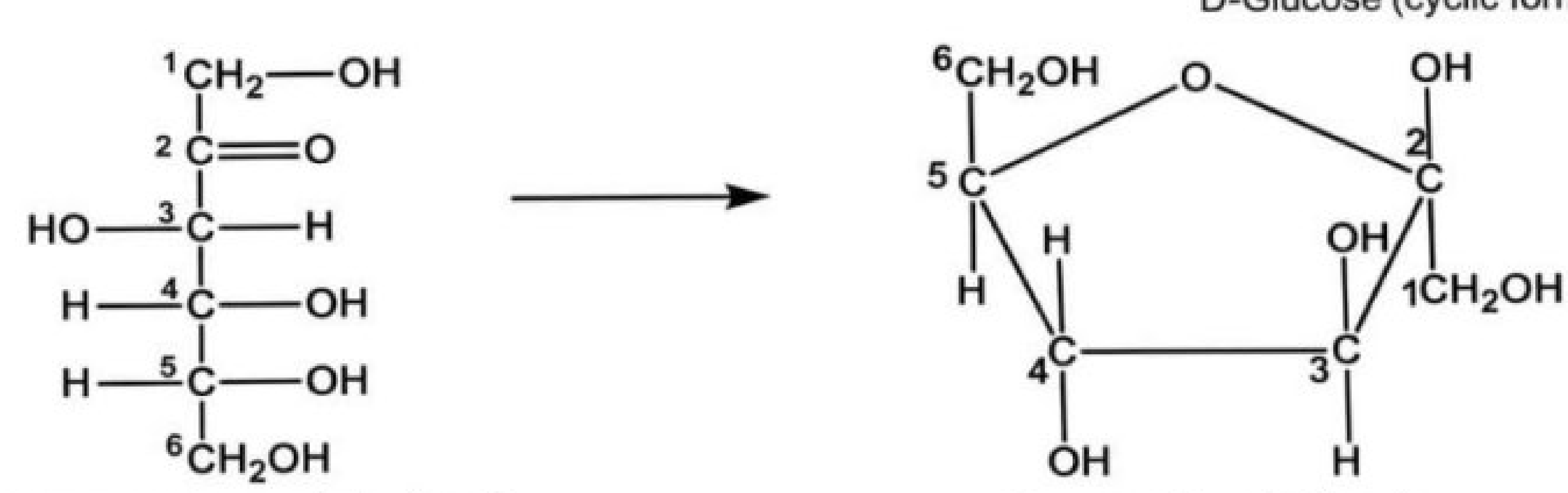
- **Glucose** is a *pentahydroxy aldehyde* (an aldose).
- **Fructose** is a *pentahydroxy ketone* (a ketose).

Monosaccharides are **white crystalline solids**, **sweet-tasting**, **soluble in water**, and **reducing in nature**. They can rotate plane-polarized light; if the rotation is clockwise, they are called **dextro-rotatory (dextrose)** sugars. Examples include glucose, mannose, and galactose.



Glucose (open chin form)

D-Glucose (cyclic form)


Fructose (open chain form)

Fructose (cyclic form)

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## 2. Oligosaccharides

Oligosaccharides are carbohydrates that yield **2 to 10 molecules of monosaccharides** upon hydrolysis. They are further classified as:

- **Disaccharides** (2 monosaccharide units)
- **Trisaccharides** (3 units)

- and so on.

They are **sweet**, **crystalline**, and **water-soluble**.
Common examples include:

| Disaccharide | Hydrolysis Products | Occurrence |
|---|---|---|
| **Sucrose ($C_{12}H_{22}O_{11}$)** | Glucose + Fructose | Sugar cane, sugar beet |
| **Lactose ($C_{12}H_{22}O_{11}$)** | Glucose + Galactose | Milk |
| **Maltose ($C_{12}H_{22}O_{11}$)** | Glucose + Glucose | Malt, germinating grains |

1. **Sucrose ($C_{12}H_{22}O_{11}$)**

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

**Sucrose → Glucose + Fructose**

2. **Lactose ($C_{12}H_{22}O_{11}$)**

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

**Lactose → Glucose + Galactose**

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3. **Maltose ($C_{12}H_{22}O_{11}$)**

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

**Maltose → Glucose**

### 3. Polysaccharides

Polysaccharides are complex carbohydrates that yield **hundreds or thousands of monosaccharide units** upon hydrolysis. They are **non-sweet**, **amorphous**, **insoluble in water**, and **non-reducing** in nature.

Common examples include:

| Polysaccharide | Structure | Occurrence | Function |
|---|---|---|---|
| **Starch** | Chains of glucose units (α-linkages) | Plant storage organs like potato, wheat | Energy storage in plants |
| **Cellulose** | Chains of glucose units (β-linkages) | Cell walls of plants | Structural support |

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## Summary Table: Common Carbohydrates

| Name | Type | Structure/Group | Occurrence |
|---|---|---|---|
| **Glucose** | Monosaccharide (aldose, hexose) | $CH_2OH–(CHOH)_4–CHO$ | Found in plants and animals |
| **Fructose** | Monosaccharide (ketose, hexose) | $CH_2OH–CO–(CHOH)_4–CH_2OH$ | Found in fruits and honey |
| **Ribose** | Monosaccharide (aldose, pentose) | Component of RNA and Vitamin $B_{12}$ | Found in nucleic acids |
| **Sucrose** | Disaccharide (glucose + fructose) | Non-reducing sugar | Sugar cane, sugar beet |
| **Maltose** | Disaccharide (glucose + glucose) | Reducing sugar | Germinating grains |
| **Lactose** | Disaccharide (glucose + galactose) | Reducing sugar | Milk |
| **Starch** | Polysaccharide | α-linked glucose chains | Plant energy storage |
| **Cellulose** | Polysaccharide | β-linked glucose chains | Plant cell walls (structural material) |

# Proteins

Proteins are nitrogenous, high molecular weight polymers. Their basic building blocks are **amino acids**, and therefore all proteins yield amino acids upon **complete hydrolysis**. Proteins are complex nitrogen-containing substances essential for various biological processes.

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## Classification of Proteins



Proteins can be classified on different bases:

### A. Structure-based Classification

Proteins are divided into four structural levels based on spatial arrangement of polypeptide chains:

1. **Primary Structure**
   The sequence of amino acids in a polypeptide chain is called primary structure. Amino acids are linked via peptide bonds. The specific arrangement of amino acids determines the primary structure.
2. **Secondary Structure**
   When a polypeptide chain coils into a spiral (α-helix) or folds into a zig-zag sheet (β-pleated **sheet)** due to hydrogen bonding, it forms a secondary structure.
   **Example:** Collagen.
3. **Tertiary Structure**
   The twisting and folding of the entire polypeptide chain into a complex three-dimensional

shape forms tertiary structure.
**Example:** Myoglobin.

4. **Quaternary Structure**
   When two or more folded polypeptide chains combine to form a multi-subunit complex, they create quaternary structure. This structure is stabilized by hydrogen bonds, disulfide bonds, salt bridges, etc.
   **Example:** Hemoglobin.

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### B. Classification Based on Constitution

Proteins are divided into three groups:

1. **Simple Proteins**
   Produce only amino acids upon hydrolysis.
   **Examples:** Albumins, globulins, collagens.
2. **Compound or Conjugated Proteins**
   Contain a simple protein (apoprotein) combined with a non-protein prosthetic group.
   **Examples:** Lipoproteins, glycoproteins, phosphoproteins, nucleoproteins, hemoproteins.
3. **Derived Proteins**
   Formed from partial hydrolysis of simple or conjugated proteins by acids, bases, or enzymes.
   **Examples:** Peptones, peptides, proteoses, proteans.

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### C. Classification Based on Shape

Proteins are grouped into two types:

1. **Fibrous Proteins**
   Composed of long, thread-like polypeptide chains that form fibers or sheets. Generally insoluble in water.
   **Examples:**
   - Keratin (hair, skin)
   - Collagen (connective tissues)
   - Myosin (muscles)
   - Elastin (elastic fibers)
2. **Globular Proteins**
   Fold into spherical shapes and are mostly water-soluble, soluble also in acids, bases, and alcohols.
   **Examples:** Albumin (egg white), hemoglobin.

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### D. Classification Based on Functions

Proteins perform various biological functions and may be classified as:

1. **Enzymes** – Catalyze biochemical reactions
   *Examples:* Lactase, catalase.
2. **Structural Proteins** – Provide support and shape
   *Example:* Collagen.
3. **Transport Proteins** – Transport substances across membranes
   *Example:* Hemoglobin (carries oxygen).
4. **Storage Proteins** – Store nutrients and ions
   *Examples:* Ferritin (stores iron), casein (stores calcium in milk).
5. **Hormonal Proteins** – Act as chemical messengers
   *Examples:* Insulin, thyroid hormones.
6. **Defensive Proteins** – Protect against pathogens
   *Example:* Antibodies.
7. **Receptor Proteins** – Receive and transmit signals
   *Example:* Insulin receptor.
8. **G Protein-Coupled Receptors (GPCRs)** – Respond to signaling molecules.
9. **Contractile Proteins** – Responsible for movement and muscle contraction
   *Examples:* Actin, myosin.
10. **Regulatory Proteins** – Control cellular activities
    *Examples:* Transcription factors, cyclins (regulate cell cycle).

## Enzymes

The term *enzyme* is derived from the Greek words *En* meaning “in” and *Zyme* meaning “yeast.” Enzymes are biocatalysts that alter the speed of metabolic activities in living organisms. They are complex protein molecules that are highly specific in their action and are sensitive to changes in temperature and pH.



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### Metabolism

Metabolism refers to a series of chemical reactions that take place in living organisms to maintain life. These metabolic reactions enable organisms to grow, reproduce, maintain their structures, and respond to environmental conditions. Metabolism involves continuous biochemical reactions inside the body, and enzymes play a central role in controlling and regulating these reactions.

### Types of Metabolic Reactions

#### *Anabolic Reactions*

Anabolic reactions are processes in which larger molecules are synthesized from smaller molecules. During anabolic reactions, enzymes are released. These reactions require energy, and they contribute to building and repairing cellular structures.

#### *Catabolic Reactions*

Catabolic reactions involve the breakdown of larger molecules into smaller, simpler molecules. Enzymes are used in catabolic reactions. These reactions release energy and help the body obtain nutrients from food.

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### Importance of Enzymes in Metabolism

Metabolism essentially involves energy transfers, and enzymes convert chemicals from one state to another. They accelerate biochemical reactions and regulate metabolic pathways. The molecules on which enzymes act are called **substrates**, and after the enzymatic reaction, new molecules known as **products** are formed.

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## Mechanism of Enzyme Action

Enzymes work by temporarily combining with the substrate to form an **Enzyme–Substrate (ES) Complex**. When an enzyme (E) attaches to its substrate (S), they form the ES complex, which later breaks down to release the unchanged enzyme and form the product (P). The reaction is represented as:

**E + S → ES Complex → E + P**.

This shows that enzymes are not consumed during the reaction and can be reused.

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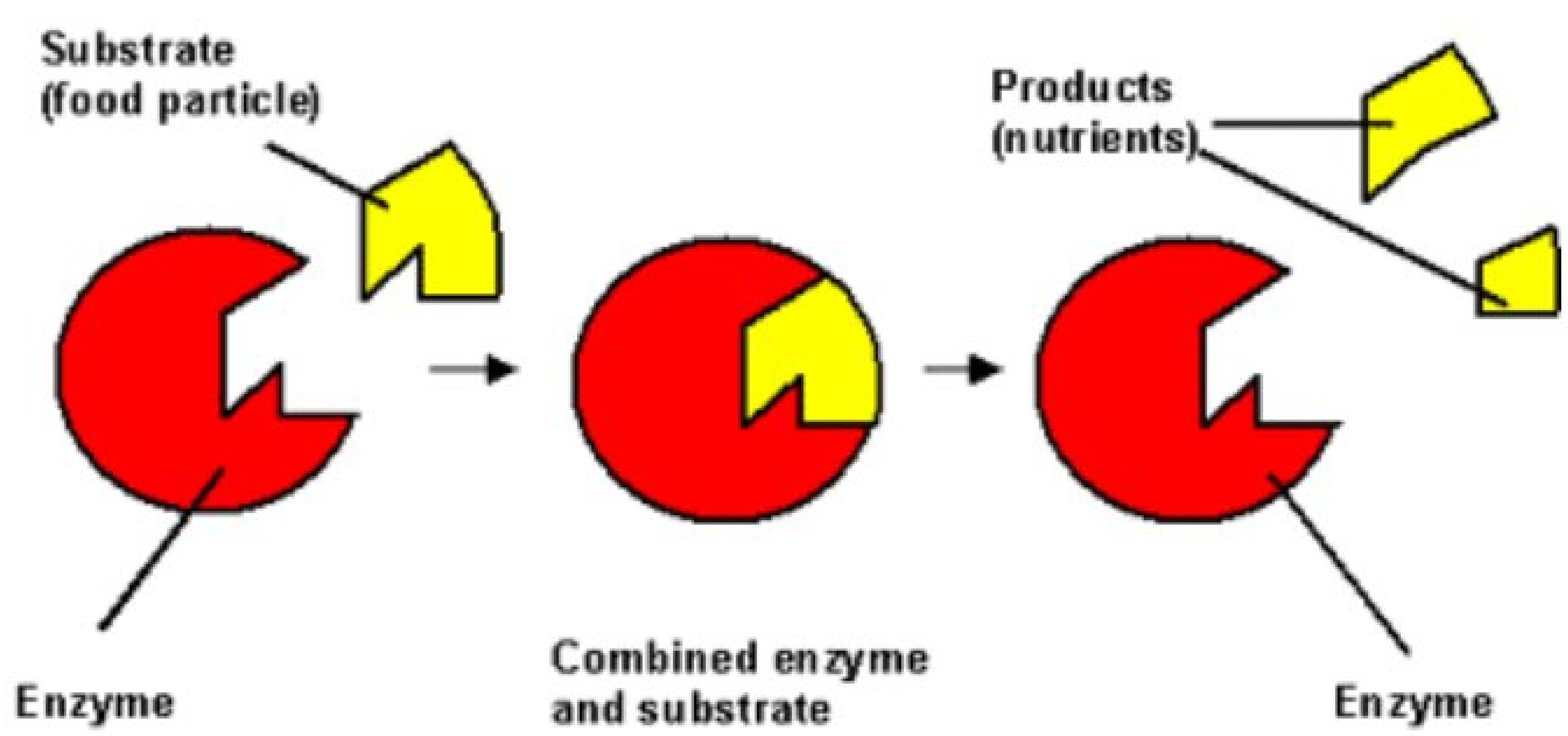
### Models Explaining Enzyme Action

### Lock and Key Model (1894)

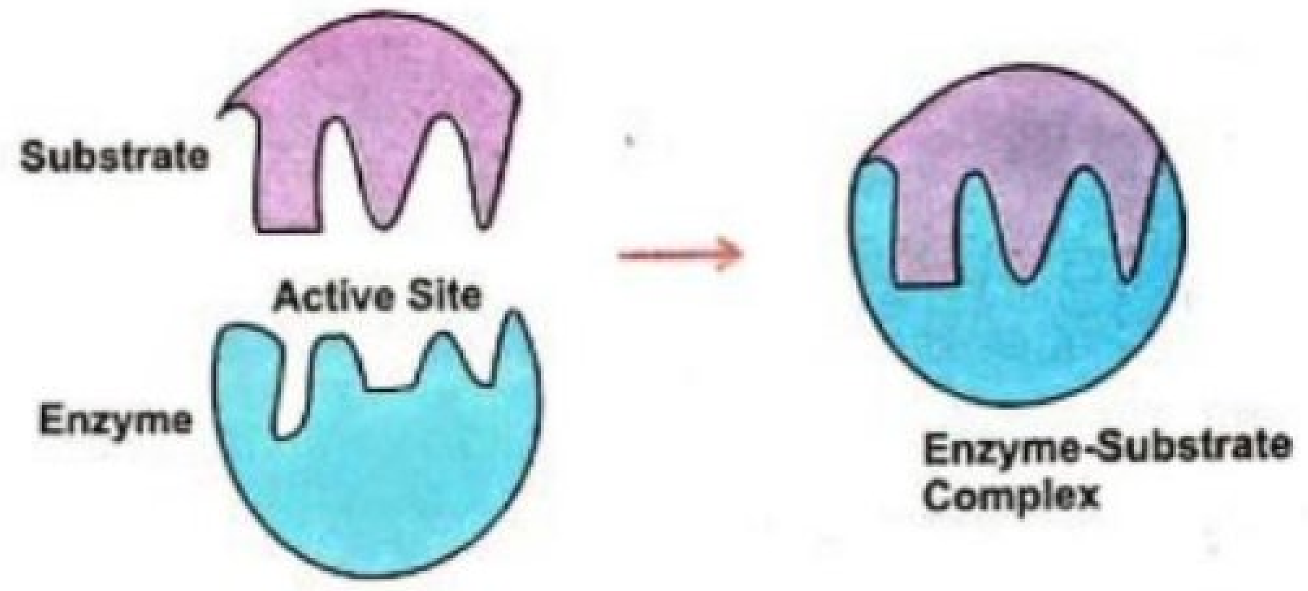
The Lock and Key Model was proposed by the German chemist **Emil Fischer** in 1894. According to this model, enzymes and substrates have specific complementary shapes that fit together perfectly, similar to how a key fits exactly into a particular lock. This model demonstrates that enzymes are highly specific in their action.




*How enzymes break down food into nutrients*

**Induced Fit Model (1958)**

The Induced Fit Model was proposed by the American biologist **Daniel Koshland** in 1958. According to this model, the active site of an enzyme is not rigid but flexible and is moulded into the required shape when it interacts with the substrate. This model suggests that the enzyme adjusts itself to fit the substrate more accurately. The Induced Fit Model is considered more acceptable and accurate than the Lock and Key Model.




## Factors Affecting the Activity of Enzymes

Enzymes are highly sensitive biological catalysts, and their activity is influenced by the conditions of their surrounding environment. Any factor that alters the chemical nature or three-dimensional structure (shape) of an enzyme can affect its efficiency or stop its function completely. The major factors that influence enzyme activity are discussed below.

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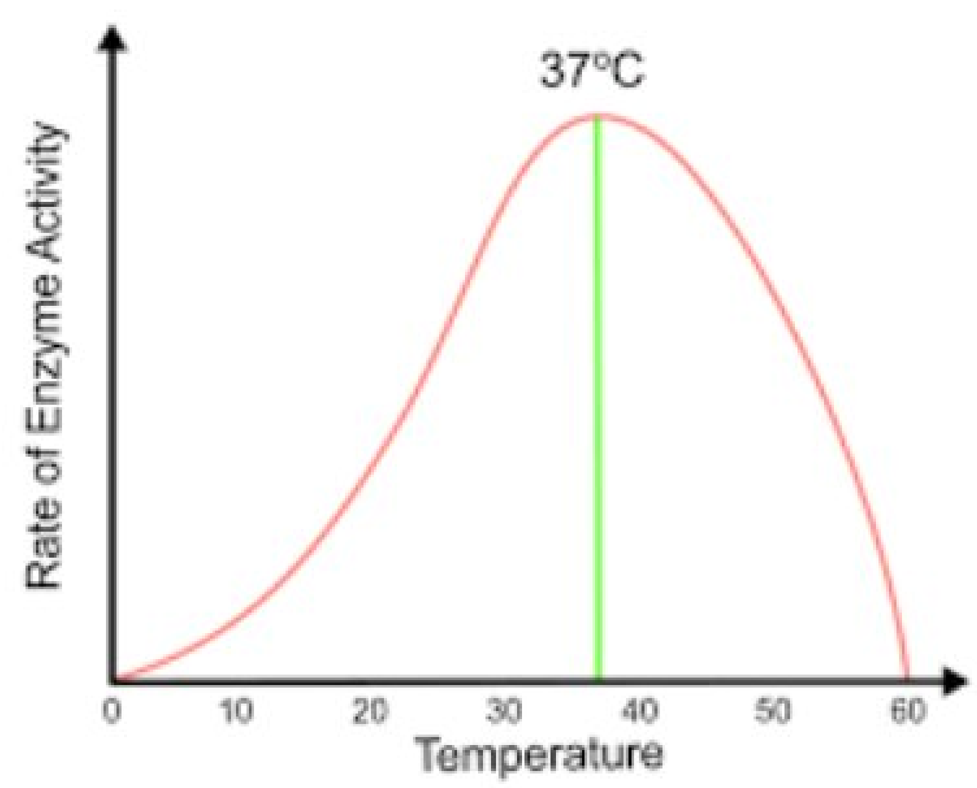
### 1. Temperature

Every enzyme works at its maximum efficiency at a specific temperature called the **optimum temperature**. For example, most enzymes in animals work best at **37°C**, while enzymes in many plants work at about **60°C**. As temperature increases, the kinetic energy of molecules also increases, resulting in faster collisions between enzymes and substrates; therefore, the **rate of reaction increases**.
However, if the temperature becomes too high, excessive vibrations break the weak bonds within the enzyme, causing the enzyme's **globular structure to unfold**. This process is called **denaturation**, which reduces enzyme activity and may stop the reaction completely.

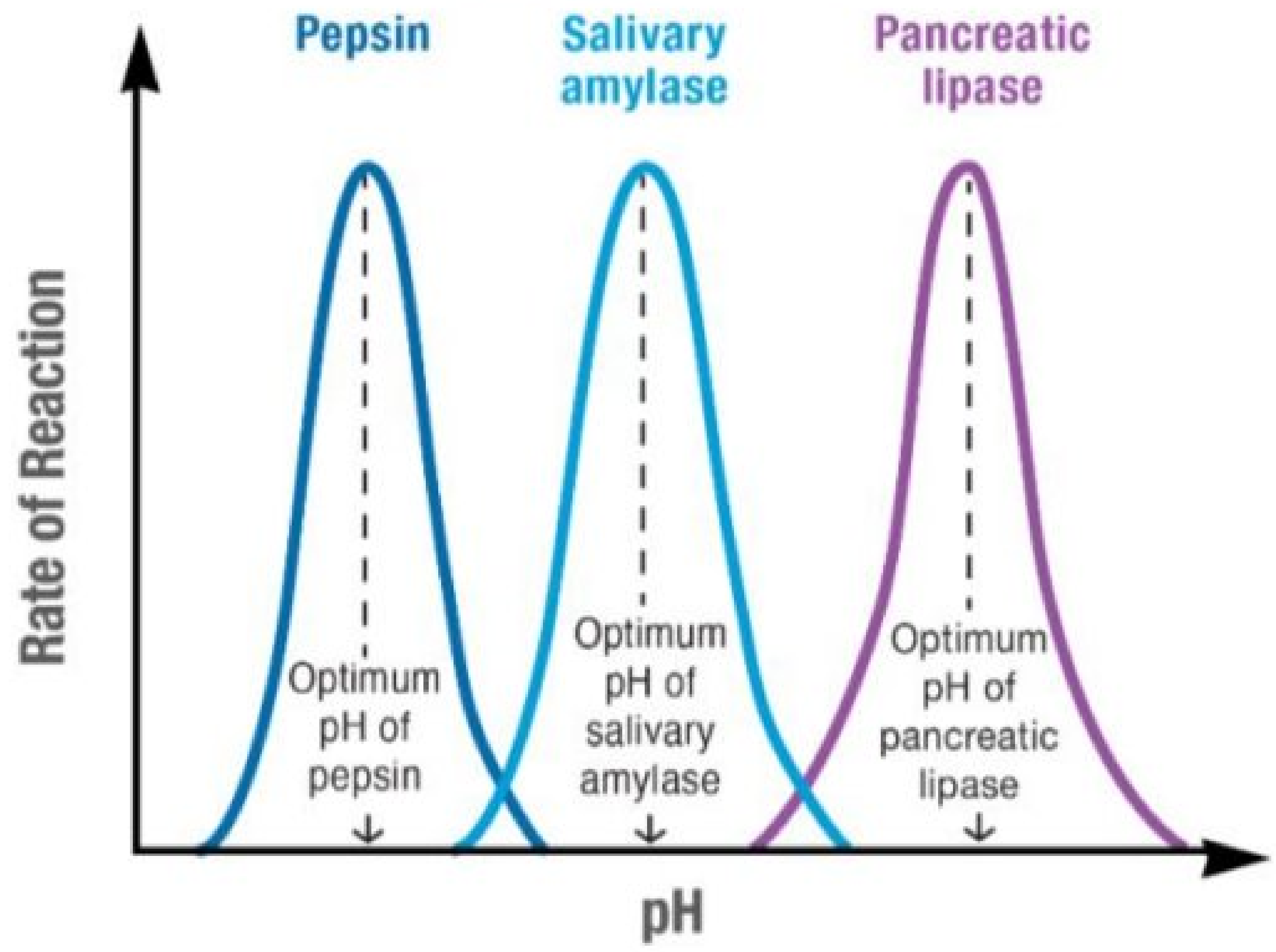


## 2. Substrate Concentration

When there are enough enzyme molecules available, increasing **substrate concentration** increases the rate of reaction because more substrate molecules can bind to enzyme active sites.
But when all enzyme active sites are occupied, adding more substrate will **not increase the reaction rate**. This condition is called **active site saturation**, and at this point, the reaction reaches its **maximum rate**.

## 3. pH

Each enzyme works best at a specific **pH value** called the **optimum pH**. A small change in pH can slow down or even stop enzyme activity by altering the shape of the enzyme or the charge of the active site.
For example, **pepsin** in the stomach works in a strongly **acidic environment (pH 2)**, while **trypsin** in the small intestine functions best in **alkaline conditions (pH 8–9)**.




# Lipids

Lipids are naturally occurring heterogeneous groups of organic compounds of plant and animal origin. They are insoluble in water but soluble in organic solvents such as ether, chloroform, and benzene. Lipids include fats, oils, waxes, hormones, and some cell membrane components.

They function as energy-storing molecules and chemical messengers in living organisms. Lipids are the main structural components of cell membranes, act as food storage molecules, and include cholesterol. The only common property among all lipids is their insolubility in water.

## Classification of Lipids

Lipids can be classified on the basis of structure, chemical composition, function, and physical characteristics.

### A. Structure-Function Based Classification

| Type | Examples | Role |
|---|---|---|
| Triglycerides | Fats and oils | Energy storing lipids |
| Phospholipids | Lecithin | Structural lipids (cell membrane) |
| Steroids | Cholesterol | Signaling lipids |
| Waxes | Beeswax, lanoline | Protective lipids |
| Terpenes | Menthol, camphor | Pigments and electron carriers |

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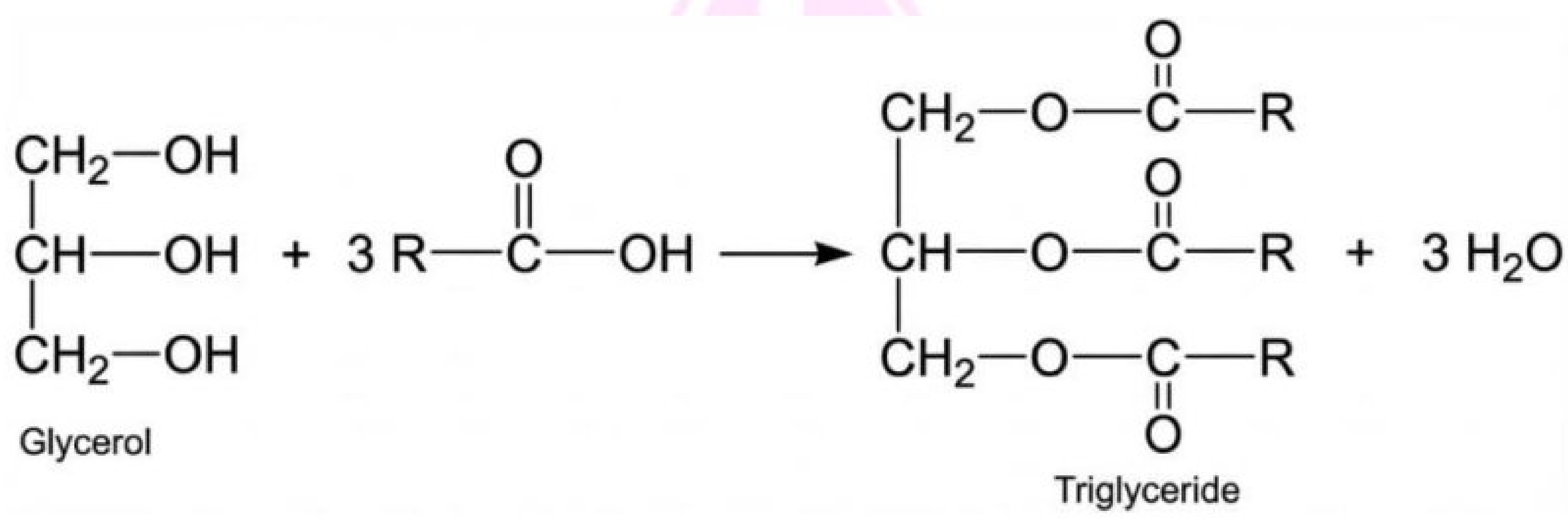
### 1. Triglycerides

Triglycerides are esters made from glycerol and three fatty acids**,** therefore they are called triglycerides**.** Fatty acids contain long hydrocarbon chains with 12–22 carbon atoms **and a** carboxylic acid group at one end. Examples include palmitic acid, oleic acid, and linoleic acid**.** They are found in oils, butter, and adipose tissue**.**

If the fatty acids are saturated**,** they form solid fats at room temperature (e.g., butter). If they are unsaturated**, they form** liquid oils **such as** olive oil, sunflower oil, and cotton seed oil**.**

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### 2. Phospholipids

Phospholipids are esters of glycerol**,** two fatty acids, and a phosphate group ($PO_4^{3-}$)**.** They are essential components of cell membranes and form the basic lipid bilayer.

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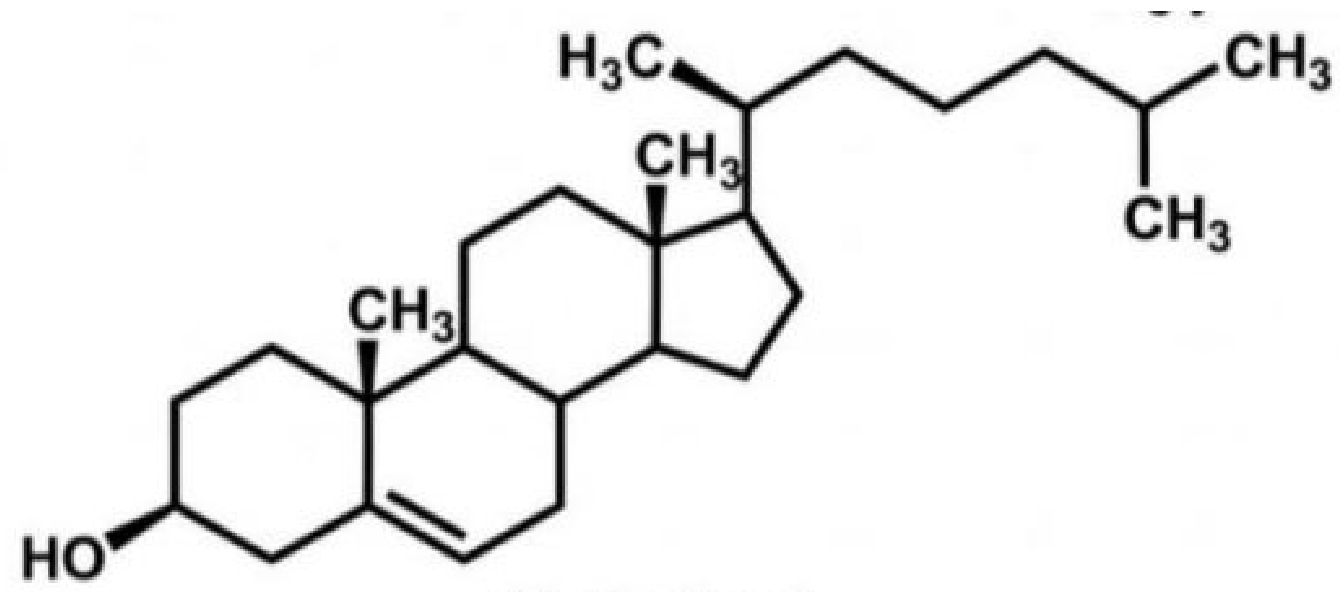
### 3. Steroids

Steroids are organic compounds containing a typical molecular structure of four fused carbon rings (three six-membered and one five-membered ring). They serve as structural components of cell membranes and are precursors of hormones. Examples include cholesterol, testosterone, and estrogen.



Cholesterol

## 4. Waxes

Waxes contain long-chain fatty acids esterified to long-chain alcohols. They act as protective coverings for plants and animals. Examples include lanoline, beeswax, carnauba wax, and whale wax oil.

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## 5. Isoprenoids or Terpenes

These lipids contain repeating isoprene ($C_5H_8$) units. They perform various roles such as pigmentation in plants (carotenoids) and electron transport in cellular respiration (ubiquinone). Examples include pinene, camphor, menthol, chlorophyll, and vitamin A.

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**Classification Based on Chemical Structure**

***1. Simple Lipids***

Simple lipids are composed only of fatty acids and glycerol.

- **Triglycerides:** Main energy storage molecules found in fats and oils.
- **Waxes:** Provide water resistance and protective coating to plants and animals.

***2. Compound Lipids***

Compound lipids contain additional groups such as phosphoric acid, nitrogenous bases, or proteins.

- **Phospholipids:** Major components of cell membranes having a hydrophilic head and a hydrophobic tail.
- **Glycolipids:** Contain carbohydrate groups and participate in cell recognition and attachment.

***3. Derivative Lipids***

These are formed by hydrolysis of simple or complex lipids.
Examples include:

- **Steroids:** Cholesterol, testosterone, estrogen.
- **Prostaglandins:** Local hormones controlling inflammation, circulation, and other physiological processes.

**Classification Based on Function**

| Type of Lipids | Example | Function |
|---|---|---|
| **Energy-Storing Lipids** | Triglycerides | Store energy in adipose tissue |
| **Structural Lipids** | Phospholipids, Glycolipids | Form cell membranes and promote stability |
| **Signaling Lipids** | Eicosanoids (prostaglandins, leukotrienes) | Control inflammation and immune response |
| **Protective Lipids** | Waxes | Provide protective covering |

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**Classification Based on Physical Characteristics**

***Saturated Glycerides***

Contain only single carbon–carbon bonds. They are solid at room temperature.
Rich sources include butter, cheese, lard, and fatty meats.

***Unsaturated Glycerides***

Contain one or more carbon-carbon double bonds. They are liquid at room temperature.
Examples: nuts, avocados, canola oil, sunflower oil, and olive oil.

# Nucleic Acid

## Structure of DNA

DNA exists in a double helix structure where two long strands coil around each other like a spiral staircase. These two strands are held together by hydrogen bonds formed between complementary nitrogenous bases (A-T and G-C).
The sequence of bases on a strand forms a genetic code that stores all the information required to make proteins.

DNA is double-stranded, which is essential for storing and transferring genetic information from one generation to the next.
The functional units of DNA that carry genetic information are called genes.

## Self-Replication

DNA has the ability **to** self-replicate**,** meaning it copies itself before cell division**.**
This ensures that each daughter cell receives the correct genetic code**,** and the characteristics of an organism are passed to its offspring**.**

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## Structure of Ribonucleic Acid (RNA)

RNA is a single-stranded nucleic acid. It is formed from DNA and carries genetic information from the nucleus to the cytoplasm.

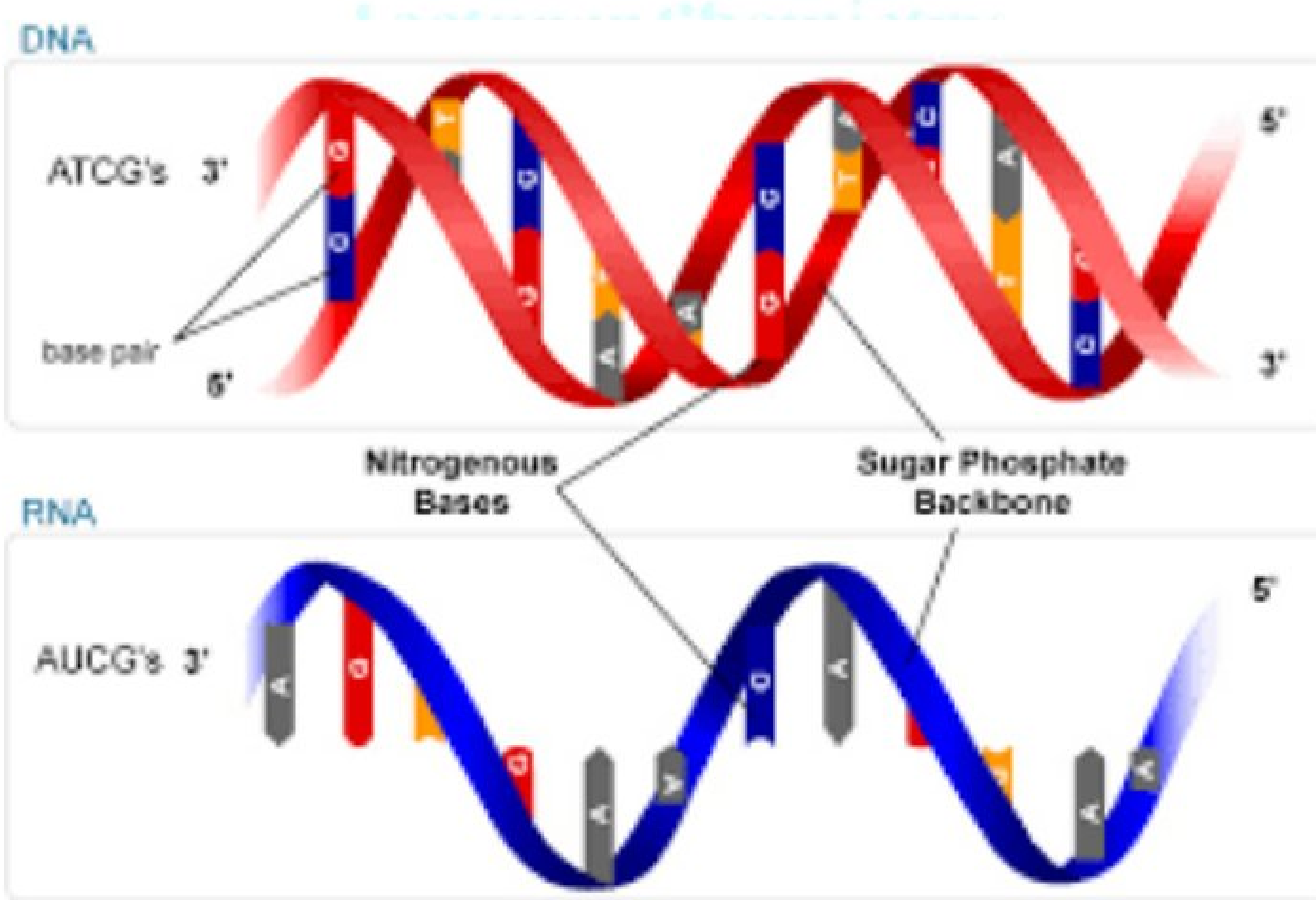
RNA plays a key role in protein synthesis by receiving, reading, and translating genetic instructions.

### Types and Functions of RNA

- **Messenger RNA (mRNA)**
  Copies genetic code from DNA and carries it to ribosomes in the cytoplasm.
- **Transfer RNA (tRNA)**
  Transports amino acids to the ribosomes during protein synthesis.
- **Ribosomal RNA (rRNA)**
  Helps build ribosomes, the sites where proteins are assembled.

### Process of Protein Synthesis

1. DNA copies information into mRNA
2. mRNA carries the code to ribosomes
3. tRNA and rRNA translate the message
4. A chain of amino acids forms a polypeptide
5. Polypeptide goes to Golgi Bodies for modification into a functional protein



## For More Information:

***Muhammad Amjad***

WhatsApp: 0306-7395469

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