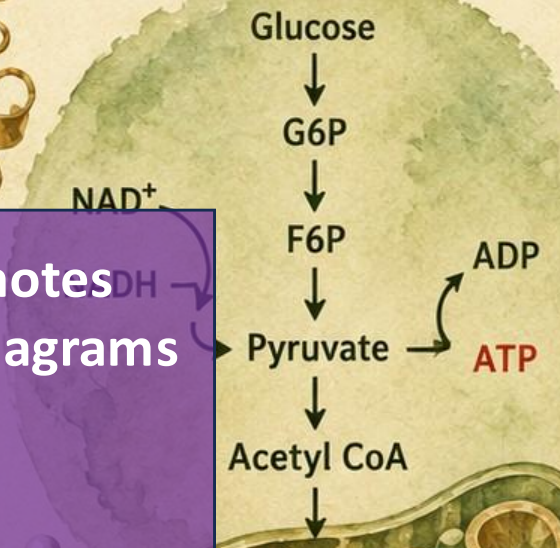
NEP Syllabus

TYBSC
ZOO – 301 – MJ
BIOCHEMISTRY

SEM V

YEAR III



- ✓ Short & easy notes
- ✓ Conceptual diagrams
- ✓ Concise study material

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ZOO – 301 – MJ : Biochemistry						
Year III Semester : V						
Teaching Scheme				Evaluation Scheme		
Course Type	Credits	Number of teaching hours	Lectures per week	Internal Assessment	Semester End Exam	Total
Major Core	2	30	2	15	35	50

Unit No.	Name of the Topic	Lectures Allotted
1.	**Foundation of Biochemistry :** Chemical constitution of life - Water and biomolecules. Concept of Mole, Molarity and Normality. 1.3. Types of bonds and their functions in biomolecules.	01
2.	**pH and Buffers :** 2.1 Water as biological solvent - Structure & polarity of water. 2.2. Concept of pH and pH scale, concept of acid and base balance with reference to Bronsted - Lowry concept, ionization of acids and bases. 2.3 Buffer - Definition, chemical nature of buffer, Derivation of Henderson-Hassel Balch equation & its applications, buffering capacity, Types of buffer system in body fluid - Bicarbonate & phosphate system.	03
3.	**Carbohydrates :** Definition, Classification & Biological importance of Carbohydrates. Monosaccharides - Classification based on number of carbon atom - from trioses to hexoses, and functional group - aldoses & ketoses, enantiomers, stereoisomerism of carbohydrates. Monosaccharides – Properties, Mutarotation, epimerization, tautomerization or enolization, reducing properties - oxidation and reduction, dehydration, osazone formation. Disaccharides - Glycosidic bond, reducing and non reducing disaccharides - lactose, maltose, sucrose, trehalose. Polysaccharides - Homo and hetero polysaccharides - types and biological importance. Biological significance of carbohydrates. Clinical Significance – Type 1 diabetes , Type 2 diabetes.	07
4.	**Amino acids and Proteins :** General structure of amino acids, classification of amino acids based on - structure, polarity & nutritional value. Peptide bond, organization of protein structures - Primary, secondary, tertiary and quaternary with suitable example, forces responsible for their stability. Ramchandran plot and protein conformation. Biological importance of proteins – Biocatalysts, carrier proteins contractile proteins, Hormonal role of proteins. 4.5. Clinical significance - Maple syrup urine disease, AKU.	06
5.	**Enzymes :** Nomenclature and classification, active site, substrate, cofactors, concept of lock and key and induced fit theory, types and properties of enzymes. Enzyme Kinetics: Enzyme activity and factors affecting enzyme activity - pH, temperature, substrate concentration, MM equation and its physiological significance. Enzyme inhibition: Types of inhibitions with examples. Coenzymes: Types and function. Isoenzymes. Regulatory enzymes: General properties of allosteric enzymes.	10
6.	**Lipids :** Introduction, classification of lipids. 6.2. Fatty acids - Types and nomenclature, saturated and unsaturated. 6.3 Physiologically important saturated and unsaturated fatty acids, tri-acylglycerols, phospholipids, glycolipids, steroids. 6.4 Clinical significance - Obesity, atherosclerosis, myocardial infraction.	03

Chapter 1: Foundations of Biochemistry

1.1 Chemical Constitution of Life: Water and Biomolecules

Life is a complex, highly organized molecular drama. To understand the zoological processes of living organisms, we must first look at the chemical elements and molecules that construct them.

The Elemental Framework

About 96% of an organism's mass is made up of just four elements: **Carbon (C), Hydrogen (H), Oxygen (O), and Nitrogen (N)**. Together with Calcium (Ca) and Phosphorus (P), these make up the bulk of biological structures.

1. Water: The Matrix of Life

Water (H_2O) is the most abundant molecule in living cells, usually accounting for 70% to 90% of a cell's weight.

Dipolar Nature: Oxygen is highly electronegative compared to hydrogen. This creates an uneven distribution of charge, making water a **polar molecule** (partial negative charge near oxygen, partial positive near hydrogen).
The Universal Solvent: Due to its polarity, water readily dissolves ionic and polar substances (hydrophilic) by forming hydration shells around them.
Thermal Stability: Water has a high specific heat capacity and high heat of vaporization. For animals, this acts as a critical thermal buffer, preventing rapid temperature fluctuations in the body and aiding in thermoregulation (e.g., sweating).

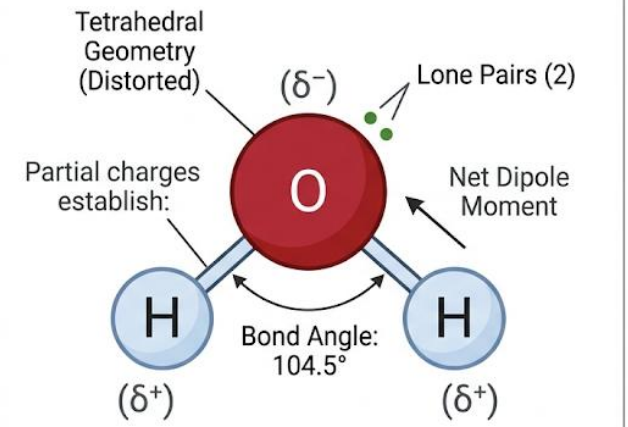


Figure 1.1A - Molecular Anatomy of H_2O

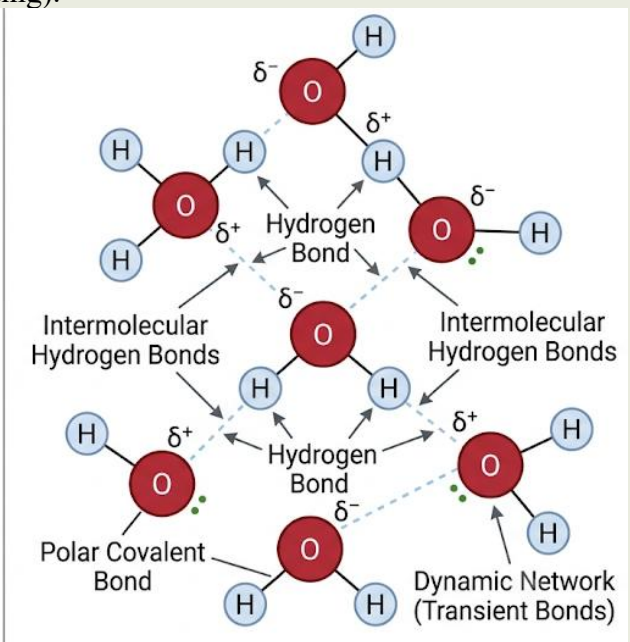


Figure 1.1B - The Dynamic Hydrogen Bond Network

2. Biomolecules: The Building Blocks

Biomolecules are organic molecules synthesized by living organisms. They are generally categorized into four major classes:

Biomolecule	Monomer / Building Block	Primary Function in Animals
Carbohydrates	Monosaccharides (e.g., Glucose)	Immediate energy source, structural components.
Proteins	Amino Acids	Cellular machinery, enzymes, muscle tissue, immune defense.
Lipids	Fatty Acids & Glycerol	Long-term energy storage, cell membrane structure (phospholipids).
Nucleic Acids	Nucleotides (A, T, C, G, U)	Genetic information storage (DNA) and protein synthesis (RNA).

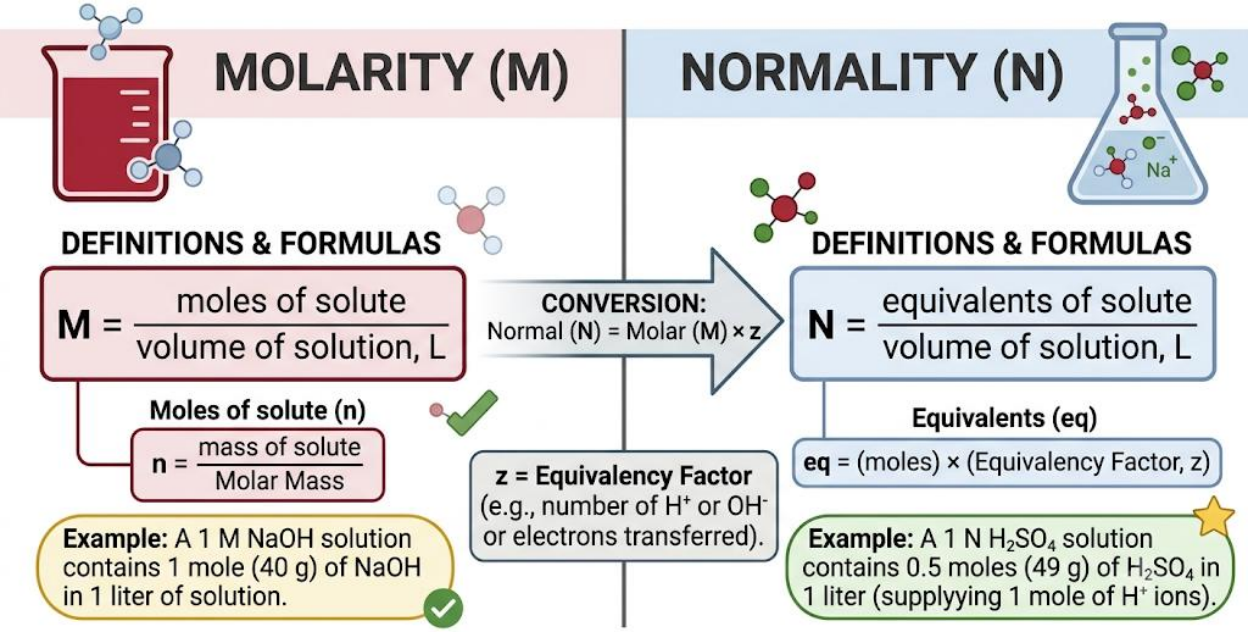


Figure 1.2: Quantitative Biochemistry - Quick Reference Conversion Box

1.2 Quantitative Biochemistry: Concept of Mole, Molarity, and Normality

To study biochemistry in a laboratory setup, you must understand how to measure and prepare solutions of these biomolecules.

1. The Mole Concept

A **mole** is the SI unit for the amount of a substance. One mole of any substance contains exactly 6.022×10^{23} elementary entities (atoms, molecules, or ions). This constant is known as **Avogadro's Number**.

$$\text{Number of Moles} = \frac{\text{Mass of substance (g)}}{\text{Molecular Weight (g/mol)}}$$

2. Molarity (M)

Molarity is defined as the number of moles of solute dissolved per liter (1000 mL) of solution. It is the most common unit of concentration used in biochemical preparations.

$$\text{Molarity (M)} = \frac{\text{Moles of Solute}}{\text{Volume of Solution in Liters}}$$

Example: To prepare a 1 M solution of Glucose (Molecular Weight = 180 g/mol), you dissolve 180 g of glucose in water and bring the total volume up to exactly 1 Liter.

3. Normality (N)
Normality is defined as the number of gram equivalents of solute per liter of solution. It is frequently used in acid-base chemistry and titration assays.

$$\text{Normality (N)} = \frac{\text{Gram equivalents of solute}}{\text{Volume of Solution in Liters}}$$

Gram equivalent depends on the chemical reaction. For an acid, it is the molecular weight divided by the number of replaceable H^+ ions. For a base, it is divided by replaceable OH^- ions. **Relationship with Molarity:** Normality = Molarity × Valency factor (n)

1.3 Types of Bonds and Their Functions in Biomolecules
Biomolecules maintain their specific three-dimensional shapes due to a combination of strong intra-molecular bonds and weaker inter-molecular interactions.

A. Intramolecular Bonds (Strong Bonds)

1. Covalent Bonds
Nature: Formed by the equal or unequal sharing of electron pairs between atoms.
Function: These are the backbone bonds. They hold the atoms of glucose together, connect amino acids via **peptide bonds**, and link nucleotides together via **phosphodiester bonds**. They require significant energy to break.

2. Ionic (Electrovalent) Bonds
Nature: Formed by the complete transfer of electrons from one atom to another, resulting in electrostatic attraction between oppositely charged ions (cations and anions).
Function: In proteins, ionic bonds are often referred to as **salt bridges**. They occur between charged amino acid side chains (like Glutamate and Lysine) and are crucial for maintaining tertiary and quaternary protein structures.

B. Intermolecular/Weak Interactions (Crucial for 3D Conformation)

3. Hydrogen Bonds
Nature: A weak electrostatic attraction between a hydrogen atom (covalently bound to an electronegative atom like O or N) and another electronegative atom.
Function: Essential for holding the two strands of the **DNA double helix** together (A=T, G$\equiv$C) and stabilizing the α-helix and β-pleated sheets in proteins.

4. Van der Waals Interactions
Nature: Weak, transient electrical attractions that occur between atoms that are very close to one another due to temporary dipoles caused by moving electrons.
Function: Though individually weak, the sum of thousands of Van der Waals interactions stabilizes the closely packed interiors of folded proteins and cell membranes.

5. Hydrophobic Interactions
Nature: The tendency of non-polar substances to aggregate together in an aqueous environment to exclude water molecules.

Function: Drives the folding of proteins (burying hydrophobic amino acids like Leucine inside the core, away from water) and forces phospholipids to form the lipid bilayer of animal cell membranes.

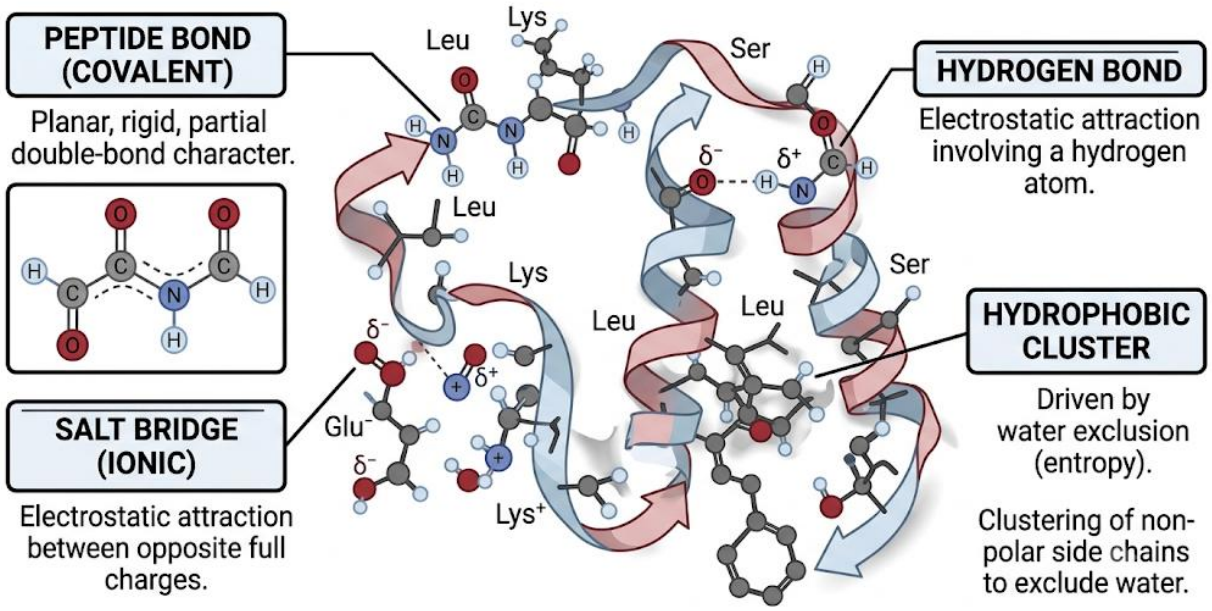


Figure 1.3: Stabilization Forces of a Folded Protein

Chapter 2: pH and Buffers

2.1 Water as a Biological Solvent: Structure & Polarity

Water (H2O) is the essential medium for all biochemical processes within an animal's body. Its unique structural properties make it the perfect biological solvent.

Molecular Structure: A water molecule consists of one oxygen atom covalently bonded to two hydrogen atoms. The oxygen atom has two pairs of unshared electrons (lone pairs). These lone pairs repel each other, forcing the molecule into a bent or asymmetric V-shape with a specific bond angle of 104.5°.

Polarity: Oxygen is highly electronegative compared to hydrogen, meaning it has a much stronger pull on the shared electrons. This creates an unequal charge distribution: the oxygen atom acquires a partial negative charge (δ^-), while the hydrogen atoms acquire partial positive charges (δ^+). This makes water a polar molecule.

Solvation Capacity: Because water is polar, it can easily dissolve ionic compounds (like NaCl) and polar compounds (like sugars) by surrounding them with hydration shells. This allows nutrients, ions, and metabolic wastes to be easily transported through blood, lymph, and cellular fluids in animals.

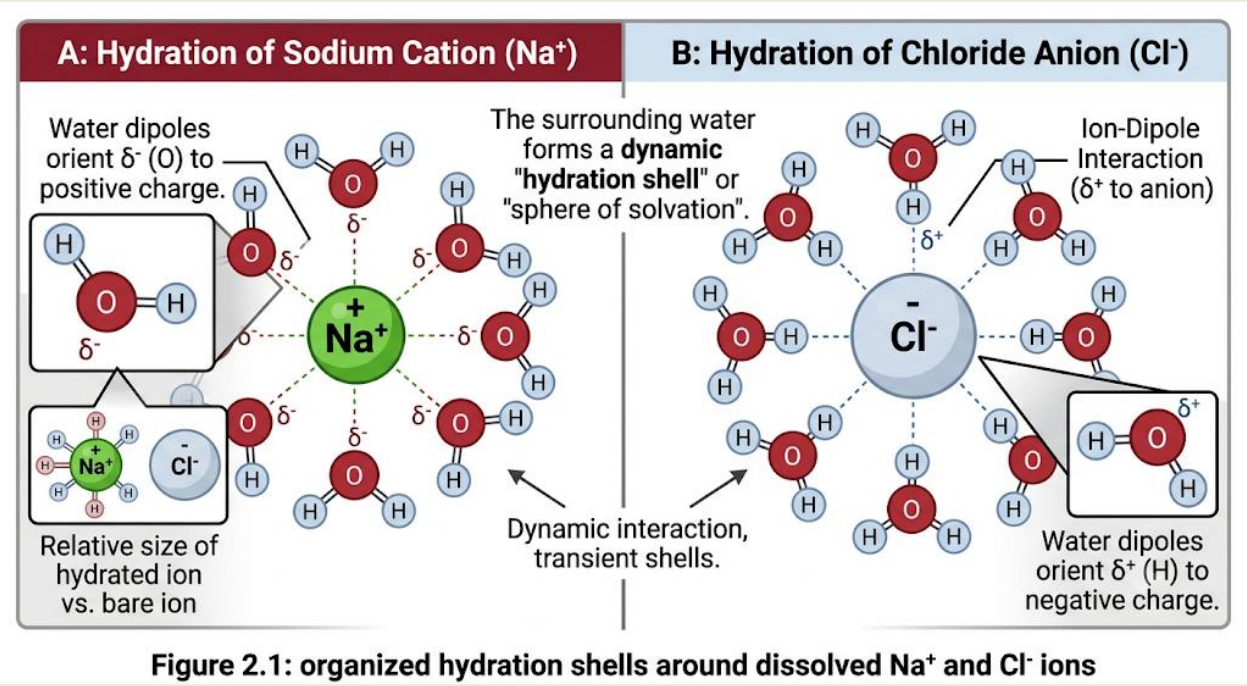


Figure 2.1: organized hydration shells around dissolved Na^+ and Cl^- ions

Concept of pH and pH Scale, Acid–Base Balance, Bronsted–Lowry Concept, and Ionization of Acids and Bases

Introduction

The concentration of hydrogen ions (H^+) in a solution plays a crucial role in determining its chemical properties and biological functions. Living organisms maintain a carefully regulated acid-base balance because even small changes in hydrogen ion concentration can affect enzyme activity, metabolic reactions, and cellular functions. The concepts of pH, acids, bases, and their ionization are therefore fundamental to understanding biochemical processes and physiological regulation.

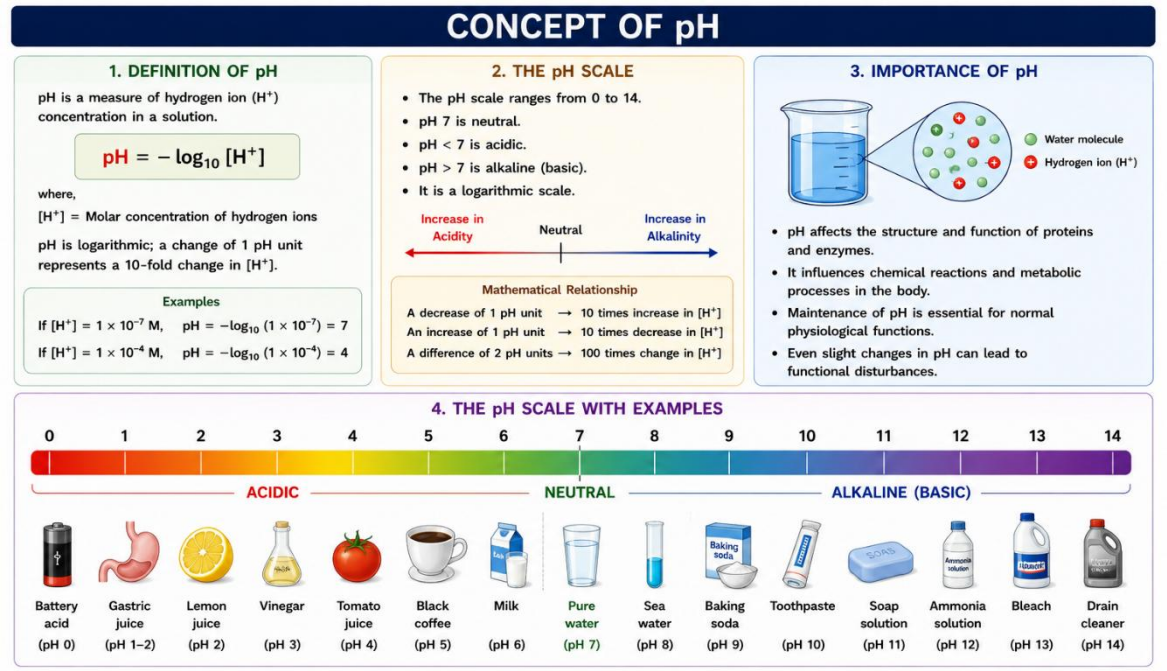
Concept of pH

The term **pH** was introduced by the Danish biochemist Søren P. L. Sørensen in 1909 as a convenient way to express hydrogen ion concentration in a solution. pH is defined as the

negative logarithm of the hydrogen ion concentration.

Mathematical Expression

$pH = -\log_{10}[H^+]$



where:

pH = hydrogen ion concentration expressed logarithmically

$[H^+]$ = molar concentration of hydrogen ions

Because the hydrogen ion concentration in biological systems is usually very small, the logarithmic scale provides a practical method for expressing acidity or alkalinity.

A solution with a high concentration of hydrogen ions has a low pH and is considered acidic, whereas a solution with a low hydrogen ion concentration has a high pH and is considered alkaline or basic.

The pH Scale

The pH scale ranges from **0 to 14** under normal conditions and provides a measure of the acidity or alkalinity of a solution.

A pH of **7** is considered neutral.

A pH below **7** indicates an acidic solution.

A pH above **7** indicates a basic or alkaline solution.

The pH scale is logarithmic, meaning that a change of one pH unit represents a tenfold change in hydrogen ion concentration. For example, a solution with pH 4 is ten times more acidic than a solution with pH 5 and one hundred times more acidic than a solution with pH 6.

pH Scale and Examples

pH Range	Nature	Example
0 – 3	Strongly Acidic	Hydrochloric acid, gastric juice
4 – 6	Weakly Acidic	Tomato juice, black coffee
7	Neutral	Pure water
8 – 10	Weakly Alkaline	Sea water
11 – 14	Strongly Alkaline	Sodium hydroxide solution

Acids and Bases: Bronsted–Lowry Concept

The Bronsted–Lowry theory, proposed by Johannes Bronsted and Thomas Lowry in 1923, provides a widely accepted definition of acids and bases based on proton transfer.

According to the Bronsted–Lowry concept, an **acid** is a substance that donates a proton (H^+), whereas a **base** is a substance that accepts a proton. This definition is broader than the Arrhenius concept because it explains acid-base reactions that occur even in the absence of water.

For example, when hydrochloric acid reacts with water, hydrochloric acid donates a proton and acts as an acid, while water accepts the proton and acts as a base.

Example

$HCl + H_2O \rightarrow H_3O^+ + Cl^-$

In this reaction:

HCl = Acid (proton donor)

H_2O = Base (proton acceptor)

Similarly, ammonia acts as a base because it accepts a proton from water.

$NH3+H2O \rightleftharpoons NH_4^+ + OH^-$

In this reaction:

NH_3 = Base

H_2O = Acid

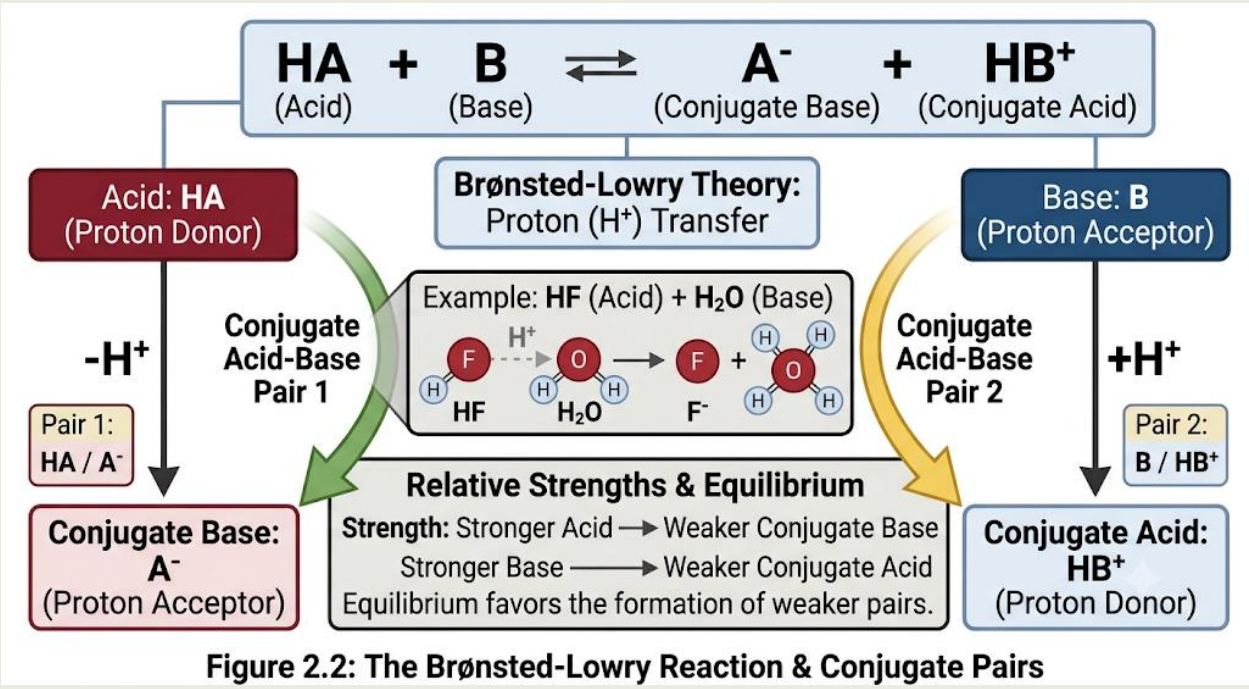


Figure 2.2: The Brønsted-Lowry Reaction & Conjugate Pairs

Conjugate Acid–Base Pairs

According to the Bronsted–Lowry theory, when an acid donates a proton, it forms its **conjugate base**. Similarly, when a base accepts a proton, it forms its **conjugate acid**.

Example

$HCl+H_2O \rightarrow H_3O^+ + Cl^-$

Substance	Role
HCl	Acid
Cl^-	Conjugate Base

H_2O	Base
H_3O^+	Conjugate Acid

Thus, acids and bases always exist as conjugate acid-base pairs.

Ionization of Acids

Ionization is the process by which an acid releases hydrogen ions when dissolved in water. Acids may be classified as strong or weak depending on the extent of ionization.

Strong acids ionize almost completely in solution, producing a large number of hydrogen ions. Examples include hydrochloric acid (HCl), nitric acid (HNO_3), and sulfuric acid (H_2SO_4).

Ionization of a Strong Acid

$HCl \rightarrow H^+ + Cl^-$

Weak acids ionize only partially, establishing an equilibrium between ionized and non-ionized forms.

Ionization of a Weak Acid

$CH_3COOH \rightleftharpoons H^+ + CH3COO^-$

Because weak acids release fewer hydrogen ions, they are less acidic than strong acids of the same concentration.

Comparison of Strong and Weak Acids

Strong Acids	Weak Acids
HCl	Acetic acid
HNO_3	Carbonic acid
H_2SO_4	Lactic acid
Nearly complete ionization	Partial ionization

Ionization of Bases

Bases ionize in water to produce hydroxyl ions (OH^-) or accept hydrogen ions from the surrounding medium. Like acids, bases may be strong or weak depending on their degree of ionization.

Strong bases dissociate almost completely in solution.

Ionization of a Strong Base

$NaOH \rightarrow Na^+ + OH^-$

Weak bases ionize only partially and establish equilibrium in solution.

Ionization of a Weak Base

$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

Weak bases produce fewer hydroxyl ions and therefore have a lower alkalinity compared with strong bases.

Comparison of Strong and Weak Bases

Strong Bases	Weak Bases
NaOH	NH_3
KOH	Amines
$Ca(OH)_2$	Pyridine
Complete ionization	Partial ionization

Acid–Base Balance in Biological Systems

Acid-base balance refers to the maintenance of hydrogen ion concentration within a narrow physiological range. In humans, normal blood pH is maintained between **7.35 and 7.45**, which

is slightly alkaline. This balance is essential because enzymes and metabolic reactions function optimally only within a specific pH range.
The body continuously produces acids through metabolic processes, including carbon dioxide, lactic acid, and keto acids. To prevent harmful changes in pH, several regulatory mechanisms operate simultaneously. These include buffer systems, respiratory regulation, and renal regulation.

Normal Physiological pH Values

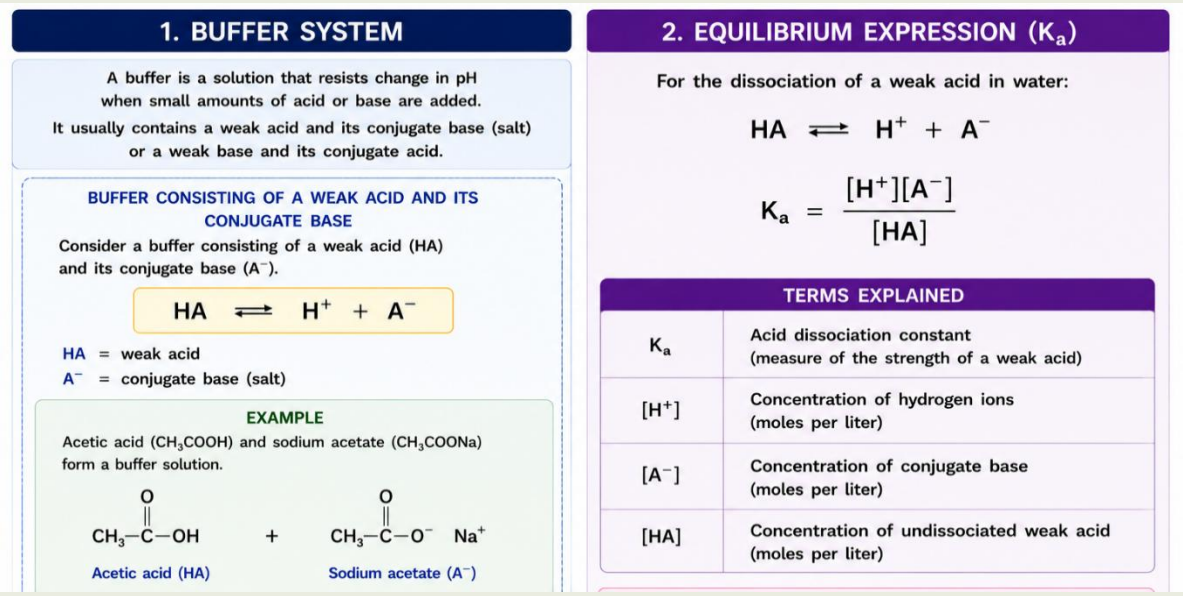
Body Fluid	Normal pH
Blood	7.35 – 7.45
Saliva	6.2 – 7.6
Gastric Juice	1.5 – 3.5
Urine	4.5 – 8.0

Importance of Acid–Base Balance

Maintenance of acid-base balance is essential for normal cellular function. Variations in pH can alter protein structure, affect enzyme activity, disturb electrolyte balance, and impair metabolic processes. Severe disturbances may result in conditions such as **acidosis** (decreased blood pH) and **alkalosis** (increased blood pH), both of which can have serious physiological consequences if left untreated.

Buffers: Principles and Physiological Systems

Living organisms continuously produce acids and bases as a result of metabolic activities. Even small changes in hydrogen ion concentration can affect enzyme activity, protein structure, and cellular functions. Therefore, the body must maintain a relatively constant pH to ensure normal physiological processes. This regulation is achieved through **buffer systems**, which resist sudden changes in pH when small amounts of acids or bases are added. Buffers constitute the first line of defense against disturbances in acid-base balance and play a crucial role in maintaining homeostasis.



Definition of Buffers

A buffer is a solution that resists changes in pH when small amounts of acid or base are added. It usually consists of a weak acid and its corresponding salt (conjugate base) or a weak base and its conjugate acid. Buffers maintain a relatively stable hydrogen ion concentration by either accepting excess hydrogen ions or releasing hydrogen ions when needed.

For example, a mixture of acetic acid and sodium acetate acts as an acidic buffer, while a mixture of ammonia and ammonium chloride acts as a basic buffer.

Principles of Buffer Action

The effectiveness of a buffer is based on the ability of a weak acid and its conjugate base to neutralize added acids or bases. When a small amount of acid is added to a buffer solution, the conjugate base combines with the excess hydrogen ions, minimizing the change in pH. Conversely, when a base is added, the weak acid donates hydrogen ions to neutralize the hydroxyl ions.

Consider the bicarbonate buffer system:

$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$

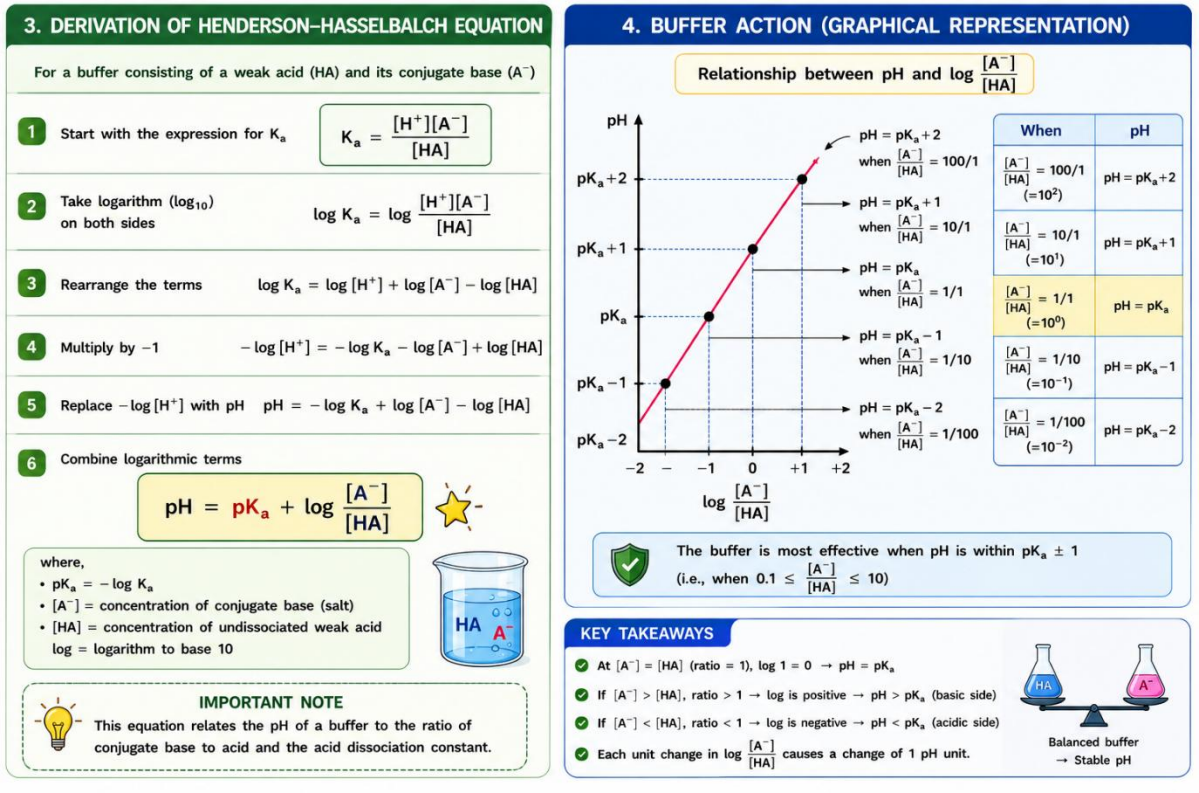
When excess acid is added:

$H^+ + HCO_3^- \rightarrow H_2CO_3$

When excess base is added:

$OH^- + H_2CO_3 \rightarrow HCO_3^- + H_2O$

Thus, the buffer prevents large fluctuations in pH by maintaining equilibrium between the weak acid and its conjugate base.



Buffer Capacity

Buffer capacity refers to the ability of a buffer solution to resist changes in pH. It depends on the concentration of the buffer components and their ratio. A buffer exhibits maximum

effectiveness when the concentrations of the weak acid and its conjugate base are approximately equal. Higher concentrations of buffer components generally provide greater buffering capacity.

Physiological Importance of Buffers

Buffers are essential for maintaining the pH of body fluids within narrow limits. Most enzymes function optimally only within a specific pH range, and deviations can impair metabolic reactions. Buffers help maintain the acid-base balance of blood, intracellular fluid, and extracellular fluid despite continuous production of metabolic acids. They also protect tissues from harmful changes in pH and contribute to the regulation of respiration, circulation, and renal function.

Physiological Buffer Systems

Several buffer systems operate in the human body to maintain acid-base balance. The most important physiological buffers include the bicarbonate buffer system, phosphate buffer system, protein buffer system, and hemoglobin buffer system.

Bicarbonate Buffer System

The bicarbonate buffer system is the most important extracellular buffer system in the human body. It consists of carbonic acid (H_2CO_3) and sodium bicarbonate ($NaHCO_3$). This system plays a crucial role in maintaining blood pH within the normal range of 7.35–7.45.

The bicarbonate buffer operates through the reversible reaction:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

When excess acid enters the blood, bicarbonate ions combine with hydrogen ions to form carbonic acid, which is subsequently converted to carbon dioxide and water. The carbon dioxide is then eliminated through the lungs. When excess base is present, carbonic acid releases hydrogen ions, thereby minimizing changes in pH.

Functions of Bicarbonate Buffer

Feature	Significance
Major extracellular buffer	Maintains blood pH
Linked to lungs and kidneys	Rapid regulation of pH
Removes excess acid as CO_2	Prevents acidosis

Phosphate Buffer System

The phosphate buffer system consists of dihydrogen phosphate ($H_2PO_4^-$) and hydrogen phosphate (HPO_4^{2-}). It is particularly important within cells and in renal tubular fluid, where phosphate concentrations are relatively high.

The system operates according to the equilibrium:

$$H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$$

When excess acid is added, hydrogen phosphate ions bind hydrogen ions to form dihydrogen phosphate. When excess base is added, dihydrogen phosphate releases hydrogen ions, thereby stabilizing pH.

Functions of Phosphate Buffer

Feature	Significance
Major intracellular buffer	Maintains cellular pH
Important in kidneys	Facilitates acid excretion
Effective near physiological pH	Supports metabolic reactions

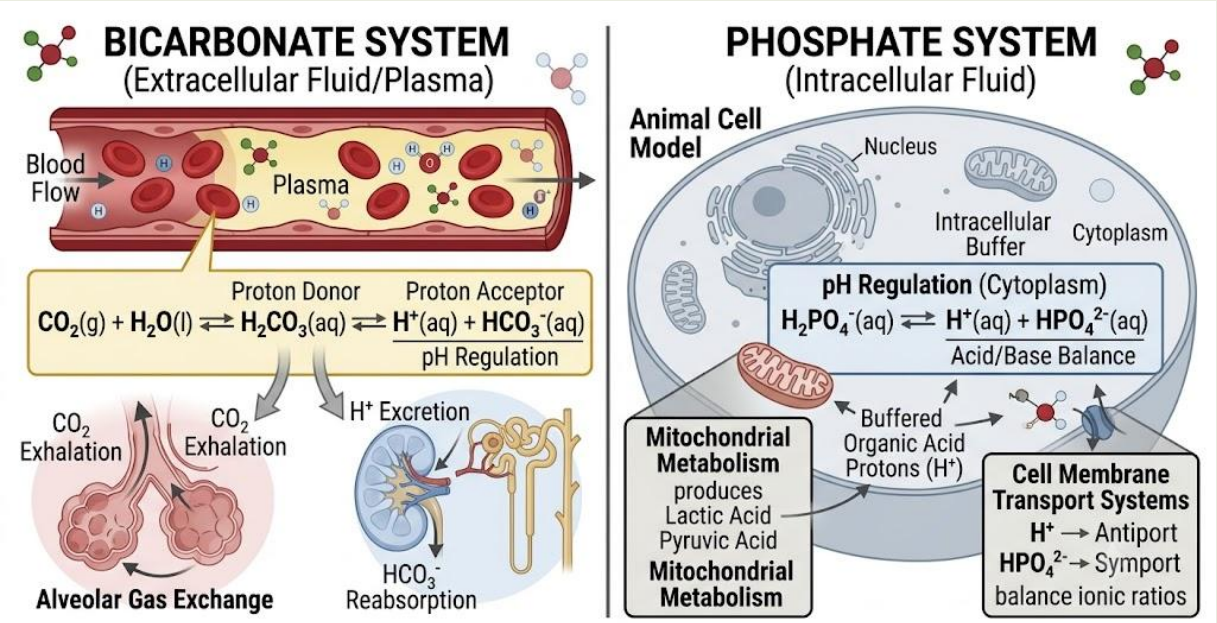


Figure 2.4: Physiological Buffer Systems - A Split View

Protein Buffer System

Proteins are among the most abundant buffers in the body because they contain amino and carboxyl groups capable of accepting or donating hydrogen ions. Plasma proteins and intracellular proteins contribute significantly to acid-base regulation.

When the pH decreases, protein molecules bind excess hydrogen ions. When the pH increases, they release hydrogen ions to counteract alkalinity. Due to their high concentration within cells, proteins represent an important intracellular buffering system.

Functions of Protein Buffers

Feature	Significance
Most abundant intracellular buffer	Maintains cellular pH
Amino acid side chains act as buffers	Accept or donate H^+ ions
Present in plasma and tissues	Broad buffering action

Hemoglobin Buffer System

Hemoglobin serves as an important buffer within red blood cells. It helps transport carbon dioxide and contributes significantly to blood pH regulation. Deoxygenated hemoglobin has a greater ability to bind hydrogen ions than oxygenated hemoglobin.

As carbon dioxide enters red blood cells, it is converted into carbonic acid, which dissociates into hydrogen ions and bicarbonate ions. Hemoglobin binds the released hydrogen ions, preventing a significant fall in blood pH.

Functions of Hemoglobin Buffer

Feature	Significance
Important buffer in red blood cells	Maintains blood pH
Binds excess hydrogen ions	Prevents acidosis
Assists CO_2 transport	Supports respiratory regulation

Comparison of Physiological Buffer Systems

Buffer System	Components	Major Location	Primary Function
Bicarbonate Buffer	H_2CO_3 / HCO_3^-	Blood plasma	Regulation of blood pH

Phosphate Buffer	$H_2PO_4^-$ / HPO_4^{2-}	Cells and kidneys	Intracellular buffering
Protein Buffer	Proteins and amino acids	Cells and plasma	General buffering
Hemoglobin Buffer	Hemoglobin	Red blood cells	Blood pH maintenance

Clinical Significance of Buffer Systems

Disturbances in buffer systems can lead to serious acid-base disorders. When buffer capacity is exceeded, conditions such as **acidosis** (blood pH below 7.35) or **alkalosis** (blood pH above 7.45) may develop. Respiratory diseases, kidney disorders, uncontrolled diabetes, and severe dehydration can impair normal buffer function and disrupt acid-base balance. Understanding physiological buffers is therefore essential for diagnosing and managing many clinical conditions.

Chapter 3: Carbohydrates: Structure, Properties, and Significance

Definition, Classification, and Biological Importance of Carbohydrates

Definition of Carbohydrates

Carbohydrates are organic compounds composed primarily of carbon, hydrogen, and oxygen, usually in the general formula **$(CH_2O)n$**. Chemically, they are defined as **polyhydroxy aldehydes or ketones**, or substances that yield such compounds upon hydrolysis. Carbohydrates are among the most abundant biomolecules in nature and serve as the primary source of energy for living organisms. They are synthesized by plants through photosynthesis and are subsequently utilized by animals and humans for energy production and various metabolic functions.

Classification of Carbohydrates

Carbohydrates are classified according to the number of sugar units they contain and their ability to undergo hydrolysis.

Monosaccharides

Monosaccharides are the simplest carbohydrates and cannot be hydrolyzed into smaller carbohydrate units. They consist of a single sugar molecule and serve as the basic building blocks of more complex carbohydrates. Monosaccharides are generally sweet, water-soluble compounds and are rapidly absorbed by the body. Common examples include glucose, fructose, and galactose.

Oligosaccharides

Oligosaccharides contain two to ten monosaccharide units linked by glycosidic bonds. The most common oligosaccharides are disaccharides, which consist of two monosaccharide molecules. These carbohydrates must be hydrolyzed into monosaccharides before absorption. Examples include sucrose, lactose, and maltose.

Polysaccharides

Polysaccharides are complex carbohydrates composed of more than ten monosaccharide units. They may contain hundreds or even thousands of sugar residues linked together. Polysaccharides function mainly as storage or structural molecules and are generally insoluble in water. Examples include starch, glycogen, cellulose, and chitin.

Classification of Carbohydrates Based on Number of Sugar Units

Class	Number of Sugar Units	Examples
Monosaccharides	One	Glucose, Fructose, Galactose
Oligosaccharides	2–10	Sucrose, Lactose, Maltose
Polysaccharides	More than 10	Starch, Glycogen, Cellulose

Classification of Monosaccharides

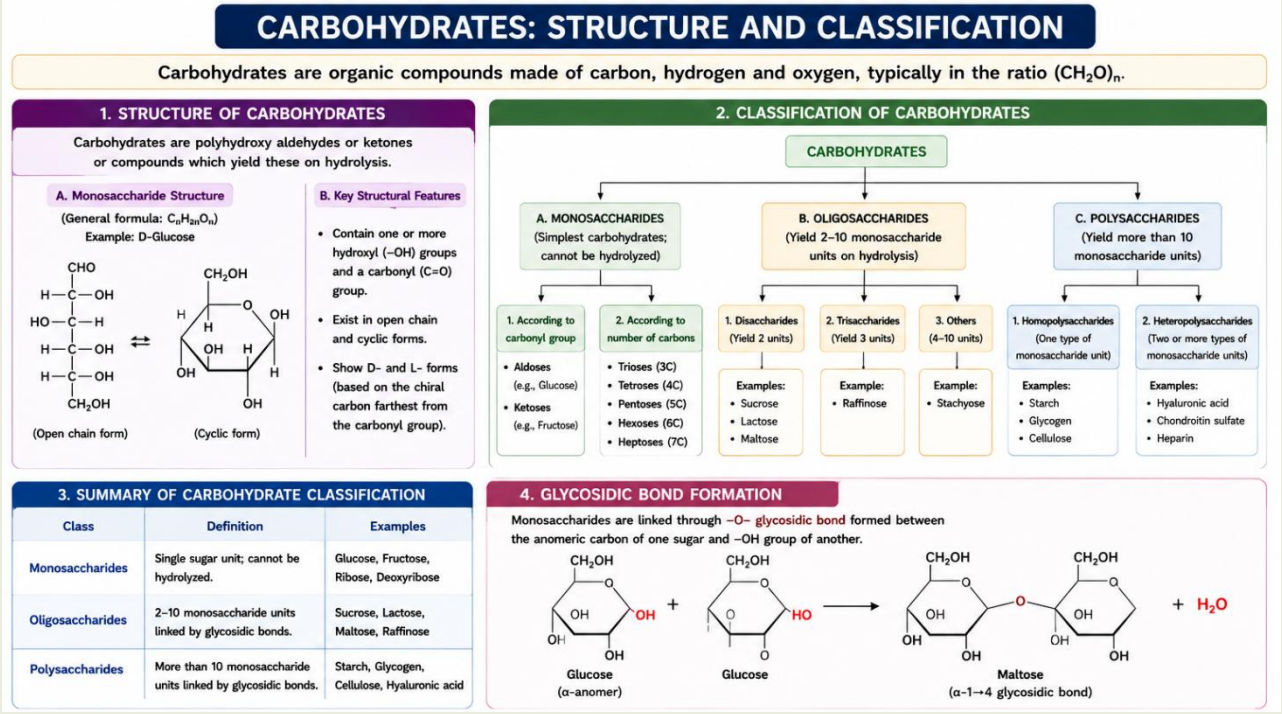
Monosaccharides may also be classified according to the type of carbonyl group present and the number of carbon atoms in the molecule.

Based on Functional Group

Type	Functional Group	Example
Aldoses	Aldehyde group	Glucose, Ribose
Ketoses	Ketone group	Fructose

Based on Number of Carbon Atoms

Type	Number of Carbon Atoms	Example
Triose	3	Glyceraldehyde
Tetrose	4	Erythrose
Pentose	5	Ribose
Hexose	6	Glucose, Fructose
Heptose	7	Sedoheptulose



Biological Importance of Carbohydrates

Source of Energy

Carbohydrates are the primary source of energy for most living organisms. During metabolism, glucose is oxidized to produce ATP, which serves as the energy currency of the cell. The brain, nervous tissue, and red blood cells rely heavily on glucose as their main energy source. Approximately **4 kcal of energy** is released from the oxidation of one gram of carbohydrate.

Energy Storage

Excess carbohydrates are stored in the body for future energy requirements. In plants, carbohydrates are stored as **starch**, while in animals they are stored as **glycogen** in the liver and muscles. These storage forms can be rapidly mobilized when energy demand increases.

Structural Function

Carbohydrates contribute to the structural framework of many biological systems. **Cellulose** forms the major component of plant cell walls, while **chitin** provides structural support in the exoskeleton of insects and crustaceans. These structural polysaccharides provide strength, rigidity, and protection.

Components of Nucleic Acids

Certain carbohydrates are essential constituents of nucleic acids. **Ribose** is present in RNA, whereas **deoxyribose** forms part of DNA. These sugars are necessary for the storage, transmission, and expression of genetic information.

Cell Recognition and Communication

Carbohydrates present on the cell surface as glycoproteins and glycolipids participate in cell recognition, adhesion, and communication. They help cells identify one another and play important roles in immune responses, tissue organization, and signal transduction.

Protective and Lubricating Functions

Some carbohydrates function as protective and lubricating substances. Hyaluronic acid and other glycosaminoglycans are found in connective tissues, synovial fluid, and the vitreous humor of the eye. These compounds provide cushioning, lubrication, and resistance to compression.

Dietary Fiber

Non-digestible carbohydrates such as cellulose, hemicellulose, and pectin constitute dietary fiber. Dietary fiber promotes healthy digestion, prevents constipation, regulates blood glucose levels, and helps reduce cholesterol levels. A fiber-rich diet is associated with improved gastrointestinal and cardiovascular health.

Precursors of Biomolecules

Carbohydrates serve as precursors for the synthesis of various biological molecules, including amino acids, fatty acids, nucleotides, and glycoproteins. They therefore play an important role in cellular metabolism and biosynthetic pathways.

3.2 Monosaccharides: Classification, Structure and Stereoisomerism

Introduction

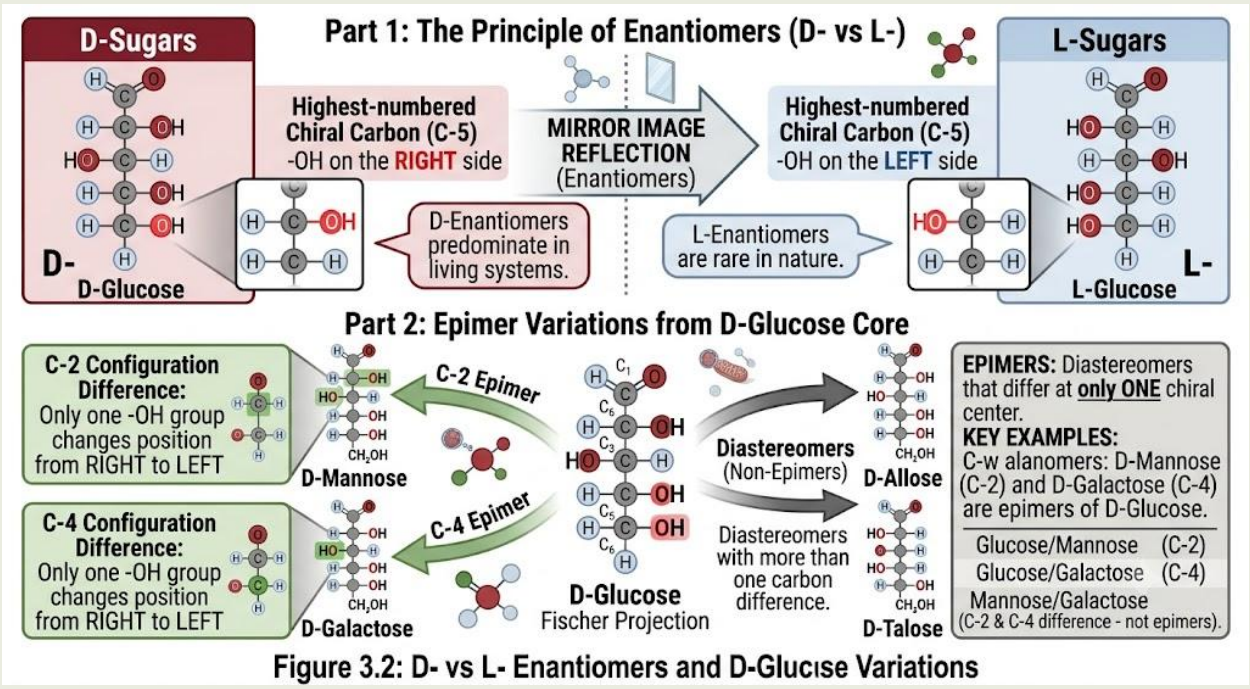


Figure 3.2: D- vs L- Enantiomers and D-Glucise Variations

Monosaccharides are the simplest carbohydrates and serve as the fundamental building blocks of all carbohydrates. They are polyhydroxy aldehydes or ketones that cannot be hydrolyzed into smaller carbohydrate units. Monosaccharides are colorless, crystalline solids that are generally sweet in taste and readily soluble in water. They play essential roles in energy metabolism and serve as precursors for the synthesis of complex carbohydrates, nucleic acids, and other biomolecules. Common monosaccharides include glucose, fructose, ribose, and galactose.

Classification of Monosaccharides

Monosaccharides are classified based on the type of carbonyl group present and the number of carbon atoms in the molecule.

Classification Based on Functional Group

Monosaccharides containing an aldehyde group (-CHO) are known as **aldoses**, whereas those containing a ketone group (>C=O) are called **ketoses**. The position of the carbonyl group influences the chemical properties and metabolic functions of the sugar.

Classification Based on Functional Group

Type	Functional Group	Example
Aldose	Aldehyde (-CHO)	Glucose, Galactose, Ribose
Ketose	Ketone (>C=O)	Fructose, Dihydroxyacetone

Classification Based on Number of Carbon Atoms

Monosaccharides may also be classified according to the number of carbon atoms present in their structure. The simplest monosaccharides contain three carbon atoms, while more complex forms may contain up to seven carbon atoms.

Classification Based on Carbon Number

Type	Number of Carbon Atoms	Example
Triose	3	Glyceraldehyde
Tetrose	4	Erythrose
Pentose	5	Ribose, Deoxyribose
Hexose	6	Glucose, Fructose, Galactose
Heptose	7	Sedoheptulose

Structure of Monosaccharides

Monosaccharides may exist in both **open-chain** and **cyclic forms**. In aqueous solutions, most monosaccharides predominantly exist in cyclic structures formed by an intramolecular reaction between the carbonyl group and a hydroxyl group. This reaction produces a hemiacetal or hemiketal ring structure.

For example, glucose exists mainly as a six-membered ring called a **pyranose ring**, while fructose commonly forms a five-membered **furanose ring**. The cyclic forms are more stable than the open-chain forms and therefore predominate in biological systems.

General Open-Chain Structure of an Aldose	General Cyclic Form of Glucose
CHO | H-C-OH | HO-C-H | H-C-OH | CH2OH	O / \ C C / \ C C \ / C ----- C

Stereoisomerism in Monosaccharides

Monosaccharides exhibit **stereoisomerism** because they contain one or more asymmetric (chiral) carbon atoms. Stereoisomers have the same molecular formula and sequence of bonds but differ in the spatial arrangement of atoms. Stereoisomerism is important because biological systems can distinguish between different stereoisomers.

Chiral Carbon and Optical Activity

A carbon atom attached to four different groups is known as a **chiral or asymmetric carbon atom**. Monosaccharides containing chiral carbons can rotate plane-polarized light and are therefore optically active.

The number of possible stereoisomers is determined by the formula: 2^n

where **n** is the number of chiral carbon atoms.

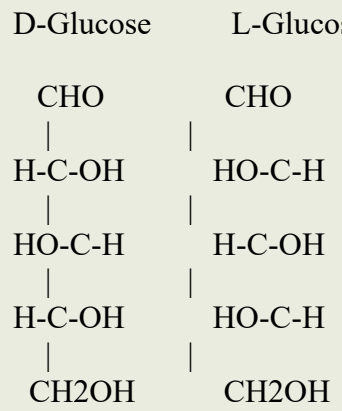
For example, glucose contains four chiral carbon atoms and therefore has: $2^4 = 16$ possible stereoisomers.

D- and L-Isomerism

Monosaccharides are classified as **D** or **L** forms based on the configuration of the chiral carbon atom farthest from the carbonyl group. If the hydroxyl group on this carbon lies to the right in the Fischer projection, the sugar is designated as a D-sugar. If it lies to the left, the sugar is designated as an L-sugar.

Most naturally occurring sugars belong to the **D-series**, with D-glucose being the most abundant monosaccharide in nature.

D- and L-Glucose



Enantiomers

Enantiomers are stereoisomers that are non-superimposable mirror images of each other. D-glucose and L-glucose are examples of enantiomers. Although they have identical chemical compositions, they differ in their interaction with polarized light and biological systems.

Enzymes are highly specific and usually recognize only one enantiomer. Consequently, D-glucose is readily metabolized by human cells, whereas L-glucose is not utilized efficiently.

Diastereomers

Diastereomers are stereoisomers that are not mirror images of each other. They differ in configuration at one or more chiral centers but not at all of them. Glucose, mannose, and galactose are examples of diastereomers.

Diastereomers possess different physical and chemical properties and often perform different biological functions.

Epimers

Epimers are a special class of diastereomers that differ in configuration at only one chiral carbon atom.

For example:

D-Glucose and D-Mannose differ at carbon 2.

D-Glucose and D-Galactose differ at carbon 4.

Important Epimers

Epimer Pair	Carbon Position of Difference
Glucose – Mannose	C-2
Glucose – Galactose	C-4

Anomers

When monosaccharides cyclize, a new chiral carbon known as the **anomeric carbon** is formed. Two stereoisomeric forms differing only at the anomeric carbon are called **anomers**.

In glucose, the hydroxyl group attached to the anomeric carbon may be positioned either below or above the plane of the ring, giving rise to **α-glucose** and **β-glucosComparison of Anomers**

Anomer	Position of OH Group on Anomeric Carbon
α-D-Glucose	Below the plane of the ring
β-D-Glucose	Above the plane of the ring

Biological Importance of Monosaccharides

Monosaccharides are the primary source of energy for cells and serve as key intermediates in metabolic pathways. Glucose is the major fuel molecule in most organisms and is essential for the functioning of the brain and nervous system. Ribose and deoxyribose form important components of RNA and DNA, respectively. Monosaccharides also serve as precursors for the synthesis of oligosaccharides, polysaccharides, glycoproteins, glycolipids, and numerous other biomolecules.

Monosaccharides: Properties, Mutarotation, Epimerization, Tautomerization (Enolization), Reducing Properties, Oxidation and Reduction, Dehydration, and Osazone Formation

Introduction

Monosaccharides are the simplest carbohydrates and possess a variety of physical and chemical properties due to the presence of hydroxyl (-OH) groups and a carbonyl group (aldehyde or ketone). These functional groups make monosaccharides highly reactive and capable of undergoing several important chemical reactions. The study of these reactions is important for understanding carbohydrate chemistry, metabolism, and identification of sugars.

Properties of Monosaccharides

Monosaccharides are generally colorless, crystalline solids with a sweet taste. They are readily soluble in water because of the presence of multiple hydroxyl groups that form hydrogen bonds with water molecules. Most monosaccharides are insoluble in non-polar solvents such as ether and chloroform. They are optically active due to the presence of one or more chiral carbon atoms and can rotate plane-polarized light. Monosaccharides exist in both open-chain and cyclic forms, with the cyclic form predominating in aqueous solution.

General Properties of Monosaccharides

Property	Description
Physical State	Colorless crystalline solids
Taste	Sweet
Solubility	Highly soluble in water
Optical Activity	Optically active due to chiral carbons
Structural Forms	Open-chain and cyclic forms

Mutarotation

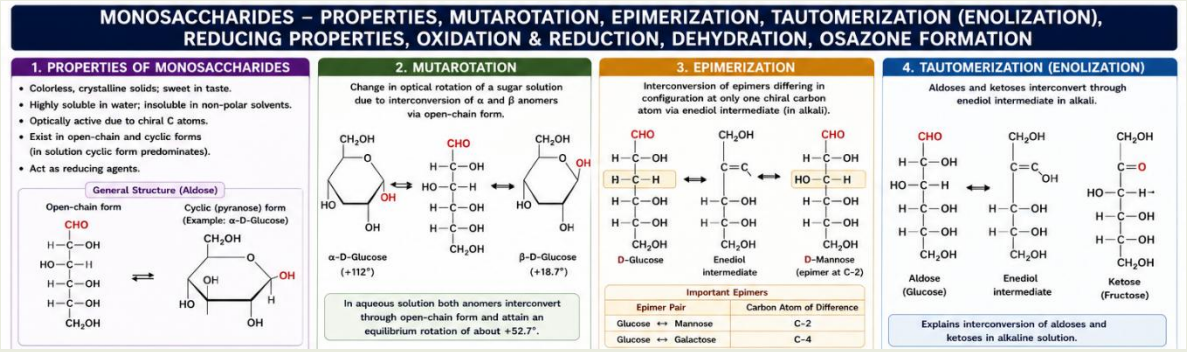
Mutarotation is the spontaneous change in the optical rotation of a sugar solution due to the interconversion between its α- and β-anomeric forms through the open-chain structure. When crystalline α-D-glucose is dissolved in water, its specific rotation gradually changes from

+112° to an equilibrium value of approximately +52.7°. Similarly, β-D-glucose changes from +18.7° to the same equilibrium value.
This phenomenon occurs because the ring structure opens to form the aldehyde form and then recloses, producing either the α- or β-anomer. Mutarotation is characteristic of reducing sugars that possess a free anomeric carbon atom.
Mutarotation in Glucose
α-D-Glucose
⇌
Open-chain form
⇌
β-D-Glucose

Epimerization
Epimerization is the process by which one epimer is converted into another through a change in configuration around a single chiral carbon atom. Epimers are stereoisomers that differ in configuration at only one asymmetric carbon atom.
For example, D-glucose and D-mannose differ only at carbon atom 2, while D-glucose and D-galactose differ only at carbon atom 4. Under alkaline conditions, these sugars can interconvert through an enediol intermediate. Epimerization plays an important role in carbohydrate metabolism and biosynthesis.
Important Epimers

Sugar Pair	Carbon Atom Involved
Glucose ↔ Mannose	C-2
Glucose ↔ Galactose	C-4

Tautomerization (Enolization)
Tautomerization is the reversible conversion of a sugar from one structural form to another through the formation of an enediol intermediate. In alkaline solution, aldoses and ketoses can interconvert via this mechanism.
For example, D-glucose (an aldose) can be converted into D-fructose (a ketose) through an enediol intermediate. This process is known as enolization because the intermediate contains both a double bond and a hydroxyl group.
Example of Enolization
Glucose
⇌
Enediol
⇌
Fructose
Tautomerization explains why aldoses and ketoses often exhibit similar reducing properties under alkaline conditions



Reducing Properties of Monosaccharides

Monosaccharides containing a free aldehyde group or a free anomeric carbon can act as reducing agents and are therefore known as reducing sugars. These sugars reduc e mild oxidizing agents such as Benedict's reagent, Fehling's solution, and Tollens' reagent.

The reducing property arises because the cyclic form can open to generate a free aldehyde or keto group capable of undergoing oxidation. Glucose, fructose, galactose, and lactose are examples of reducing sugars.

Common Tests for Reducing Sugars

Reagent	Observation
Benedict's Solution	Brick-red precipitate
Fehling's Solution	Red cuprous oxide precipitate
Tollens' Reagent	Silver mirror formation

Oxidation of Monosaccharides

Monosaccharides can be oxidized by various oxidizing agents to form different products depending on the reaction conditions.

Mild oxidizing agents convert the aldehyde group of aldoses into a carboxylic acid, producing **aldonic acids**. Strong oxidizing agents oxidize both the aldehyde group and the terminal alcohol group, producing **aldaric acids**. Oxidation of the terminal primary alcohol group alone yields **uronic acids**, which are important components of connective tissue polysaccharides.

Products of Oxidation

Oxidation Site	Product Formed	Example
Aldehyde Group	Aldonic Acid	Gluconic acid
Primary Alcohol Group	Uronic Acid	Glucuronic acid
Both Ends	Aldaric Acid	Glucaric acid

Reduction of Monosaccharides

Reduction involves the conversion of the carbonyl group of monosaccharides into an alcohol group. This reaction produces compounds known as **sugar alcohols** or **alditols**.

For example, glucose is reduced to sorbitol, while mannose yields mannitol. Sugar alcohols are widely used in pharmaceuticals and food industries as sweetening agents.

Examples of Reduction Products

Monosaccharide	Reduction Product
Glucose	Sorbitol
Mannose	Mannitol
Fructose	Sorbitol and Mannitol

Dehydration of Monosaccharides

When monosaccharides are heated with concentrated mineral acids such as sulfuric acid or hydrochloric acid, they undergo dehydration. During this reaction, water molecules are removed from the sugar molecule, producing furfural derivatives.

Pentoses form **furfural**, whereas hexoses produce **5-hydroxymethylfurfural**. These products react with phenolic compounds to produce colored complexes that form the basis of several carbohydrate identification tests, including Molisch's test.

Dehydration Products

Sugar Type	Product Formed
Pentoses	Furfural
Hexoses	Hydroxymethylfurfural

Osazone Formation

Osazones are crystalline derivatives formed when reducing sugars react with excess phenylhydrazine. The reaction involves the carbonyl carbon and the adjacent carbon atom of the sugar molecule.

Different sugars may produce characteristic osazone crystals that can be used for identification. Interestingly, glucose, fructose, and mannose form identical osazones because they differ only in the configuration of carbon atoms involved in the reaction.

Characteristics of Osazone Formation

Sugar	Osazone Type
Glucose	Needle-shaped crystals
Fructose	Needle-shaped crystals
Mannose	Needle-shaped crystals
Lactose	Powder-puff crystals
Maltose	Sunflower-shaped crystals

Simplified Reaction

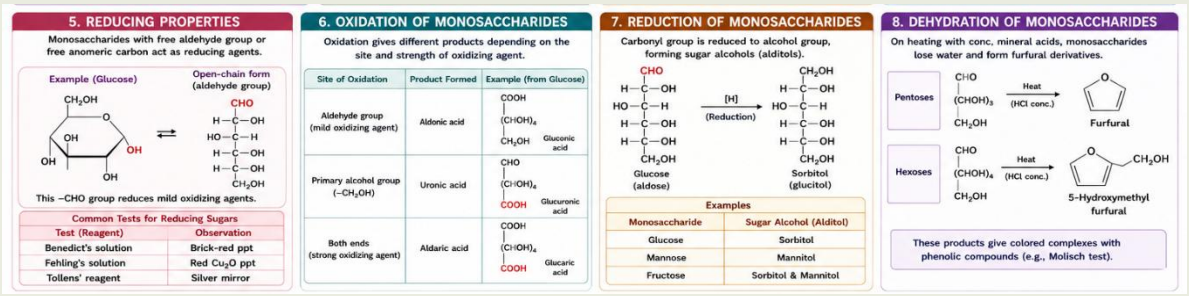
Reducing Sugar

\+

Phenylhydrazine

↓

Osazone



Disaccharides: Glycosidic Bond, Reducing and Non-Reducing Disaccharides

Disaccharides are carbohydrates composed of two monosaccharide units joined together by a glycosidic bond. They are formed through a condensation reaction in which a molecule of water is removed when two monosaccharides combine. Disaccharides are important dietary carbohydrates and serve as readily available sources of energy. Upon hydrolysis, they yield two monosaccharide molecules. Common disaccharides include lactose, maltose, sucrose, and trehalose.

Glycosidic Bond

A glycosidic bond is a covalent bond formed between the anomeric carbon atom of one monosaccharide and a hydroxyl group of another monosaccharide. The bond is formed through a dehydration (condensation) reaction accompanied by the removal of a water molecule. Glycosidic bonds may be designated as α or β depending on the configuration of the anomeric carbon involved in bond formation.

For example, maltose contains an α(1→4) glycosidic bond, whereas lactose contains a β(1→4) glycosidic bond. The nature of the glycosidic bond determines the structure, digestibility, and biological properties of the disaccharide.

Formation of a Glycosidic Bond
Monosaccharide + Monosaccharide
|
Condensation
|
Loss of H2O
|
▼
Disaccharide

Reducing and Non-Reducing Disaccharides

Disaccharides are classified as reducing or non-reducing based on the presence or absence of a free anomeric carbon atom capable of acting as a reducing agent.

A disaccharide is called a reducing disaccharide if one of its monosaccharide units possesses a free anomeric carbon. Such sugars can undergo mutarotation and give positive reactions with Benedict's and Fehling's reagents. In contrast, a non-reducing disaccharide lacks a free anomeric carbon because both anomeric carbons participate in glycosidic bond formation. These sugars do not exhibit mutarotation and do not reduce Benedict's or Fehling's solutions.

Classification of Important Disaccharides

Disaccharide	Constituent Monosaccharides	Glycosidic Bond	Reducing Nature
Maltose	**Glucose + Glucose**	**α(1→4)**	**Reducing**
Lactose	**Galactose + Glucose**	**β(1→4)**	**Reducing**
Sucrose	**Glucose + Fructose**	**α(1→2)β**	**Non-Reducing**
Trehalose	**Glucose + Glucose**	**α(1→1)α**	**Non-Reducing**

Lactose

Lactose, commonly known as milk sugar, is the principal carbohydrate present in milk and dairy products. It consists of one molecule of β-D-galactose linked to one molecule of D-glucose through a β(1→4) glycosidic bond. Because the glucose residue retains a free anomeric carbon atom, lactose is a reducing disaccharide and exhibits mutarotation.

Lactose is hydrolyzed by the enzyme lactase (β-galactosidase) into glucose and galactose. Deficiency of lactase results in lactose intolerance, a condition characterized by abdominal discomfort, bloating, and diarrhea following milk consumption.

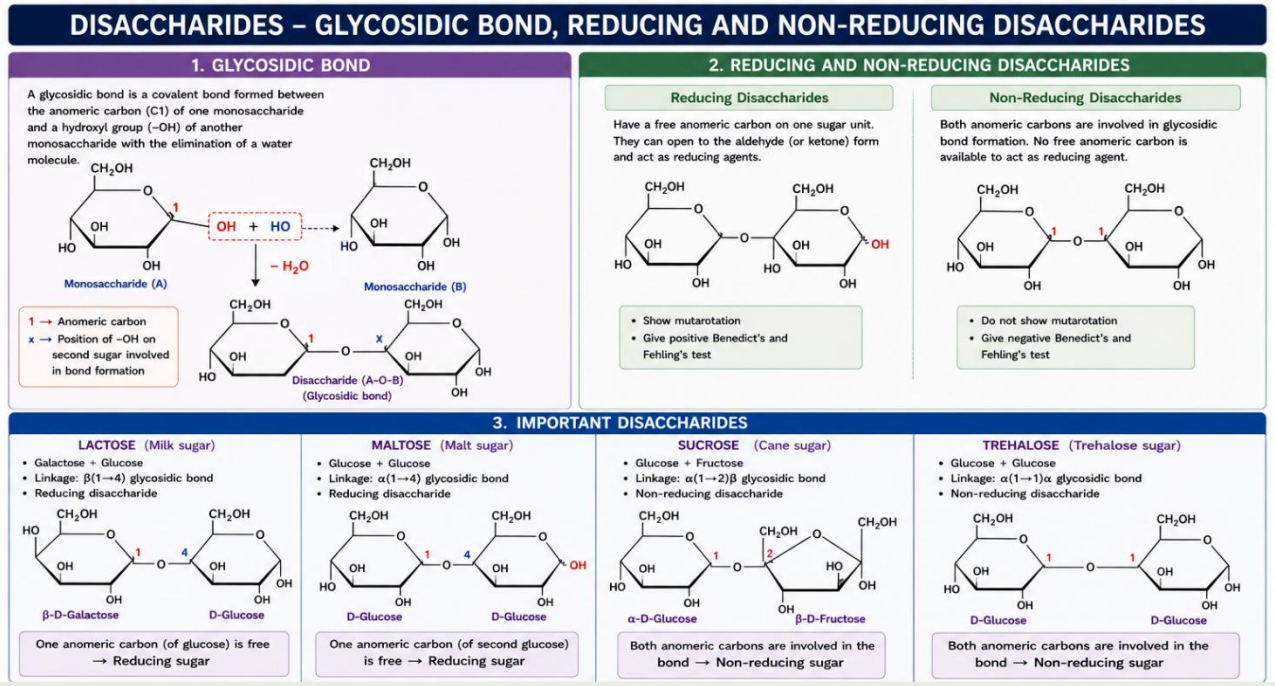
Structure of Lactose
Galactose ──β(1→4)── Glucose

Maltose

Maltose, also known as malt sugar, is produced during the digestion of starch and glycogen. It consists of two molecules of glucose linked through an α(1→4) glycosidic bond. One glucose residue retains a free anomeric carbon atom, making maltose a reducing sugar.

Maltose is hydrolyzed by the enzyme maltase into two molecules of glucose. It is commonly found in germinating cereals and malted grains and serves as an important intermediate in carbohydrate digestion.

Structure of Maltose
Glucose ──α(1→4)── Glucose



Sucrose

Sucrose, commonly called table sugar or cane sugar, is one of the most abundant carbohydrates in nature. It is composed of one molecule of α-D-glucose and one molecule of β-D-fructose linked through an α(1→2)β glycosidic bond. In sucrose, both anomeric **carbon atoms** participate in bond formation, leaving no free anomeric carbon.

As a result, sucrose is a non-reducing disaccharide and does not exhibit mutarotation or reducing properties. Sucrose is hydrolyzed by the enzyme sucrase (invertase) into glucose and fructose.

Structure of Sucrose

Glucose ──α(1→2)β── Fructose

Trehalose

Trehalose is a naturally occurring disaccharide found in fungi, yeast, insects, and certain plants. It consists of two glucose molecules joined by an α(1→1)α glycosidic bond. Because both anomeric carbon atoms participate in bond formation, trehalose lacks a free reducing group and is therefore a non-reducing sugar.

Trehalose is highly stable and resistant to acid hydrolysis compared with many other disaccharides. It functions as a protective carbohydrate in organisms exposed to dehydration, heat stress, and environmental extremes. The enzyme trehalase hydrolyzes trehalose into two glucose molecules.

Structure of Trehalose

Glucose ──α(1→1)α── Glucose

Comparison of Important Disaccharides

Property	Lactose	Maltose	Sucrose	Trehalose
Constituent Sugars	Galactose + Glucose	Glucose + Glucose	Glucose + Fructose	Glucose + Glucose
Glycosidic Bond	β(1→4)	α(1→4)	α(1→2)β	α(1→1)α
Reducing Property	Yes	Yes	No	No

Mutarotation	Present	Present	Absent	Absent
Hydrolyzing Enzyme	Lactase	Maltase	Sucrase	Trehalase
Common Source	Milk	Germinating grains	Sugar cane, sugar beet	Fungi, yeast, insects

Polysaccharides: Homo- and Heteropolysaccharides – Types and Biological Importance
Polysaccharides are complex carbohydrates composed of a large number of monosaccharide units linked together by glycosidic bonds. They may contain hundreds or even thousands of sugar residues and are formed through repeated condensation reactions. Unlike monosaccharides and disaccharides, polysaccharides are generally tasteless, insoluble in water, and non-reducing in nature. They serve important functions in living organisms, including energy storage, structural support, lubrication, and protection. Based on the types of monosaccharides present, polysaccharides are classified into homopolysaccharides and heteropolysaccharides.

Classification of Polysaccharides
Polysaccharides are broadly classified into two major groups:
Homopolysaccharides (Homoglycans)
Heteropolysaccharides (Heteroglycans)

Classification of Polysaccharides

Type	Composition	Examples
Homopolysaccharides	Composed of only one type of monosaccharide	Starch, Glycogen, Cellulose, Chitin
Heteropolysaccharides	Composed of two or more different monosaccharides	Hyaluronic acid, Heparin, Chondroitin sulfate

Homopolysaccharides
Homopolysaccharides are polysaccharides composed of repeating units of the same monosaccharide. They are among the most abundant carbohydrates in nature and function mainly as storage or structural materials**.**

Starch
Starch is the principal storage polysaccharide of plants and serves as the major carbohydrate reserve in seeds, roots, and tubers. It is composed entirely of glucose units and consists of two components: amylose, which is a linear polymer of α(1→4)-linked glucose, and amylopectin, which is a branched polymer containing α(1→4) and α(1→6) glycosidic linkages. Starch is an important source of dietary energy for humans and animals.

Glycogen
Glycogen is the major storage polysaccharide of animals and is often referred to as animal starch. It consists of highly branched chains of glucose linked by α(1→4) glycosidic bonds with α(1→6) branch points. Glycogen is stored primarily in the liver and skeletal muscles and serves as a rapidly mobilizable source of glucose during periods of increased energy demand.

Cellulose
Cellulose is the most abundant organic compound on Earth and forms the structural framework of plant cell walls. It consists of linear chains of β-D-glucose molecules linked by β(1→4)

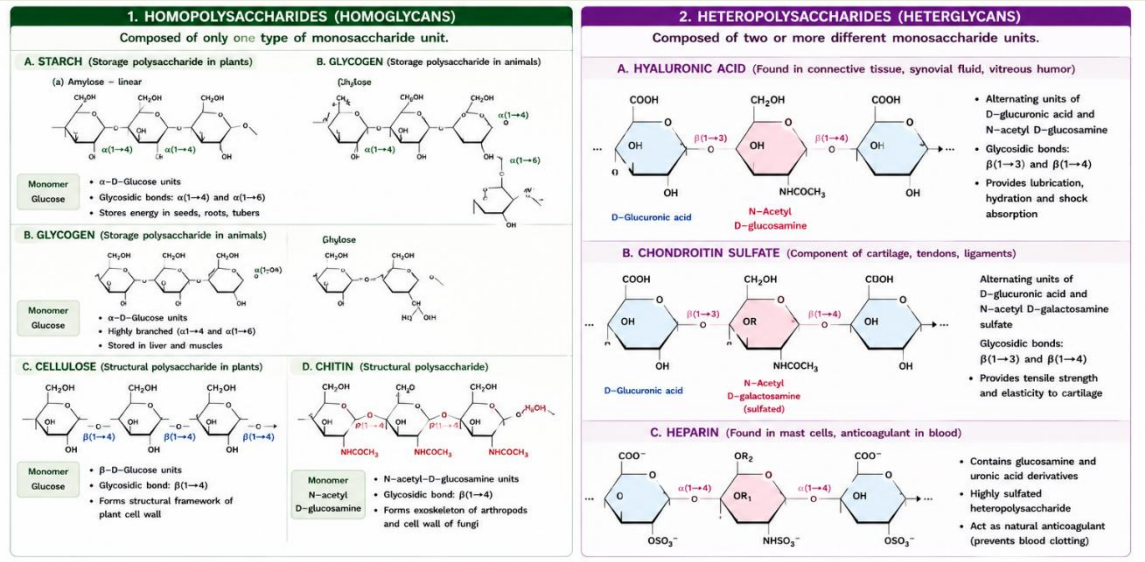
glycosidic bonds. These chains are arranged in parallel and held together by hydrogen bonds, providing exceptional strength and rigidity. Humans lack the enzyme cellulase and therefore cannot digest cellulose, although it serves as an important component of dietary fiber.

Chitin

Chitin is a structural polysaccharide found in the exoskeleton of insects, crustaceans, and the cell walls of fungi. It is composed of repeating units of N-acetyl-D-glucosamine linked by β(1→4) glycosidic bonds. Chitin provides mechanical strength, protection, and structural support to organisms that contain it.

Important Homopolysaccharides

Homopolysaccharide	Monomer Unit	Major Function
Starch	Glucose	Energy storage in plants
Glycogen	Glucose	Energy storage in animals
Cellulose	Glucose	Structural support in plants
Chitin	N-acetylglucosamine	Structural support in fungi and arthropods



Heteropolysaccharides

Heteropolysaccharides are polysaccharides composed of two or more different types of monosaccharides or their derivatives. They are commonly found in connective tissues, extracellular matrices, and biological fluids, where they perform structural, protective, and lubricating functions.

Hyaluronic Acid

Hyaluronic acid is a high-molecular-weight heteropolysaccharide composed of alternating units of glucuronic acid and N-acetylglucosamine. It is widely distributed in connective tissues, synovial fluid, skin, and the vitreous humor of the eye. Hyaluronic acid acts as a lubricant and shock absorber and helps maintain tissue hydration.

Chondroitin Sulfate

Chondroitin sulfate is a major component of cartilage, tendons, ligaments, and blood vessel walls. It consists of alternating units of glucuronic acid and N-acetylgalactosamine sulfate. This polysaccharide provides tensile strength and elasticity to connective tissues and contributes to

the resilience of cartilage.

Heparin
Heparin is a highly sulfated heteropolysaccharide found in mast cells and certain tissues. It consists of repeating units of glucosamine and uronic acid derivatives. Heparin functions as a powerful anticoagulant by preventing blood clot formation and is widely used in clinical medicine during surgeries and dialysis procedures.

Important Heteropolysaccharides

Heteropolysaccharide	Components	Major Function
Hyaluronic Acid	Glucuronic acid + N-acetylglucosamine	Lubrication and hydration
Chondroitin Sulfate	Glucuronic acid + N-acetylgalactosamine sulfate	Cartilage support
Heparin	Glucosamine + Uronic acid derivatives	Anticoagulant

Biological Importance of Monosaccharides
Monosaccharides are the primary source of energy for cells and serve as key intermediates in metabolic pathways. Glucose is the major fuel molecule in most organisms and is essential for the functioning of the brain and nervous system. Ribose and deoxyribose form important components of RNA and DNA, respectively. Monosaccharides also serve as precursors for the synthesis of oligosaccharides, polysaccharides, glycoproteins, glycolipids, and numerous other biomolecules.

Biological importance of Charbohtdrates
Biological Importance of Disaccharides
Disaccharides serve as important dietary sources of energy and play significant roles in nutrition and metabolism. Lactose provides energy to infants and promotes calcium absorption, while maltose acts as an intermediate in starch digestion. Sucrose is the major transport sugar in plants and an important dietary sweetener. Trehalose functions as a reserve carbohydrate and protective molecule in many microorganisms and invertebrates. The digestion and utilization of these sugars contribute significantly to energy metabolism in living organisms.

Biological Importance of Polysaccharides

Energy Storage
Polysaccharides serve as the principal storage form of carbohydrates in living organisms. Starch stores glucose in plants, while glycogen performs a similar role in animals. These storage polysaccharides provide a readily available source of energy during periods of metabolic demand.

Structural Support
Many polysaccharides function as structural materials. Cellulose provides rigidity and strength to plant cell walls, while chitin forms protective exoskeletons in arthropods and strengthens fungal cell walls. These structural polysaccharides are essential for maintaining shape and integrity.

Protection and Lubrication
Heteropolysaccharides such as hyaluronic acid and chondroitin sulfate protect tissues against mechanical stress and facilitate smooth movement between joints. Their water-binding

properties help maintain tissue hydration and elasticity.

Regulation of Biological Processes

Certain polysaccharides participate in important physiological processes. Heparin regulates blood coagulation by acting as a natural anticoagulant. Other glycosaminoglycans influence cell signaling, tissue repair, and cellular interactions.

Dietary Fiber

Non-digestible polysaccharides such as cellulose contribute to dietary fiber. Fiber promotes healthy digestion, improves intestinal motility, prevents constipation, and supports cardiovascular health by helping regulate cholesterol levels.

Comparison of Homo- and Heteropolysaccharides

Feature	Homopolysaccharides	Heteropolysaccharides
Monomer Composition	One type of monosaccharide	Two or more types of monosaccharides
Complexity	Relatively simple	More complex
Major Functions	Energy storage and structural support	Protection, lubrication, and regulation
Examples	Starch, Glycogen, Cellulose, Chitin	Hyaluronic acid, Chondroitin sulfate, Heparin

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Clinical Significance of Carbohydrate Metabolism: Type 1 and Type 2 Diabetes Mellitus

Diabetes mellitus is a chronic metabolic disorder characterized by persistent elevation of blood glucose levels (hyperglycemia) resulting from defects in insulin secretion, insulin action, or both. Insulin is a hormone produced by the β-cells of the pancreas and plays a crucial role in regulating carbohydrate metabolism by facilitating glucose uptake into cells. Disturbances in insulin production or function lead to abnormal carbohydrate metabolism and the development of diabetes mellitus. The two major forms of diabetes are Type 1 Diabetes Mellitus (T1DM) and Type 2 Diabetes Mellitus (T2DM).

Type 1 Diabetes Mellitus (T1DM)

Type 1 Diabetes Mellitus is an autoimmune disorder in which the body's immune system mistakenly attacks and destroys the insulin-producing β-cells of the pancreas. As a result, little or no insulin is produced, leading to severe hyperglycemia. This form of diabetes usually develops during childhood or adolescence, although it can occur at any age.

Because insulin is absent, glucose cannot enter most body cells efficiently and accumulates in the bloodstream. To meet energy requirements, the body begins breaking down fats and proteins, resulting in weight loss and the production of ketone bodies. Excessive ketone production may lead to a serious condition known as diabetic ketoacidosis (DKA).

Clinical Features of Type 1 Diabetes

The common symptoms include excessive thirst (polydipsia), frequent urination (polyuria), increased hunger (polyphagia), unexplained weight loss, fatigue, and blurred vision. The onset is usually sudden, and symptoms may develop rapidly over a few weeks.

Diagnosis

Diagnosis is based on elevated blood glucose levels, glycated hemoglobin (HbA1c) measurements, and the detection of autoimmune antibodies against pancreatic β-cells. Reduced or absent insulin production is often confirmed by low C-peptide levels.

Treatment

Since the body cannot produce sufficient insulin, lifelong insulin therapy is essential. Treatment also includes blood glucose monitoring, dietary management, regular exercise, and patient education regarding insulin administration and diabetes management.

Type 2 Diabetes Mellitus (T2DM)

Type 2 Diabetes Mellitus is the most common form of diabetes and accounts for approximately 90–95% of all diabetes cases. It is characterized by insulin resistance, in which body cells fail to respond effectively to insulin, combined with a gradual decline in insulin production by pancreatic β-cells.

Type 2 diabetes usually develops in adults but is increasingly being observed in younger individuals due to obesity, sedentary lifestyles, and unhealthy dietary habits. Unlike Type 1 diabetes, insulin is initially present, but its effectiveness is reduced.

The disease develops gradually, often over several years, and many individuals remain undiagnosed until complications appear. Risk factors include obesity, family history, advancing age, hypertension, physical inactivity, and poor dietary habits.

Clinical Features of Type 2 Diabetes

Patients commonly experience excessive thirst, increased urination, fatigue, blurred vision, delayed wound healing, recurrent infections, and numbness or tingling in the hands and feet. The symptoms are generally milder and develop more slowly than in Type 1 diabetes.

Diagnosis

Diagnosis is based on fasting blood glucose levels, oral glucose tolerance tests, random blood glucose measurements, and HbA1c values. Unlike Type 1 diabetes, insulin levels may initially be normal or even elevated due to insulin resistance.

Treatment

Management primarily focuses on lifestyle modification, including weight reduction, regular physical activity, and a balanced diet. Oral antidiabetic drugs such as metformin are commonly prescribed to improve insulin sensitivity and glucose utilization. In advanced stages, insulin therapy may also be required.

Comparison Between Type 1 and Type 2 Diabetes Mellitus

Feature	Type 1 Diabetes Mellitus	Type 2 Diabetes Mellitus
Cause	Autoimmune destruction of β-cells	Insulin resistance and β-cell dysfunction
Insulin Production	Very low or absent	Initially normal or high, later decreases
Age of Onset	Usually childhood or adolescence	Usually adulthood
Body Weight	Often normal or underweight	Frequently overweight or obese
Onset of Symptoms	Sudden	Gradual
Ketoacidosis	Common	Rare
Treatment	Insulin therapy required	Lifestyle changes, oral drugs, insulin if needed
Prevalence	5–10% of cases	90–95% of cases

Complications of Diabetes Mellitus

Long-term uncontrolled diabetes can damage various organs and tissues due to persistent hyperglycemia. Common complications include cardiovascular disease, kidney damage

(diabetic nephropathy), nerve damage (diabetic neuropathy), eye disorders (diabetic retinopathy), delayed wound healing, and an increased risk of infections. Proper glucose control significantly reduces the risk of these complications.

Major Complications

Acute Complications	Chronic Complications
Diabetic Ketoacidosis (T1DM)	Cardiovascular disease
Hyperosmolar Hyperglycemic State (T2DM)	Diabetic nephropathy
Severe Hypoglycemia	Diabetic neuropathy
Metabolic disturbances	Diabetic retinopathy

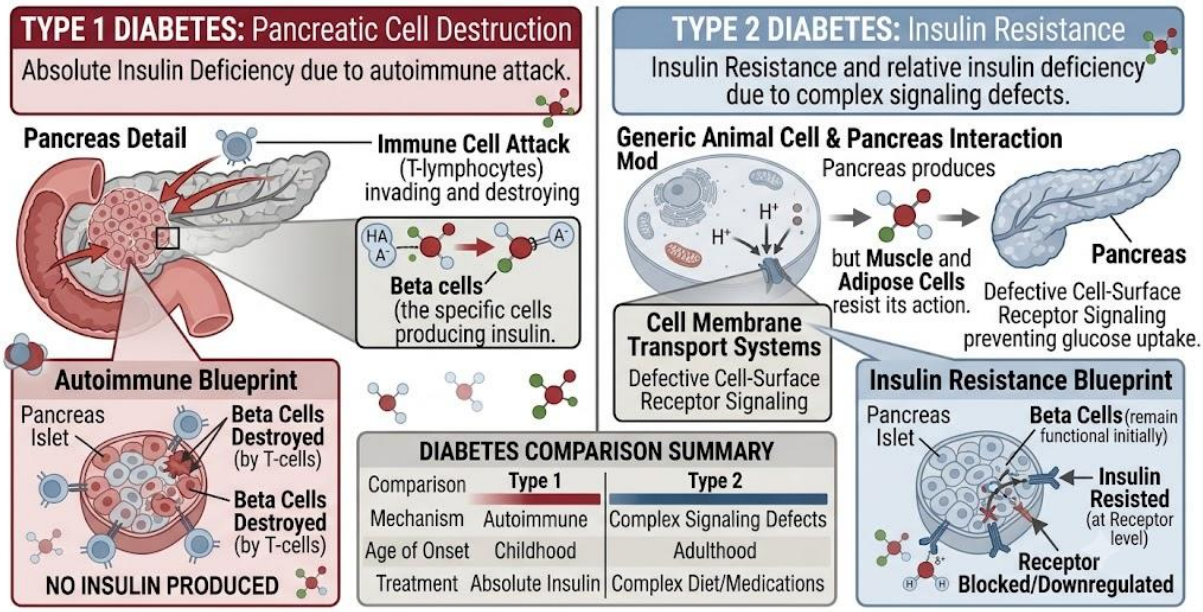
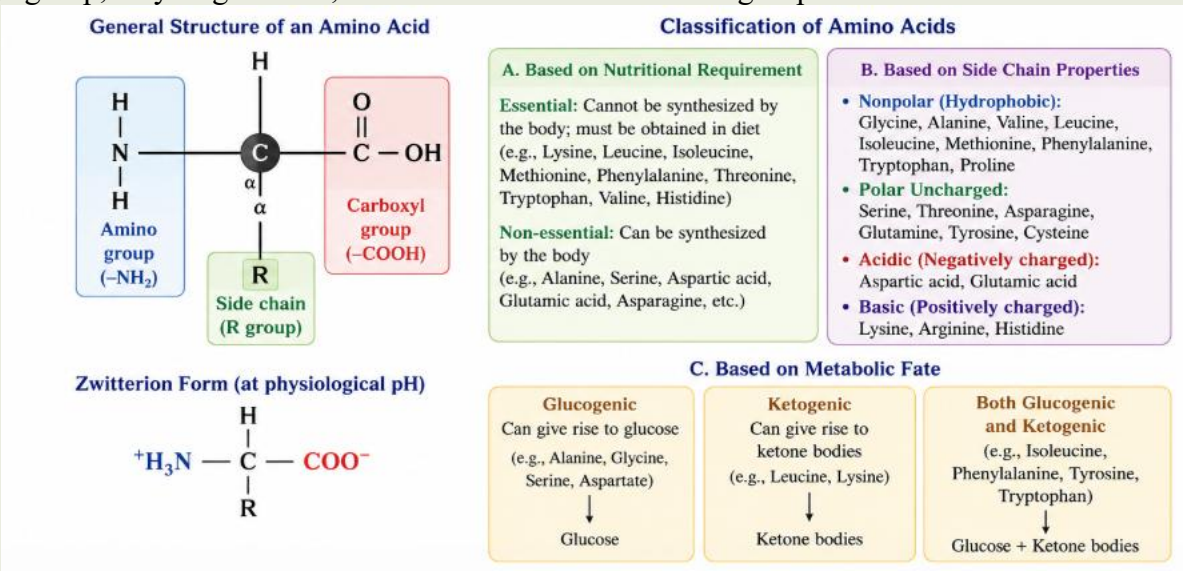


Figure 3.6: Clinical Pathophysiology of Diabetes - Oioptimized Text and Visual

Chapter 4: Amino Acids and Proteins

4.1 Amino Acids: Structural Foundation and Classification

Amino acids are the carboxylic acid derivatives of organic compounds, serving as the universal monomeric building blocks of proteins. Each amino acid possesses a central alpha-carbon (Cα) covalently bonded to four distinct chemical functional groups: a basic amino group, an acidic carboxyl group, a hydrogen atom, and a variable side chain or R-group.



Classification Profiles

A. Based on Side-Chain (R-Group) Structure: Categorized into Aliphatic amino acids (Glycine, Alanine, Valine, Leucine, Isoleucine), Aromatic residues containing benzene rings (Phenylalanine, Tyrosine, Tryptophan), Heterocyclic architectures (Proline), Sulfur-containing units (Cysteine, Methionine), and Hydroxy-amino acids (Serine, Threonine).

B. Based on Polarity (Solubility in Water): Grouped into Non-Polar Hydrophobic amino acids that bury inward away from water (Alanine, Valine, Leucine), Polar Uncharged Hydrophilic molecules that form stable hydrogen bonds (Glycine, Serine, Glutamine), Acidic Negative Charged residues (Aspartate, Glutamate), and Basic Positive Charged species (Lysine, Arginine, Histidine).

C. Nutritional / Physiological Classification: Divided into Essential amino acids that cannot be synthesized de novo and require direct dietary source intake (Valine, Leucine, Lysine), Non-Essential residues synthesized naturally by transamination pathways (Alanine, Aspartate, Glutamate), and Semi-Essential blocks needed during rapid growth phases (Arginine, Histidine).

4.2 Structural Organization of Proteins and Stabilizing Forces

Proteins are complex biomolecules composed of amino acids linked by peptide bonds. Their biological function depends on their three-dimensional structure, which is organized into four hierarchical levels. The **primary structure** is the linear sequence of amino acids. The **secondary structure** consists of local folding patterns such as α-helices and β-pleated sheets stabilized by hydrogen bonds. The **tertiary structure** is the overall three-dimensional shape formed by interactions among amino acid side chains, including hydrogen bonds, ionic bonds, hydrophobic interactions, and disulfide bridges. Some proteins consist of multiple polypeptide chains, forming a **quaternary structure**, which represents the arrangement of these subunits into a functional protein.

The Peptide Bond

A peptide bond is a covalent bond formed between the carboxyl group (–COOH) of one amino acid and the amino group ($–NH_2$) of another amino acid through a condensation (dehydration) reaction, releasing one molecule of water (H_2O). This bond links amino acids together to form peptides and proteins. Peptide bonds are strong, stable, and provide the primary structure of proteins.

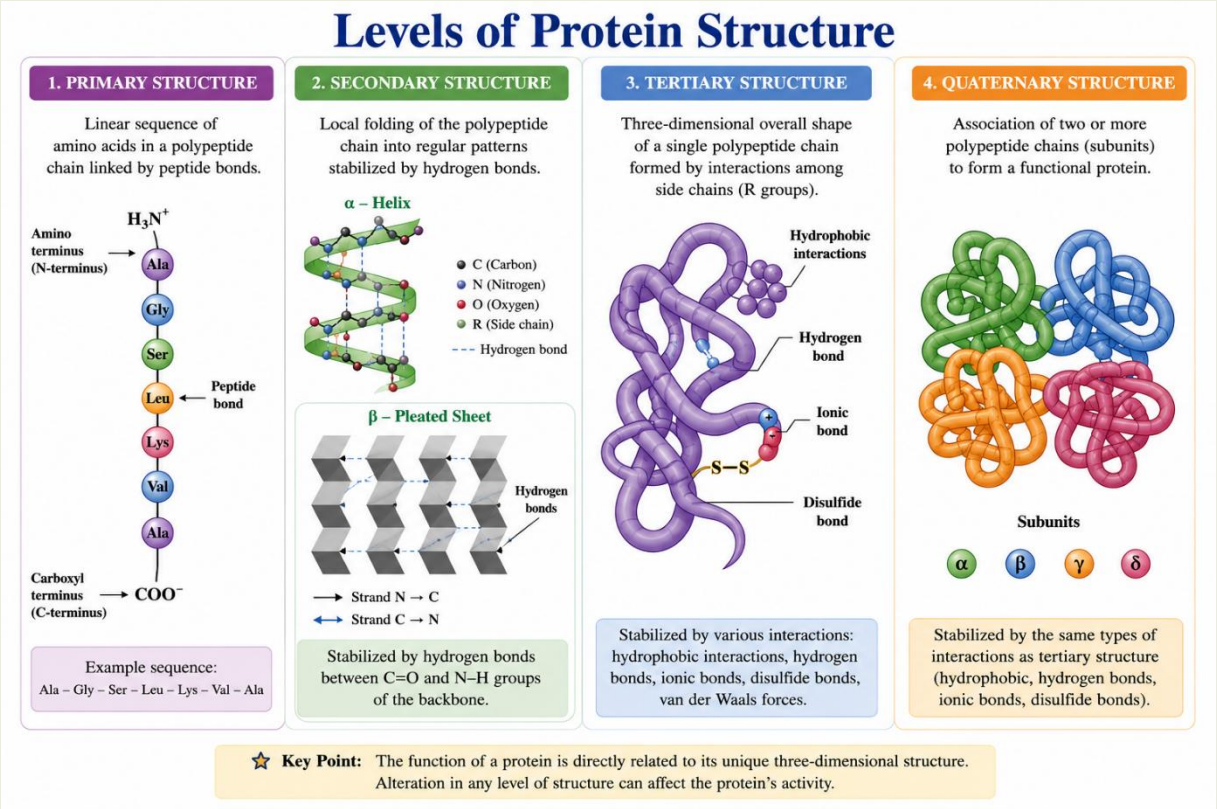
Levels of Protein Structure

A. Primary Structure: The linear, sequential arrangement of amino acid residues along a polypeptide chain, dictated entirely by genetic nucleotide sequences and stabilized by covalent peptide bonds (e.g., Insulin).

B. Secondary Structure: Localized spatial folding of the polypeptide backbone into regular, repeating geometric patterns stabilized by hydrogen bonds between backbone carbonyl oxygen (C=O) and amide nitrogen (N-H) groups (e.g., Alpha-Helix in Keratin, Beta-Pleated Sheets in Silk Fibroin).

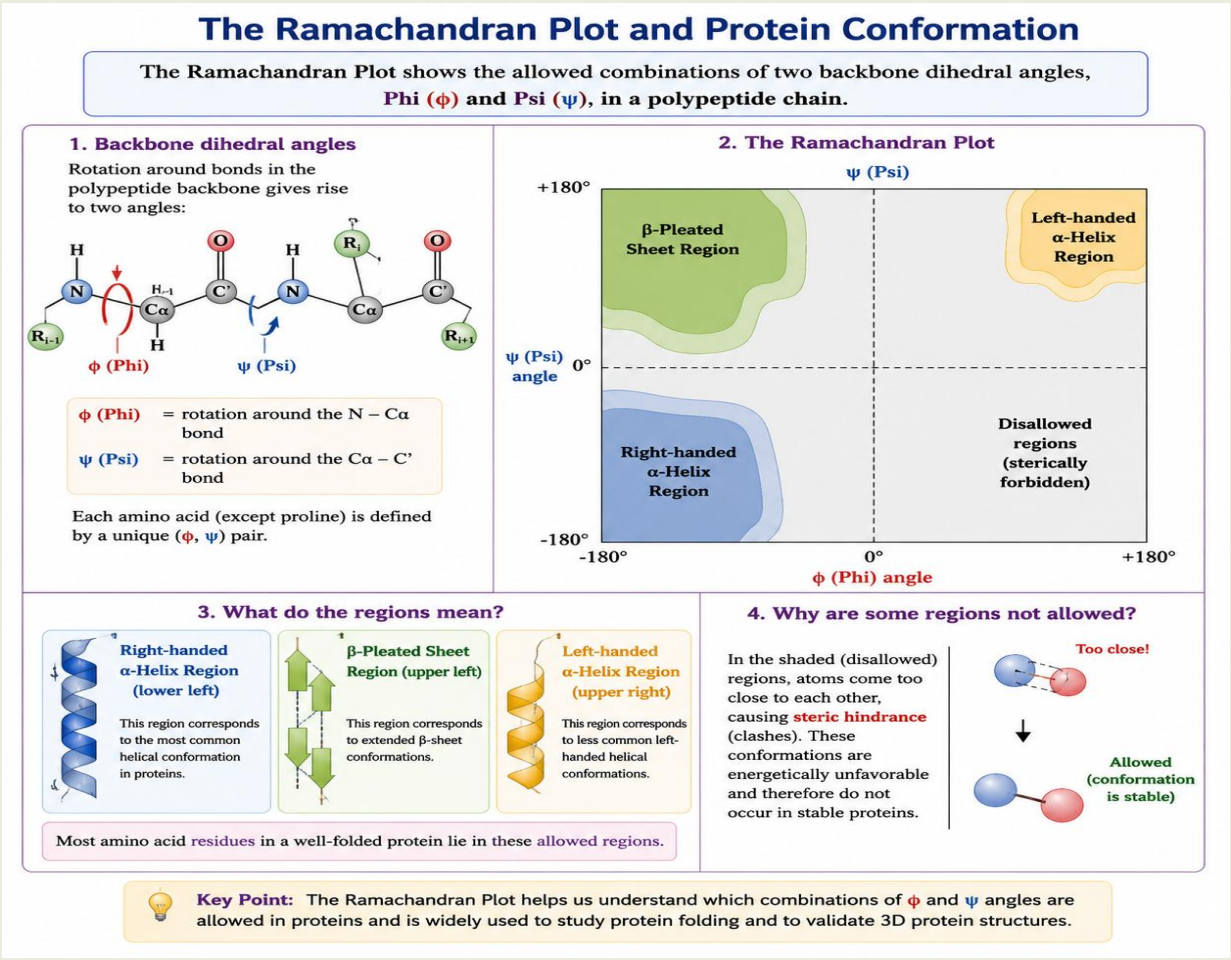
C. Tertiary Structure: The overall comprehensive three-dimensional folding of a single polypeptide chain into a compact, globular or fibrous shape. It brings distant amino acids together to form active enzymatic pockets and is stabilized by R-group interactions, including hydrophobic forces, ionic links (salt bridges), and covalent disulfide bridges (e.g., Myoglobin).

D. Quaternary Structure: The spatial arrangement and structural assembly of multiple independent polypeptide chains (subunits) working together as a single functional multi-subunit macromolecule, stabilized by non-covalent subunit interfaces (e.g., Tetrameric Hemoglobin).



4.3 The Ramachandran Plot and Protein Conformation

The **Ramachandran Plot** is a graph used to show the possible shapes that a protein chain can adopt. It was developed by **G. N. Ramachandran**. The plot displays two backbone angles of amino acids, called **Phi (φ)** and **Psi (ψ)**. Because atoms in a protein cannot occupy the same space, only certain combinations of these angles are allowed. These allowed regions correspond to common protein structures such as **α-helices**, **β-pleated sheets**, and **left-handed helices**. Therefore, the Ramachandran Plot is an important tool for understanding protein folding and checking the accuracy of protein structures.



4.4 Biological and Physiological Importance of Proteins

Proteins are essential biomolecules that perform a wide range of biological and physiological functions in living organisms. They are required for **growth, repair, and maintenance of body tissues**. Proteins act as **enzymes**, which catalyze biochemical reactions, and as **hormones**, which regulate various physiological processes. They play a crucial role in **transporting substances**, such as oxygen by hemoglobin, and in **body defense** through antibodies. Proteins are also involved in **muscle contraction**, **cell signaling**, **maintenance of fluid balance**, and can serve as an **energy source** when required. Thus, proteins are indispensable for the structure, function, and regulation of cells and tissues.

1. Structural Function

Proteins provide structural support and strength to cells, tissues, and organs. Structural proteins such as collagen, keratin, and elastin form important components of skin, bones, cartilage, hair, and nails. These proteins help maintain the shape and integrity of body structures while

protecting them from damage. They also provide elasticity and flexibility necessary for normal body function.

2. Enzymatic Function
Many proteins function as enzymes, which act as biological catalysts that speed up chemical reactions in the body. Enzymes allow metabolic processes such as digestion, respiration, and DNA replication to occur efficiently at normal body temperatures. Examples include amylase, pepsin, and lipase, which aid in the digestion of food. Without enzymes, essential biochemical reactions would occur too slowly to sustain life**.**

3. Transport Function
Transport proteins carry molecules and ions throughout the body and across cell membranes. Hemoglobin transports oxygen from the lungs to body tissues and returns carbon dioxide to the lungs for exhalation. Albumin carries hormones, fatty acids, vitamins, and other substances in the bloodstream. These proteins ensure the efficient distribution of nutrients, gases, and essential molecules throughout the body.

4. Hormonal and Regulatory Function
Some proteins act as hormones that regulate physiological processes and maintain homeostasis. Hormones such as insulin and glucagon control blood glucose levels, while growth hormone regulates growth and development. These protein hormones function as chemical messengers that coordinate activities between different organs and tissues. Through their regulatory actions, they help maintain normal metabolism and body functions.

5. Protective and Immune Function
Proteins play an important role in protecting the body against infections and diseases. Antibodies, also known as immunoglobulins, recognize and neutralize harmful microorganisms and foreign substances. Other proteins, such as complement proteins and interferons, assist the immune system in fighting pathogens. These protective **proteins helmaintain health and provide immunity against various diseases.**

4.5 Clinical Significance: Inborn Errors of Amino Acid Metabolism
Inborn Errors of Amino Acid Metabolism are a group of inherited genetic disorders caused by the absence or deficiency of specific enzymes involved in amino acid metabolism. As a result, certain amino acids or their metabolic by-products accumulate in the body to toxic levels, or essential metabolic products fail to be synthesized. These disorders are usually inherited in an autosomal recessive manner and often become apparent during infancy or early childhood. Early diagnosis and appropriate dietary management can prevent serious complications and improve the quality of life of affected individuals.

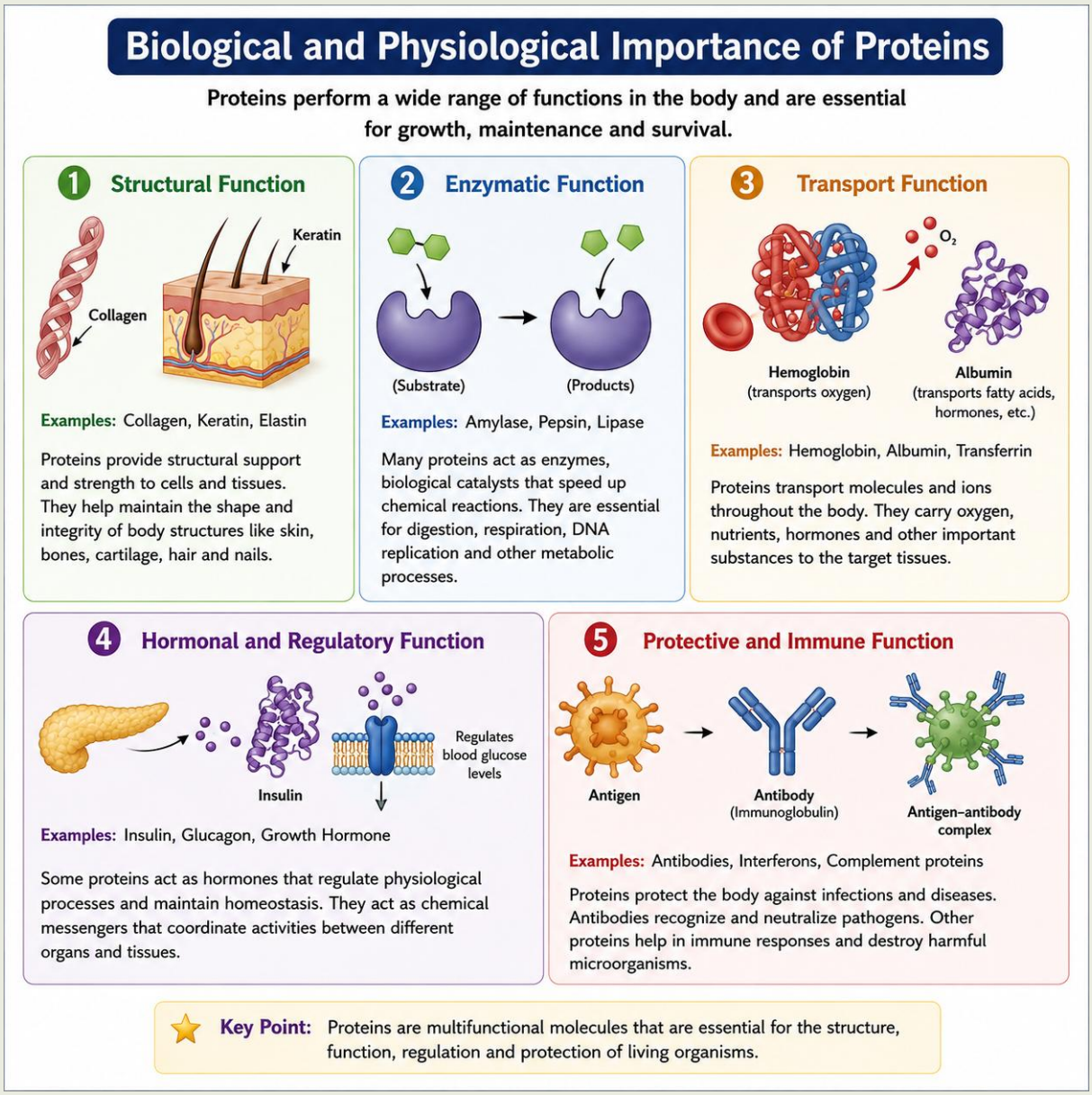
1. Phenylketonuria (PKU)-Phenylketonuria is caused by a deficiency of the enzyme phenylalanine hydroxylase, which converts phenylalanine into tyrosine. Due to this deficiency, phenylalanine accumulates in the blood and tissues, leading to neurological damage if left untreated. Common symptoms include intellectual disability, developmental delay, seizures, and a characteristic musty odor of urine. Treatment involves a lifelong diet low in phenylalanine and supplementation with tyrosine.

2. Alkaptonuria-Alkaptonuria results from a deficiency of the enzyme homogentisate oxidase, which is involved in the metabolism of tyrosine. The disorder causes accumulation of

homogentisic acid in the body, which is excreted in urine. A characteristic feature is that urine turns dark brown or black upon standing due to oxidation of homogentisic acid. Long-term accumulation may lead to pigmentation of connective tissues (ochronosis) and arthritis.

3. Maple Syrup Urine Disease (MSUD)-Maple Syrup Urine Disease is caused by a deficiency of enzymes required for the breakdown of the branched-chain amino acids leucine, isoleucine, and valine. The accumulation of these amino acids and their metabolites causes severe neurological symptoms and developmental problems. The urine of affected individuals has a distinctive sweet odor resembling maple syrup. Treatment involves dietary restriction of branched-chain amino acids and careful metabolic monitoring.

4. Homocystinuria-Homocystinuria is caused by a deficiency of the enzyme cystathionine β-synthase, which is involved in methionine metabolism. This results in the accumulation of homocysteine in blood and urine. Patients may exhibit intellectual disability, visual problems due to lens dislocation, skeletal abnormalities, and an increased risk of blood clot formation. Treatment includes vitamin B_6 supplementation, dietary restriction of methionine, and folic acid supplementation.



5. TyrosinemiaTyrosinemia is a disorder caused by defects in enzymes involved in tyrosine degradation. The accumulation of tyrosine and its metabolites can damage the liver, kidneys, and nervous system. Symptoms may include liver failure, growth retardation, and developmental abnormalities. Treatment involves dietary restriction of tyrosine and phenylalanine along with specific medications.

Summary Table

Disorder	Enzyme Deficiency	Amino Acid Involved	Major Symptoms
Phenylketonuria (PKU)	Phenylalanine hydroxylase	Phenylalanine	Intellectual disability, developmental delay
Alkaptonuria	Homogentisate oxidase	Tyrosine	Black urine, ochronosis, arthritis
Maple Syrup Urine Disease	Branched-chain α-ketoacid dehydrogenase	Leucine, Isoleucine, Valine	Neurological defects, sweet-smelling urine
Homocystinuria	Cystathionine β-synthase	Methionine	Lens dislocation, thrombosis, skeletal abnormalities
Tyrosinemia	Various enzymes of tyrosine metabolism	Tyrosine	Liver and kidney damage

Chapter 5: Enzymes: Kinetics, Mechanism, and Regulation

5.1 Nomenclature, Classification, and Mechanisms of Action

Enzymes are specialized biological catalysts, primarily proteinaceous in nature (with the exception of catalytic RNA molecules called ribozymes), synthesized by living cells to accelerate biochemical reactions. They function by lowering the activation energy barrier of areaction without changing its overall chemical equilibrium or being consumed in the process.
Substrate: The specific chemical reactant molecule upon which an enzyme acts.
Active Site: A highly specialized, three-dimensional cleft or pocket within the folded structure of the enzyme molecule. It is formed by a small cluster of amino acid residues that match the shape, charge, and polarity of the substrate. It is split into a Binding Site (holds the substrate) and a Catalytic Site (chemically cleaves or forms covalent bonds).

Holoenzymes and Cofactors

Many enzymes require non-protein chemical components to become catalytically active: Holoenzyme (Active Enzyme) = Apoenzyme (Protein Part) + Cofactor (Non-Protein Part).
Inorganic Metal Ions: Essential metallic elements that help stabilize the active site conformation or participate directly in electron transfers (e.g., Mg^{2+} for Hexokinase, Zn^{2+} for Carbonic Anhydrase).
Coenzymes: Complex, non-protein organic molecules that are transiently and loosely bound to the enzyme during catalysis. They function as mobile carriers transporting chemical groups or electrons, frequently derived from B-vitamins (e.g., NAD^+, $NADP^+$, Coenzyme A).
Prosthetic Groups: Organic cofactors that are permanently and covalently attached to the apoenzyme structure (e.g., Heme in catalase, FAD in succinate dehydrogenase, Biotin).

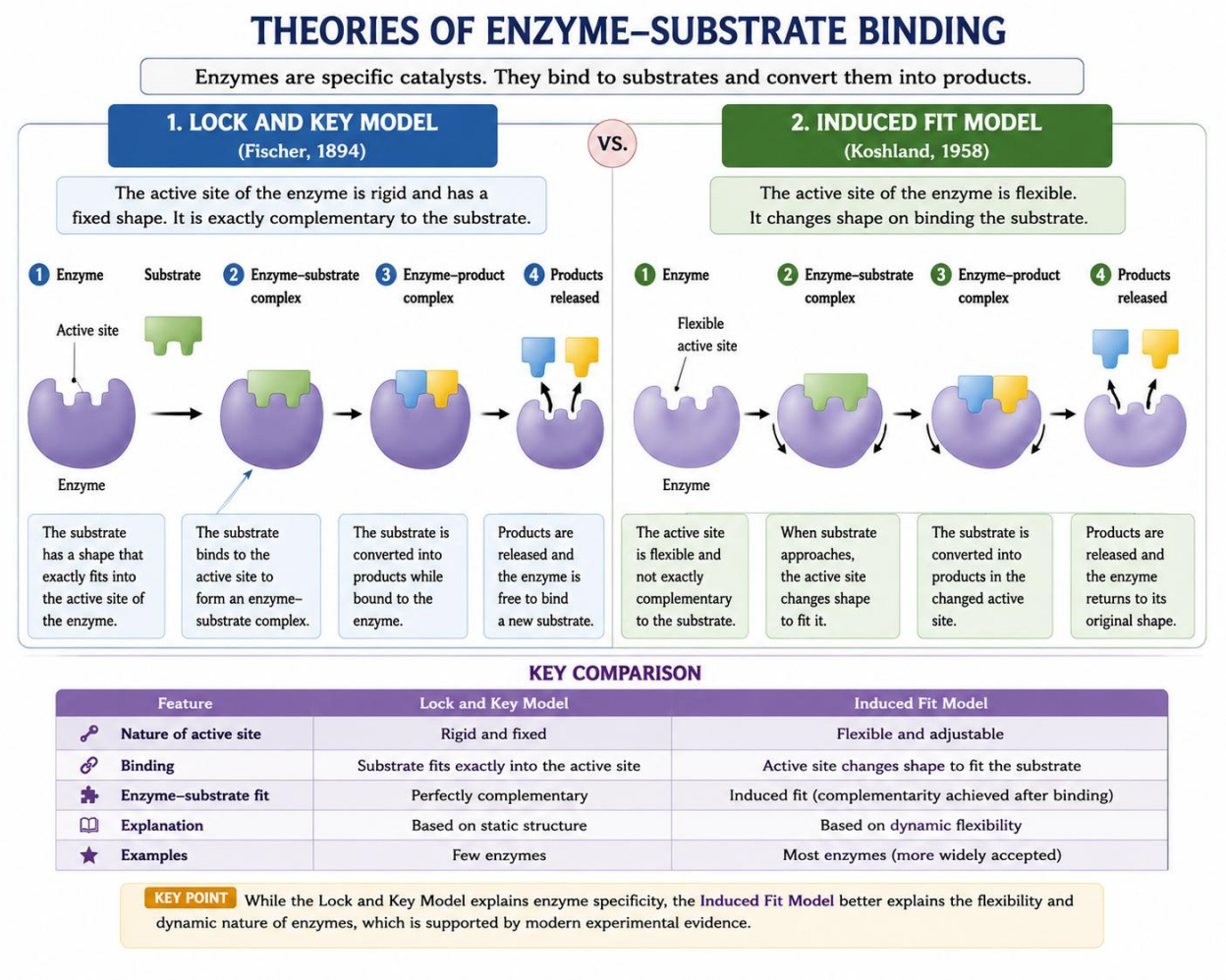
Classification and International Nomenclature

The International Union of Biochemistry and Molecular Biology (IUBMB) classifies all enzymes into six major classes based on the reaction type:
Class 1: Oxidoreductases: Catalyze oxidation-reduction (redox) reactions involving the transfer of electrons, hydrogen atoms, or oxygen atoms (e.g., Dehydrogenases, Oxidases).
Class 2: Transferases: Catalyze the transfer of a functional chemical group (such as methyl, phosphate, or amino groups) from a donor molecule to an acceptor molecule (e.g., Hexokinase).
Class 3: Hydrolases: Catalyze the hydrolytic cleavage of covalent bonds (C-O, C-N, C-C) by adding a molecule of water. Includes digestive enzymes like Pepsin, Trypsin, Amylase, and Lipase.
Class 4: Lyases: Catalyze the cleavage of chemical bonds by mechanisms other than hydrolysis or oxidation, frequently leaving double bonds, or catalyze the reverse addition of groups to double bonds (e.g., Decarboxylases).
Class 5: Isomerases: Catalyze structural or geometric rearrangements within a single molecule to generate its isomer (e.g., Phosphohexose Isomerase, Epimerases, Mutases).
Class 6: Ligases (Synthetases): Catalyze the condensation and joining together of two separate molecules, accompanied by the hydrolysis of a high-energy phosphate bond like ATP (e.g., DNA Ligase).

Theories of Enzyme-Substrate Binding

The two primary models describing how an enzyme interacts with its substrate are Emil Fischer's **Lock-and-Key Model** and Daniel Koshland's **Induced Fit Model**. While both explain the formation of the enzyme-substrate (ES) complex, they differ significantly in their assumptions regarding the flexibility of the protein structure.

Lock and Key Model (Emil Fischer): This theory proposes that the active site of an enzyme has a rigid, pre-formed shape that perfectly matches the shape of the substrate, much like a key fits into a lock.
Induced Fit Model (Daniel Koshland): This modern model suggests that the active site is flexible. As the substrate approaches, it induces a conformational change that shapes the active site tightly around it, aligning catalytic groups ideally.



5.2 Enzyme Kinetics: Factors and the Michaelis-Menten Framework

Factors Influencing Enzyme Activity

Enzyme activity refers to the rate at which an enzyme converts substrate into product. The activity of enzymes is affected by several physical and chemical factors, including temperature, pH, substrate concentration, enzyme concentration, inhibitors, activators, and cofactors. Each enzyme functions optimally under specific conditions, and any deviation from these conditions can alter its catalytic efficiency. Understanding these factors is important in biochemistry, physiology, medicine, and biotechnology.

1) Effect of Temperature on Enzyme Activity

Temperature has a profound effect on enzyme activity because it influences the kinetic energy of enzyme and substrate molecules. As temperature increases, the molecules move more rapidly, resulting in a greater frequency of collisions between enzymes and substrates and

consequently an increased rate of reaction. Enzyme activity continues to rise until an optimum temperature is reached, at which the enzyme exhibits **maximum catalytic efficiency. Beyond** this optimum temperature, the weak bonds that maintain the enzyme's three-dimensional structure begin to break, leading to denaturation of the enzyme. Denaturation alters the shape of the active site, preventing substrate binding and causing a sharp decline in enzyme activity. In humans, most enzymes function optimally at approximately 37°C, which corresponds to normal body temperature.

2) Effect of pH on Enzyme Activity

The hydrogen ion concentration of the medium, expressed as pH, significantly influences enzyme activity by affecting both the structure of the enzyme and the charge of amino acid residues present at the active site. Every enzyme has a specific optimum pH at which its catalytic activity is highest. When the pH deviates from this optimum value, the ionic and hydrogen bonds responsible for maintaining the enzyme's conformation may be disrupted. Such structural alterations can reduce substrate binding and catalytic efficiency. Extreme acidic or alkaline conditions may cause irreversible denaturation of the enzyme. Different enzymes have different optimum pH values depending on their physiological environment; for example, pepsin functions best in the acidic conditions of the stomach, whereas trypsin is most active in the alkaline environment of the small intestine.

3) Effect of Substrate Concentration on Enzyme Activity

Substrate concentration plays a crucial role in determining the rate of an enzyme-catalyzed reaction. At low substrate concentrations, many active sites of the enzyme remain unoccupied, and therefore an increase in substrate concentration results in a proportional increase in reaction rate. As more substrate molecules become available, the frequency of enzyme-substrate complex formation increases, accelerating product formation. However, this increase continues only until all available active sites become occupied by substrate molecules. Once enzyme saturation is achieved, the reaction reaches its maximum velocity (Vmax), and further increases in substrate concentration no longer enhance the reaction rate. This relationship between substrate concentration and reaction rate is explained by the Michaelis-Menten theory of enzyme kinetics.

4) Effect of Enzyme Concentration on Enzyme Activity

The concentration of enzyme present in a reaction mixture directly affects the rate of reaction when an adequate amount of substrate is available. Increasing enzyme concentration increases the number of active sites available for substrate binding, thereby increasing the rate of product formation. Under conditions where substrate is abundant, doubling the enzyme concentration approximately doubles the reaction rate. However, if substrate becomes limiting, the effect of increasing enzyme concentration gradually diminishes. Therefore, the influence of enzyme concentration is dependent on the availability of sufficient substrate molecules. This principle is widely appl
ied in industrial biotechnology and clinical enzymology.

5) Effect of Inhibitors on Enzyme Activity

Enzyme inhibitors are molecules that reduce or completely prevent enzyme activity by interfering with substrate binding or catalysis. Competitive inhibitors resemble the substrate and compete for the active site of the enzyme, thereby reducing the rate of reaction. Their inhibitory effect can often be overcome by increasing substrate concentration. In contrast, non-competitive inhibitors bind to sites other than the active site and induce conformational changes that reduce catalytic activity regardless of substrate concentration. Certain heavy metals,

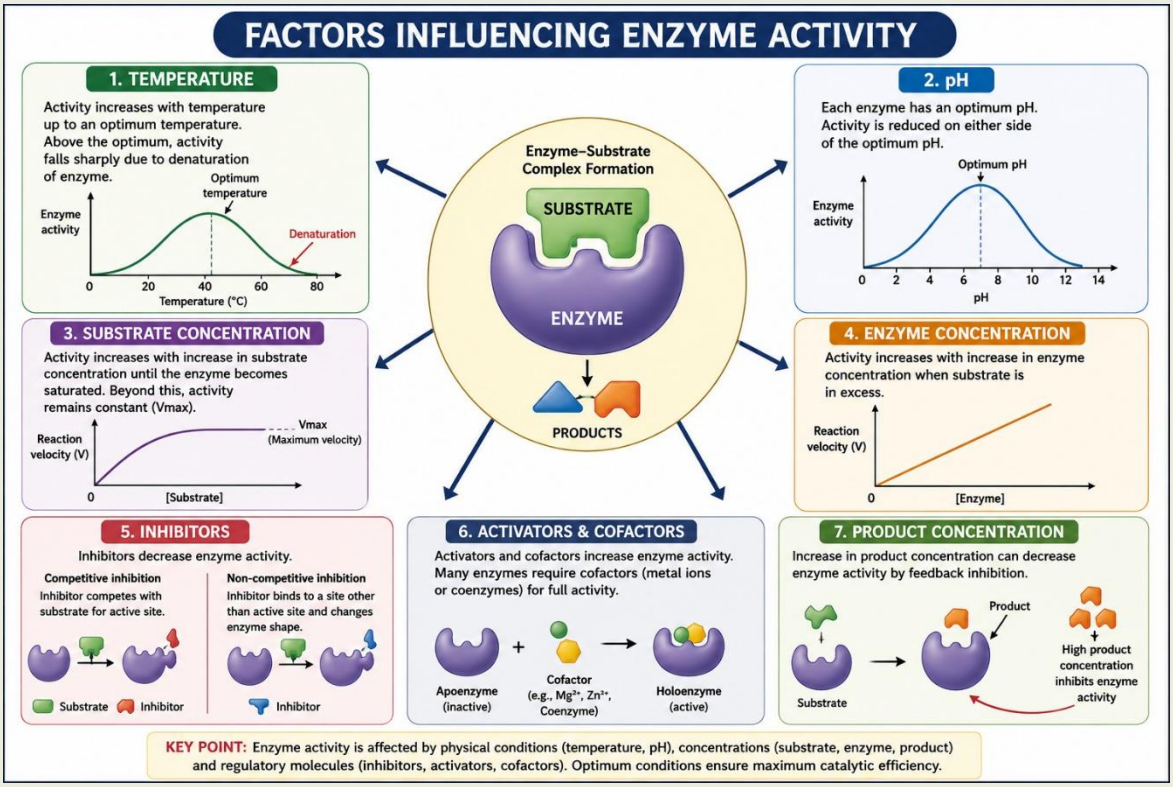
toxins, and pharmaceutical drugs act as enzyme inhibitors. Inhibitors play an important role in regulating metabolic pathways and are widely utilized in medicine for the treatment of various diseases.

6) Effect of Activators and Cofactors on Enzyme Activity

Many enzymes require the presence of additional substances known as cofactors or coenzymes to achieve full catalytic activity. Cofactors may be inorganic ions such as magnesium, zinc, iron, or calcium, whereas coenzymes are organic molecules often derived from vitamins. These molecules assist in substrate binding, electron transfer, or stabilization of the enzyme-substrate complex. In their absence, the enzyme may remain inactive or exhibit greatly reduced activity. The combination of an apoenzyme and its cofactor forms a fully functional holoenzyme capable of carrying out catalysis efficiently. Thus, cofactors and coenzymes are essential components of many metabolic reactions.

7) Effect of Product Concentration on Enzyme Activity

The accumulation of reaction products can also influence enzyme activity through a mechanism known as feedback inhibition. As the concentration of product increases, it may bind to regulatory sites on enzymes involved earlier in the metabolic pathway and reduce their activity. This serves as an important mechanism for controlling metabolic flux and preventing the excessive accumulation of cellular products. Feedback inhibition helps maintain metabolic balance and conserves cellular resources by ensuring that biochemical pathways operate only when their products are needed. Such regulation is commonly observed in amino acid, nucleotide, and hormone biosynthesis pathways.



Michaelis–Menten (MM) Equation

The Michaelis–Menten equation describes the relationship between the rate of an enzyme-catalyzed reaction and the substrate concentration. It was proposed by Leonor Michaelis and Maud Menten in 1913. The equation explains how the reaction rate increases as substrate

concentration increases, but only up to a certain limit. Once all the active sites of the enzyme become occupied by substrate molecules, the enzyme becomes saturated and the reaction reaches its maximum rate.

Michaelis–Menten Equation

$$V = \frac{Vmax\ [S]}{km + [S]}$$

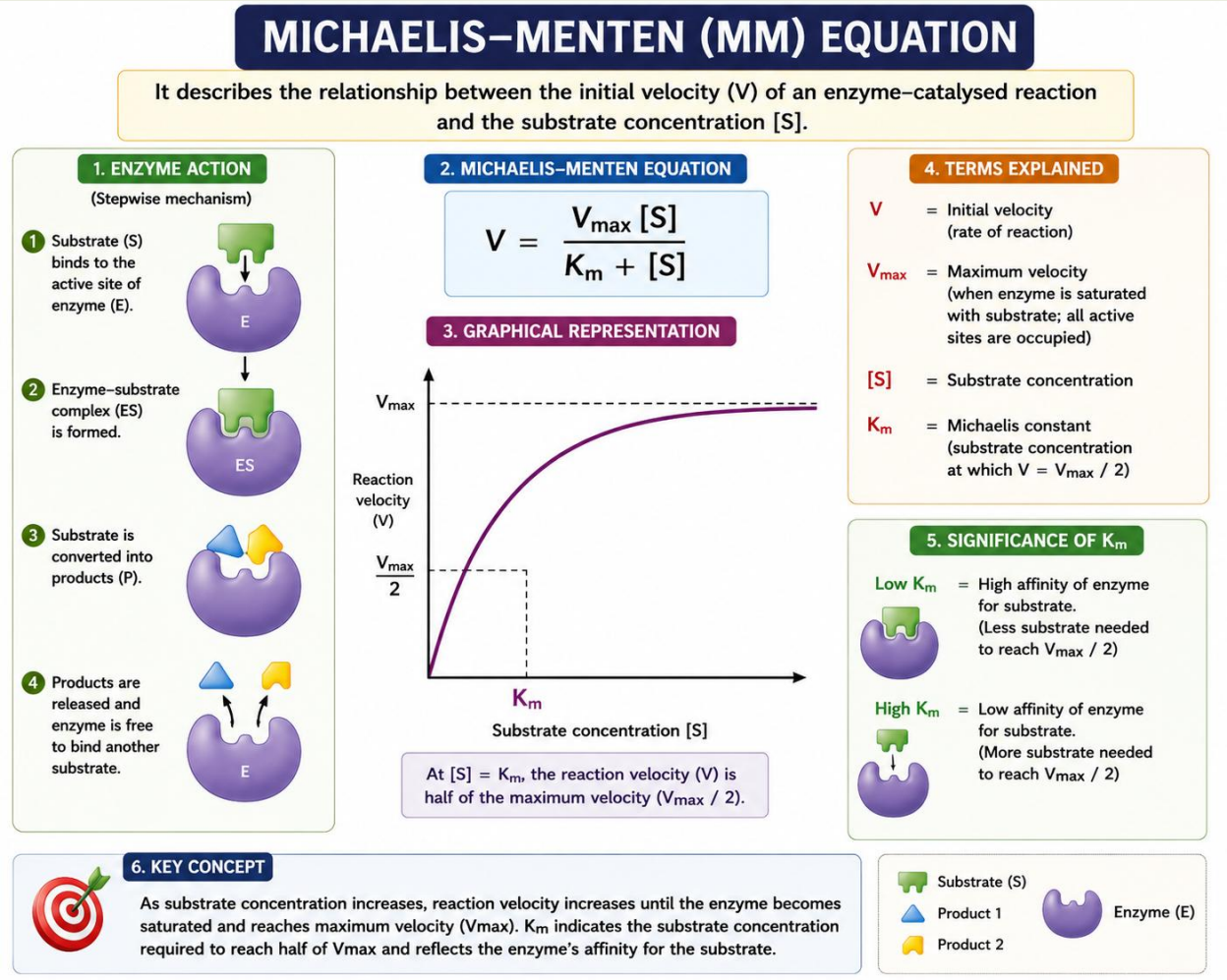
Where:

V = Reaction velocity (rate of reaction)

Vmax = Maximum reaction velocity

[S] = Substrate concentration

Km = Michaelis constant



Simple Explanation

Imagine an enzyme as a worker in a factory and the substrate as raw material. When only a few substrate molecules are available, the worker spends time waiting, so the reaction rate is low. As more substrate is added, the worker remains busy and the reaction rate increases. Eventually, all active sites of the enzyme become occupied, and the enzyme works at its maximum capacity. At this point, adding more substrate does not increase the reaction rate because the enzyme is already saturated.

Michaelis Constant (Km)

The Michaelis constant (Km) is the substrate concentration at which the reaction rate is equal

to half of Vmax.

$$V=\frac{Vmax}{2}$$
when
$[S] = K_m$

A low Km value indicates that the enzyme has a high affinity for the substrate because only a small amount of substrate is needed to reach half-maximal velocity. A high Km value indicates a low affinity for the substrate because more substrate is required.
Significance of the Michaelis–Menten Equation
The Michaelis–Menten equation helps scientists understand enzyme kinetics and compare the efficiency of different enzymes. It provides information about enzyme affinity for substrates and the maximum catalytic capacity of enzymes. The equation is widely used in biochemistry, pharmacology, biotechnology, and clinical research to study enzyme behavior and the effects of inhibitors and drugs.

5.3 Enzyme Inhibition: Types and Examples
Enzyme inhibition is the process by which the activity of an enzyme is reduced or completely stopped by a substance known as an inhibitor. Inhibitors interfere with the formation of the enzyme-substrate complex or prevent the enzyme from carrying out its catalytic function. Enzyme inhibition plays an important role in regulating metabolic pathways and is widely used in medicine and pharmacology. Depending on how the inhibitor interacts with the enzyme, enzyme inhibition can be classified into different types**.**

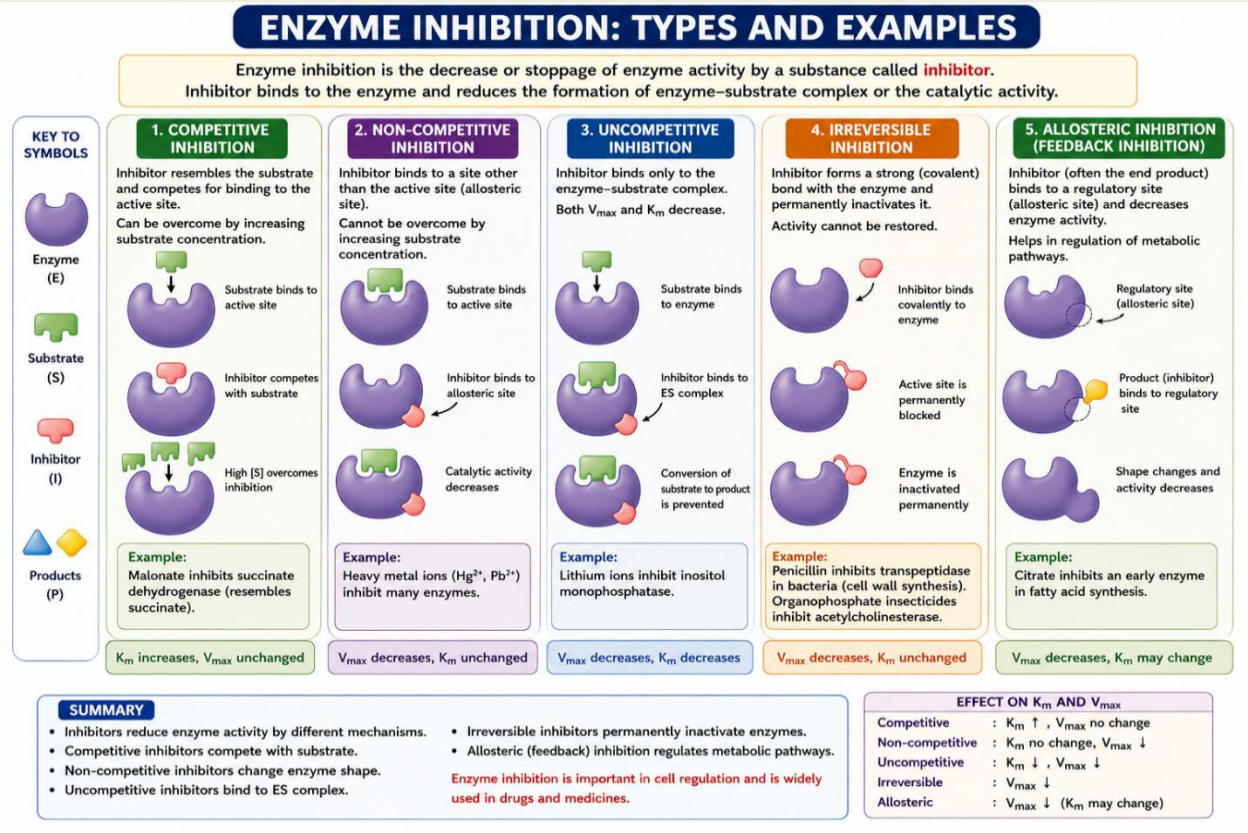
1) **Competitive Inhibition** -In competitive inhibition, the inhibitor closely resembles the substrate and competes with it for binding to the active site of the enzyme. Because both the substrate and inhibitor cannot bind simultaneously, the presence of the inhibitor reduces enzyme activity. However, this type of inhibition can be overcome by increasing the substrate concentration, allowing more substrate molecules to compete successfully for the active site. A classic example is malonate, which competitively inhibits the enzyme succinate dehydrogenase by resembling its natural substrate, succinate.

2) Non-Competitive Inhibition-In non-competitive inhibition, the inhibitor binds to a site on the enzyme other than the active site, known as an allosteric site. This binding changes the shape of the enzyme and reduces its catalytic activity. Since the inhibitor does not compete with the substrate for the active site, increasing substrate concentration cannot overcome this inhibition. Heavy metal ions such as mercury and lead often act as non-competitive inhibitors by altering enzyme structure and function.

3) Uncompetitive Inhibition-In uncompetitive inhibition, the inhibitor binds only to the enzyme-substrate complex after the substrate has already attached to the enzyme. This binding prevents the conversion of substrate into product and decreases the overall reaction rate. Both the maximum velocity (Vmax) and the Michaelis constant (Km) are reduced in this type of inhibition. Although less common than competitive and non-competitive inhibition, uncompetitive inhibition is observed in several metabolic pathways.

4) Irreversible Inhibition- In irreversible inhibition, the inhibitor forms a strong covalent bond with the enzyme, permanently inactivating it. Once the enzyme is inhibited, its activity cannot be restored, and new enzyme molecules must be synthesized to replace the damaged ones. Many toxins, poisons, and certain drugs act through irreversible inhibition. For example,

penicillin irreversibly inhibits enzymes involved in bacterial cell wall synthesis, while some organophosphate insecticides inhibit acetylcholinesterase.**5) Allosteric Inhibition** (Feedback Inhibition)-In allosteric inhibition, an inhibitor binds to a regulatory site on the enzyme rather than the active site. This causes a conformational change that decreases enzyme activity. A common example is feedback inhibition, where the final product of a metabolic pathway inhibits an enzyme that acts earlier in the pathway. This mechanism prevents the unnecessary production of excess products and helps maintain metabolic balance within the cell.



5.4 Coenzymes: Functional Classification

Coenzymes are small organic, non-protein molecules that assist enzymes in carrying out biochemical reactions. Most coenzymes are derived from vitamins and act as carriers of electrons, atoms, or functional groups during metabolic processes. They bind temporarily to enzymes and participate directly in the catalytic reaction. Based on the type of chemical group they transfer, coenzymes can be functionally classified into several categories.

1. Oxidation–Reduction Coenzymes-Oxidation–reduction coenzymes participate in electron and hydrogen transfer reactions during cellular respiration and energy production. They act as electron carriers and help in oxidation-reduction (redox) reactions occurring in metabolic pathways. Important examples include **NAD^+ (Nicotinamide Adenine Dinucleotide)**, **$NADP^+$ (Nicotinamide Adenine Dinucleotide Phosphate)**, **FAD (Flavin Adenine Dinucleotide)**, and **FMN (Flavin Mononucleotide)**. These coenzymes are derived from B-complex vitamins and play a central role in ATP generation.

2. Acyl Group Transfer Coenzymes-Acyl group transfer coenzymes are involved in the transfer of acyl groups during the metabolism of carbohydrates, fats, and proteins. The most

important member of this group is **Coenzyme A (CoA)**, which carries acetyl and other acyl groups in metabolic pathways such as the Krebs cycle and fatty acid metabolism. Coenzyme A is derived from **pantothenic acid (Vitamin B_5)** and is essential for cellular energy production.

3. Amino Group Transfer Coenzymes-These coenzymes participate in the transfer of amino groups during amino acid metabolism. The most important coenzyme in this category is **Pyridoxal Phosphate (PLP)**, which is derived from **Vitamin B_6 (Pyridoxine)**. PLP functions in transamination, decarboxylation, and deamination reactions and is crucial for the synthesis and breakdown of amino acids.

4. One-Carbon Group Transfer Coenzymes-One-carbon transfer coenzymes transport single-carbon units such as methyl, methylene, or formyl groups between molecules. **Tetrahydrofolate (THF)**, derived from **folic acid (Vitamin B_9)**, is the principal coenzyme in this group. THF plays a vital role in nucleotide synthesis, amino acid metabolism, and DNA formation. Deficiency of folic acid can impair cell division and lead to anemia.

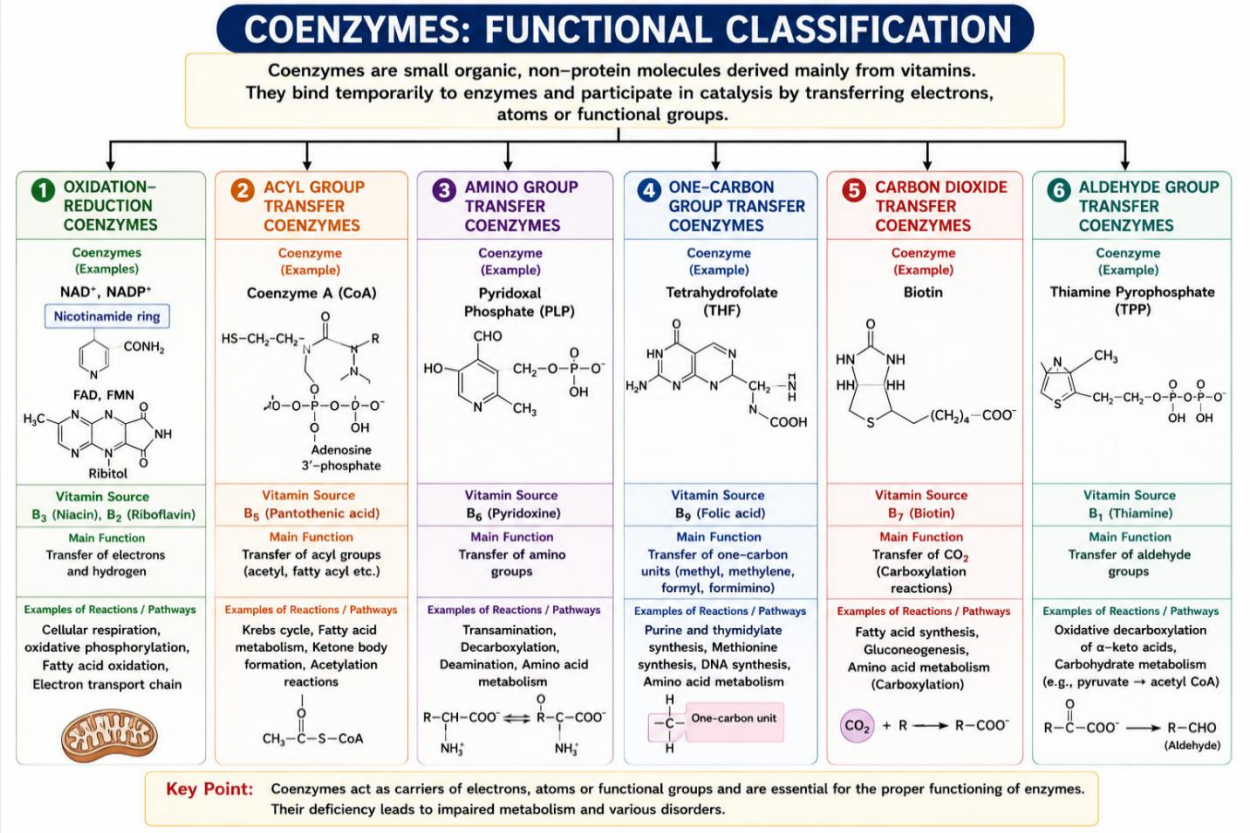
5. Carbon Dioxide Transfer Coenzymes-These coenzymes are involved in the transfer of carbon dioxide during carboxylation reactions. **Biotin**, also known as **Vitamin B_7**, acts as a carrier of activated carbon dioxide molecules. It participates in fatty acid synthesis, gluconeogenesis, and amino acid metabolism. Biotin-dependent enzymes are essential for maintaining normal metabolic function.

6. Aldehyde Group Transfer Coenzymes-Coenzymes involved in aldehyde group transfer reactions are important in carbohydrate metabolism. **Thiamine Pyrophosphate (TPP)**, derived from **Vitamin B_1 (Thiamine)**, functions as a coenzyme for enzymes involved in oxidative decarboxylation and carbohydrate metabolism. It plays a critical role in energy production through the Krebs cycle.

Summary Table

Functional Class	Major Coenzyme	Vitamin Source	Main Function
Oxidation–Reduction	NAD^+, $NADP^+$, FAD, FMN	B_3, B_2	Electron transfer
Acyl Group Transfer	Coenzyme A	B_5	Acyl group transfer
Amino Group Transfer	Pyridoxal Phosphate (PLP)	B_6	Amino group transfer
One-Carbon Transfer	Tetrahydrofolate (THF)	B_9	Transfer of one-carbon units
Carbon Dioxide Transfer	Biotin	B_7	CO_2 transfer
Aldehyde Group Transfer	Thiamine Pyrophosphate (TPP)	B_1	Aldehyde group transfer

5.5 Isoenzymes and Allosteric Regulation



1. Isoenzymes (Isozymes): Physically distinct molecular forms of an enzyme that catalyze the same reaction but differ in structure, tissue distribution, and kinetics. Lactate Dehydrogenase (LDH) exists as 5 tetrameric tissue variants composed of H and M subunits. Serum profile shifts serve as key clinical diagnostic markers for myocardial infarction (heart attack) and tissue damage.

2. Allosteric Enzymes: Multi-subunit regulatory proteins that do not follow classic Michaelis-Menten profiles. They exhibit a characteristic sigmoidal (S-shaped) velocity curve due to cooperative subunit transitions. They bind modulators at distinct regulatory allosteric sites, playing a primary role in homeostatic metabolic feedback inhibition cascades.
binding and rightward shifts under allosteric inhibitor binding parameters.

Chapter 6: Lipids: Structure, Classification, and Clinical Significance

6.1 Introduction and Classification of Lipids

Lipids are a heterogeneous group of organic compounds that are relatively insoluble in water (hydrophobic) but highly soluble in non-polar organic solvents such as ether, chloroform, and benzene. Unlike carbohydrates and proteins, lipids are not strict polymers built from repeating monomeric units. Instead, they are small molecular assemblies composed primarily of hydrocarbon chains, esters of fatty acids, or complex polycyclic rings.

In animal systems, lipids are vital because they serve as high-density energy storage molecules, structural components of all cellular membranes, electrical insulators around nerve fibers (myelin sheaths), and chemical signaling molecules (steroid hormones).

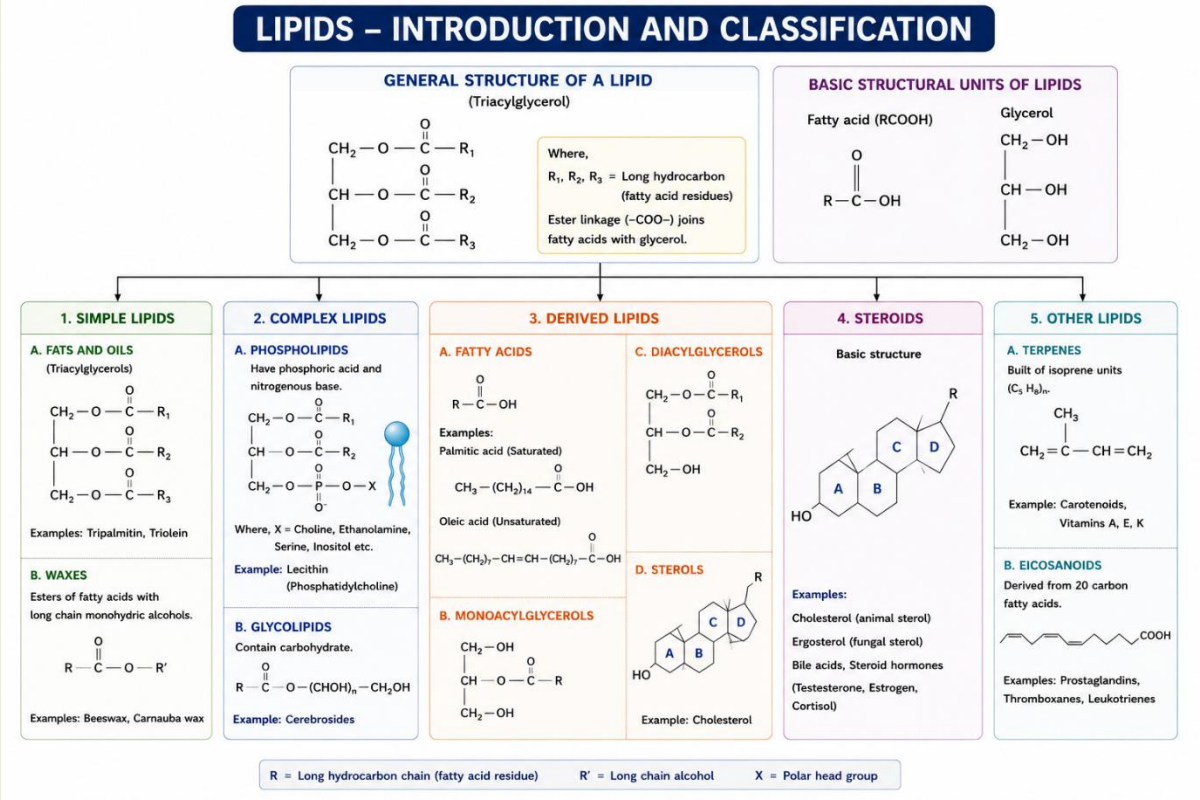
General Classification of Lipids

Lipids are classified into three major operational groups based on their structural composition and chemical complexity:

Simple Lipids: Esters of fatty acids with various alcohols. This contains Triacylglycerols (neutral fats stored in tissue) and Waxes (esters of long-chain fatty acids with high-molecular-weight monohydric alcohols).

Compound (Complex) Lipids: Esters of fatty acids containing an alcohol, fatty acids, and an additional chemical group. This includes Phospholipids (containing a phosphoric acid residue and nitrogenous bases) and Glycolipids (lipids containing a carbohydrate group, lacking phosphate).

Derived Lipids: Chemical substances produced by the hydrolytic cleavage of simple or compound lipids, or unique polycyclic structures that retain classic lipid solubility characteristics (e.g., free fatty acids, glycerol, steroid molecules, and lipid-soluble vitamins).



6.2 Fatty Acids: Types, Nomenclature, and Saturation Profiles

Fatty Acids: Types, Nomenclature, and Saturation Profiles

Fatty acids are long-chain organic acids that serve as the fundamental building blocks of many lipids, including triglycerides, phospholipids, and glycolipids. They consist of a hydrocarbon chain attached to a terminal carboxyl group (-COOH). Fatty acids play essential roles in energy storage, membrane structure, insulation, and cellular signaling. The chemical and biological properties of fatty acids depend mainly on their chain length and degree of saturation.

General Structure of Fatty Acids

A fatty acid molecule consists of a long hydrocarbon chain and a carboxyl group. The hydrocarbon chain is hydrophobic, whereas the carboxyl group is hydrophilic, making fatty acids amphipathic molecules.

General Formula

$CH3 – (CH2)n – COOH$

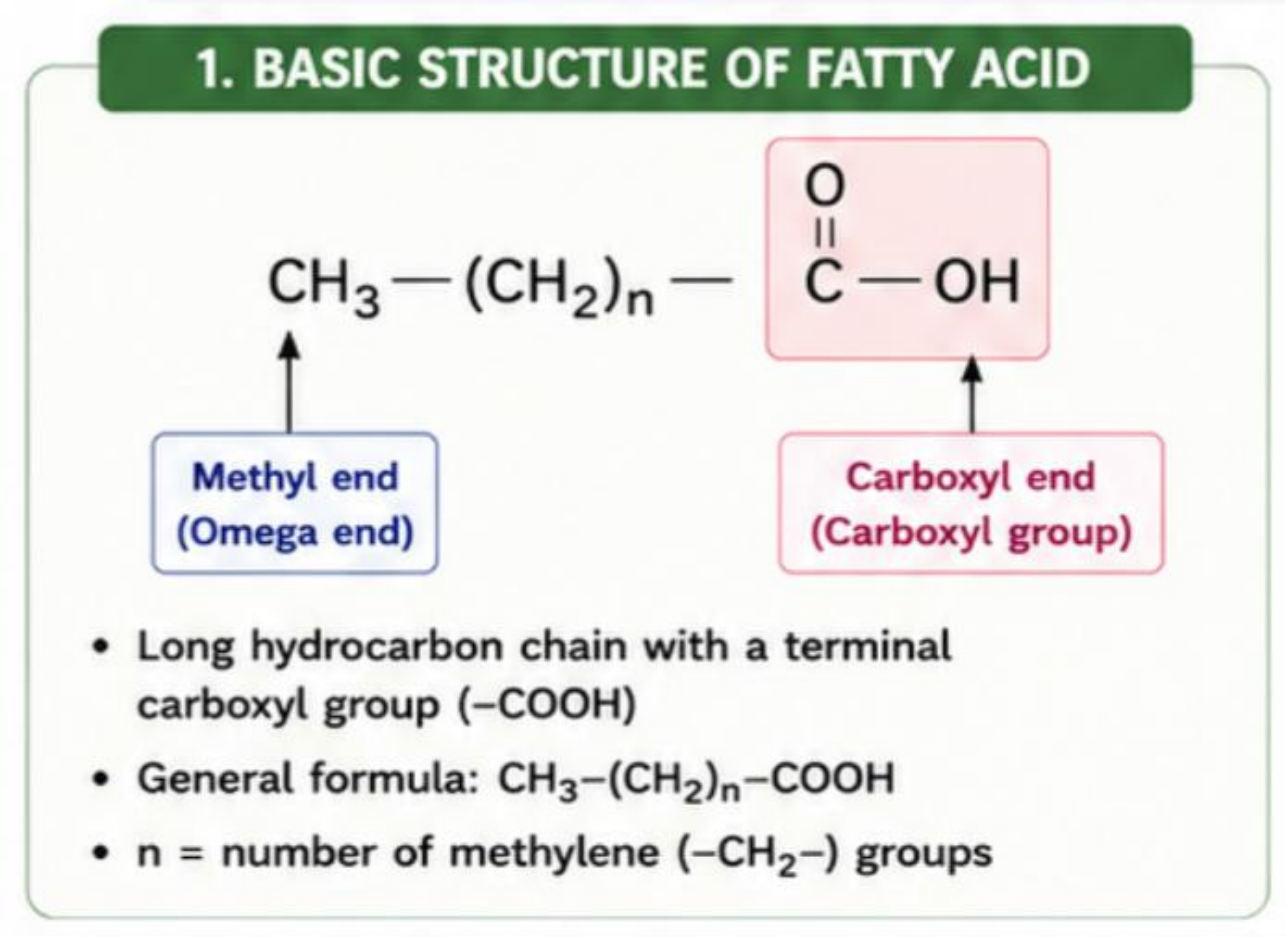
Where:

CH_3 = Methyl end (Omega end)

COOH = Carboxyl group

$(CH_2)n$ = Hydrocarbon chain

The number of carbon atoms may vary from 4 to more than 24, although 16- and 18-carbon fatty acids are the most common in biological systems.



Types of Fatty Acids

Fatty acids are primarily classified according to the number of double bonds present in their hydrocarbon chain.

Saturated Fatty Acids

Saturated fatty acids contain only single bonds between carbon atoms and are completely saturated with hydrogen atoms. Because their chains are straight, the molecules can pack closely together, resulting in higher melting points. Consequently, they are generally solid at room temperature and are commonly found in animal fats and dairy products.

Examples of saturated fatty acids include palmitic acid (16:0) and stearic acid (18:0).

Monounsaturated Fatty Acids (MUFAs)

Monounsaturated fatty acids contain a single carbon-carbon double bond. The double bond introduces a bend or kink in the hydrocarbon chain, preventing close packing of molecules. As a result, these fatty acids usually remain liquid at room temperature.

The most common monounsaturated fatty acid is oleic acid (18:1), which is abundant in olive oil, avocado, and nuts.

Polyunsaturated Fatty Acids (PUFAs)

Polyunsaturated fatty acids contain two or more double bonds in their hydrocarbon chain. The presence of multiple double bonds creates several bends in the molecule, increasing membrane fluidity and lowering the melting point. These fatty acids are generally found in vegetable oils, seeds, fish oils, and nuts.

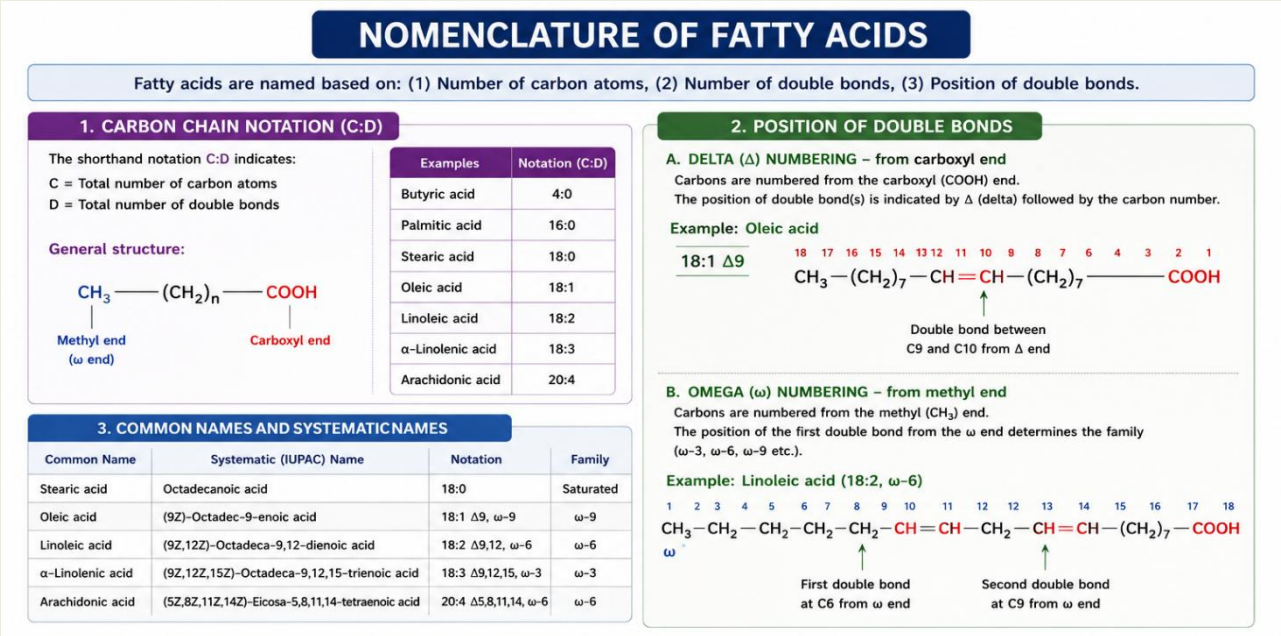
Common examples include linoleic acid (18:2), α-linolenic acid (18:3), and arachidonic acid (20:4).

Classification Based on Saturation

Type	Number of Double Bonds	Example
Saturated Fatty Acid	0	Palmitic acid (16:0)
Monounsaturated Fatty Acid	1	Oleic acid (18:1)
Polyunsaturated Fatty Acid	2 or more	Linoleic acid (18:2)

Fatty Acid Nomenclature

The naming of fatty acids is based on the number of carbon atoms and double bonds present in the molecule. A shorthand notation known as C:D notation is widely used, where the **first**



number represents the total number of carbon atoms and the second number represents the number of double bonds.

Examples of Fatty Acid Nomenclature

Fatty Acid	Carbon Atoms	Double Bonds	Notation
Palmitic Acid	16	0	16:0
Stearic Acid	18	0	18:0
Oleic Acid	18	1	18:1
Linoleic Acid	18	2	18:2
α-Linolenic Acid	18	3	18:3

Thus, the notation 18:2 indicates a fatty acid containing 18 carbon atoms and two double bonds.

Delta (Δ) Numbering System

In the delta numbering system, carbon atoms are counted starting from the carboxyl end of the molecule. The position of the double bond is indicated by the symbol Δ followed by the carbon number.

For example, oleic acid (18:1 Δ9) contains a double bond between carbon atoms 9 and 10 when counted from the carboxyl end. This system is commonly used in biochemistry and lipid metabolism studies.

Omega (ω) Numbering System

In the omega numbering system, carbon atoms are counted from the methyl end of the fatty acid chain. The position of the first double bond determines whether the fatty acid belongs to the omega-3, omega-6, or omega-9 family.

Omega Fatty Acid Families

Family	First Double Bond Position	Example
Omega-3 (ω-3)	Carbon 3	α-Linolenic acid
Omega-6 (ω-6)	Carbon 6	Linoleic acid
Omega-9 (ω-9)	Carbon 9	Oleic acid

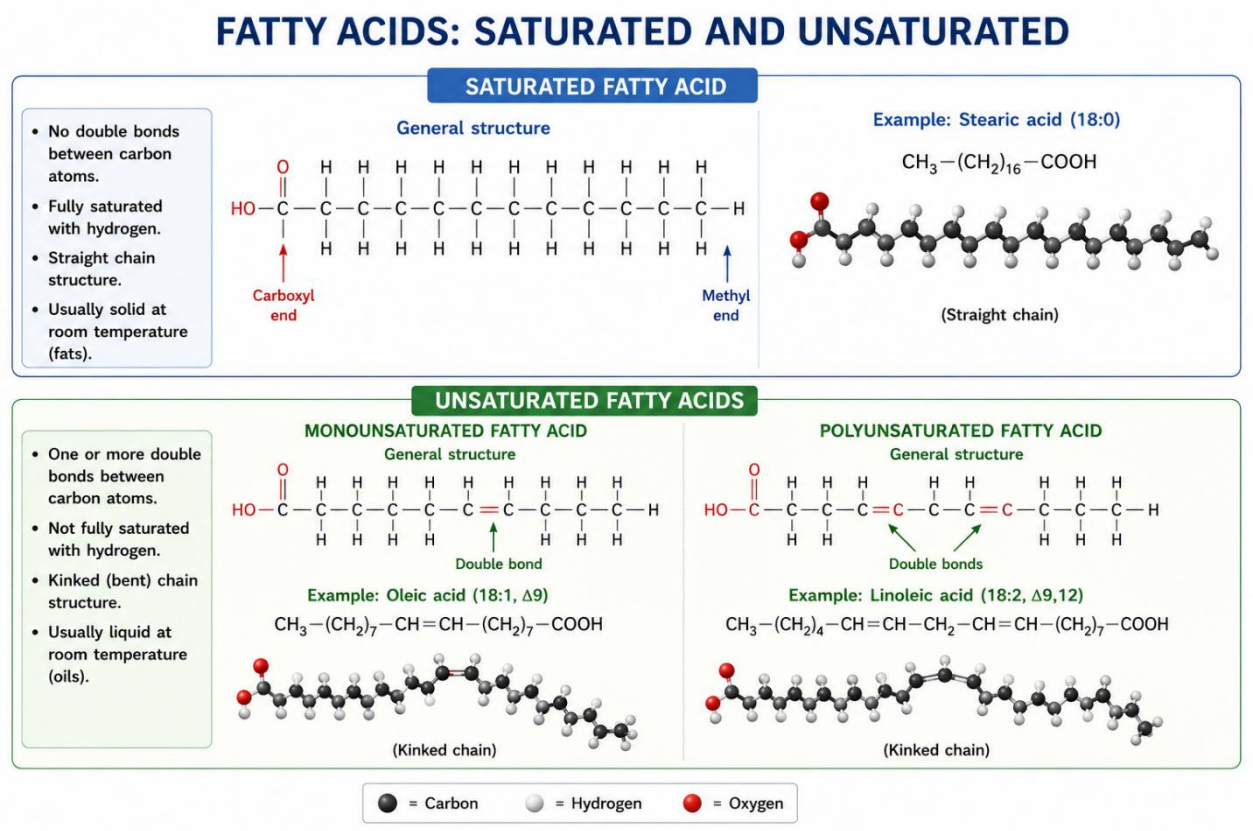
Omega fatty acids are nutritionally important because they participate in membrane structure and cellular signaling.

Saturation Profiles and Physical Properties

The degree of saturation significantly influences the physical properties of fatty acids. Saturated fatty acids have straight chains that allow tight molecular packing, resulting in higher melting points and solid consistency. Unsaturated fatty acids possess one or more double bonds that introduce bends into the chain, reducing intermolecular interactions and lowering melting points. Consequently, unsaturated fatty acids are generally liquid at room temperature.

Comparison of Saturation Profiles

Property	Saturated FA	Monounsaturated FA	Polyunsaturated FA
Double Bonds	0	1	2 or more
Chain Shape	Straight	Bent	Highly Bent
Melting Point	High	Intermediate	Low
Physical State	Solid	Liquid	Liquid
Membrane Fluidity	Low	Moderate	High
Example	Stearic Acid	Oleic Acid	Linoleic Acid



Essential Fatty Acids

Certain fatty acids cannot be synthesized by the human body and must therefore be obtained through the diet. These are known as essential fatty acids. The two principal essential fatty acids are linoleic acid (ω-6) and α-linolenic acid (ω-3).

These fatty acids are necessary for normal growth, brain development, immune function, reproduction, and maintenance of healthy cell membranes. They also serve as precursors for the synthesis of biologically active compounds known as eicosanoids.

Essential Fatty Acids

Fatty Acid	Family	Major Functions
Linoleic Acid	Omega-6	Growth, skin health, membrane integrity
α-Linolenic Acid	Omega-3	Brain function, cardiovascular health, anti-inflammatory effects

Biological Importance of Fatty Acids

Fatty acids are a major source of metabolic energy and are stored in adipose tissue as triglycerides. They form important structural components of cell membranes and help maintain membrane fluidity. Certain fatty acids act as precursors of signaling molecules such as prostaglandins, thromboxanes, and leukotrienes, which regulate inflammation, blood clotting, and immune responses. Omega-3 and omega-6 fatty acids are particularly important for cardiovascular health, nervous system development, and regulation of cellular functions. Fatty acids are essential lipid components that vary in chain length, degree of saturation, and position of double bonds. Their classification into saturated, monounsaturated, and polyunsaturated forms, together with their nomenclature and saturation profiles, provides important information

about their chemical properties and biological functions. Understanding fatty acid structure and classification is fundamental to the study of lipid metabolism, membrane biology, nutrition, and human health.

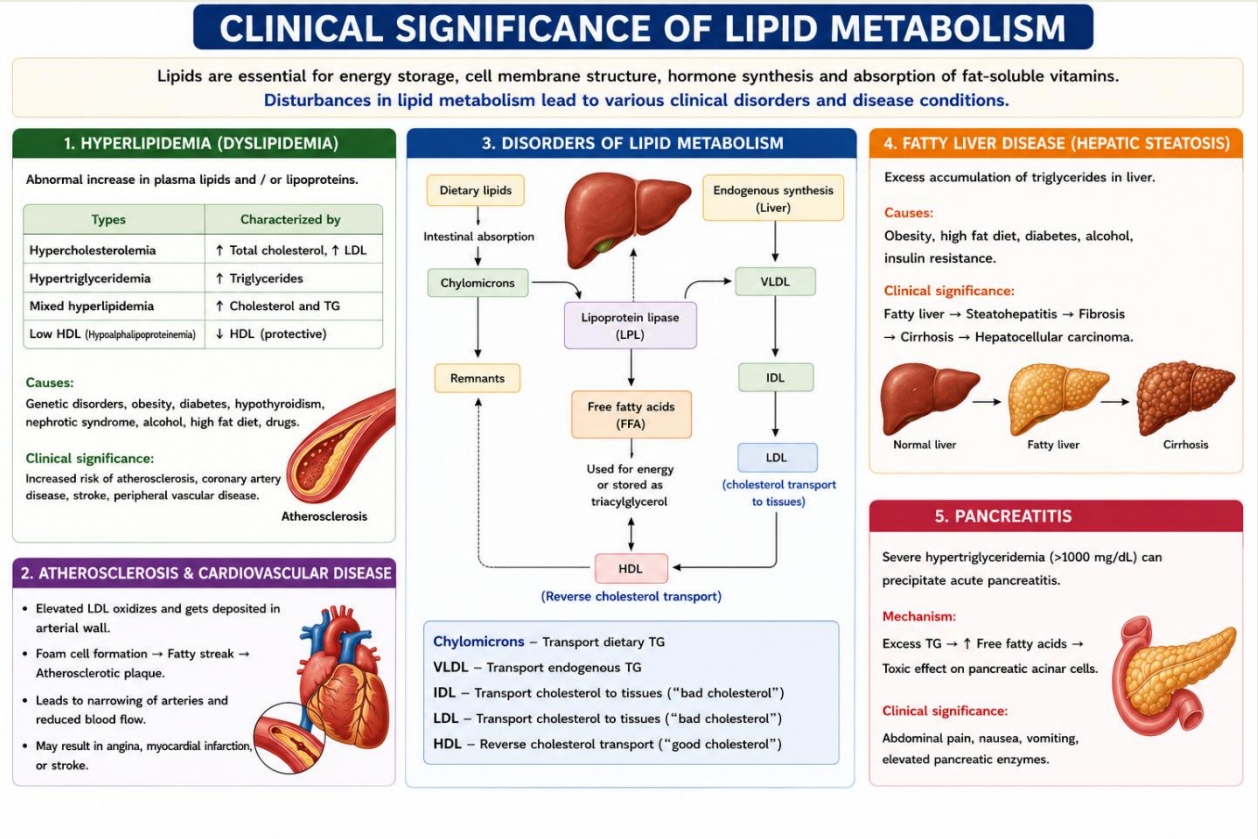
6.3 Physiologically Important Lipids and Macromolecules

1. Key Fatty Acids in Animal Physiology
Palmitic Acid (16:0) & Stearic Acid (18:0): The most abundant saturated fatty acids in animal tissues, serving as structural membrane stabilizers and key components of fat stores.
Oleic Acid (18:1; Δ9): The primary monounsaturated fatty acid found in mammalian adipose tissue.
Essential Fatty Acids (EFAs): Polyunsaturated fatty acids that cannot be synthesized by animal cells because animals lack the specific desaturase enzymes required to introduce double bonds beyond carbon-9. They must be obtained through the diet. Examples include Linoleic Acid (an Omega-6 fatty acid) and Linolenic Acid (an Omega-3 fatty acid critical for neural development). Arachidonic Acid serves as the vital metabolic precursor for synthesizingeicosanoids (local tissue hormones like prostaglandins that regulate inflammation).

2. Triacylglycerols (TAGs / Triglycerides)
Composed of a single glycerol alcohol backbone covalently linked to three fatty acid chains via ester bonds. Triacylglycerols are completely non-polar, hydrophobic neutral fats stored inside specialized animal cells called adipocytes, which aggregate to form adipose tissue.
TAGs represent the primary high-density energy store in animals. Gram for gram, the oxidation of triacylglycerols yields more than twice the metabolic energy (9 kcal/g) of carbohydrates (4 kcal/g). Because they are hydrophobic, they store without holding water, saving body weight in mobile animal species. In marine mammals (whales, seals), thick subcutaneous layers of TAGs (blubber) also provide vital buoyancy and thermal insulation.

3. Phospholipids
Phospholipids are the primary structural building blocks of all animal cellular membranes. They are amphipathic, containing both a highly hydrophilic (polar) head group and long hydrophobic (non-polar) tails.
Glycerophospholipids: Built on a glycerol core. Carbons 1 and 2 are esterified to two fatty acids, while Carbon 3 is attached to a highly polar phosphate group linked to a nitrogenous base or alcohol. Examples include Lecithin (Phosphatidylcholine), which is the most abundant membrane lipid, and Cephalin (Phosphatidylethanolamine), found abundantly in nervous system tissues.
Sphingophospholipids: Built on a complex amino-alcohol base called sphingosine instead of glycerol. Sphingomyelin is formed by linking a fatty acid, a phosphate group, and a choline molecule to a sphingosine backbone. It is highly concentrated in the myelin sheaths around vertebrate axons, providing electrical insulation that dramatically accelerates nerve impulse conduction.

4. Glycolipids
Glycolipids are compound lipids that contain a carbohydrate group attached to a sphingosine base, without a phosphate group.
Cerebrosides: The simplest glycolipids, containing a single monosaccharide unit (glucose or galactose) linked to a ceramide core. They are highly concentrated in the myelin sheaths of white matter within the animal brain.



Gangliosides: Complex glycolipids featuring branched oligosaccharide chains terminating in sialic acid residues. They are located on the outer surface of nerve cell membranes, where they act as essential receptors for cell-cell recognition and surface signaling.

5. Steroids

Steroids are derived lipids characterized by a unique polycyclic core structure composed of four fused carbon rings: the cyclopentanoperhydrophenanthrene (CPPP) nucleus. They lack fatty acid chains.

Cholesterol (The Archetypal Animal Steroid): Cholesterol embeds itself parallel to the phospholipid tails within animal cell membranes, acting as a bidirectional fluidity buffer (preventing membranes from becoming too fluid at high temperatures or crystallizing at low temperatures). It serves as the universal chemical starting material for synthesizing steroid hormones (cortisol, aldosterone, estrogen, testosterone), Vitamin D3, and liver bile acids used to emulsify dietary fats.

6.4 Clinical Significance of Lipid Metabolism

1. Obesity: A chronic metabolic disorder characterized by the abnormal or excessive accumulation of triacylglycerols within adipose tissue sites due to long-term positive energy balances. It involves both hypertrophy (increase in size of adipocytes) and hyperplasia (increase in total number of cells). Excess visceral fat releases elevated free fatty acids and inflammatory cytokines that disrupt insulin receptors, triggering insulin resistance and Type 2 diabetes.

2. Atherosclerosis: A progressive vascular disease characterized by the thickening and hardening of arterial walls due to the formation of lipid-laden plaques within the medium and large arteries. Initiated by chronic endothelial injury, leading to the deposition and oxidation of Low-Density Lipoproteins (LDL). Macrophages engulf this toxic ox-LDL, turning into bloated foam cells, while smooth muscle cells migrate over the area to form a firm fibrous cap

that constricts the blood vessel.

3. Myocardial Infarction (Heart Attack): A life-threatening cardiac event defined as ischemic necrosis (tissue death) of a region of the heart muscle, resulting from a sudden, complete occlusion of a coronary artery. It occurs when an unstable atherosclerotic plaque ruptures, exposing its hydrophobic lipid core to blood. This triggers immediate platelet aggregation and blood clot (thrombus) formation, leading to rapid cell death, severe crushing chest pain, and cardiac arrhythmias.