MODULE 1: OVERVIEW: INTRODUCTION TO BIOLOGY, LIVING MATTER, AND BASIC CHEMICAL CONCEPTS

Biology is the science that studies life. Biochemistry and physiology are two branches of biological science that are fundamentally intertwined in explaining life processes. Biochemistry examines the chemical processes within and related to living organisms, while physiology explores the functions and mechanisms that operate within these systems. Together, they provide a comprehensive understanding of how life is sustained at both the molecular and systemic levels.. At the core of life's biochemistry are the four major macromolecules: **Carbohydrates, Lipids, Proteins, And Nucleic Acids.** These molecules contribute to cellular structure, energy provision, genetic information storage, and numerous physiological functions that keep organisms alive and responsive to their environment.

MACROMOLECULES

Macromolecules are large, complex molecules with high molecular weights, playing essential roles in biological systems. The major classes of macromolecules in living organisms are carbohydrates, lipids, proteins, and nucleic acids. These macromolecules are vital for the structure, function, and regulation of the body's tissues and organs. They are involved in nearly every cellular process and are necessary for growth, development, and the sustenance of life. Macromolecules are composed of smaller subunits called monomers. These monomers are linked together by covalent bonds to form polymers. For example, amino acids are the monomers that form proteins, and nucleotides are the monomers of nucleic acids. Despite their large size, macromolecules are essential for life, and their structures are carefully arranged to perform highly specific biological functions. These structures can be influenced by a variety of factors such as pH, temperature, and interactions with other molecules.

Properties of Life

All groups of living organisms share several key characteristics or functions: order, sensitivity or response to stimuli, reproduction, adaptation, growth and development, regulation/ homeostasis, energy processing, and evolution. When viewed together, these eight characteristics serve to define life.

The eight characteristics that define life are:

1. **Cellular Organization**: All living organisms are made up of one or more cells, which are the basic units of life.

2. **Reproduction**: Living organisms have the ability to reproduce, either sexually or asexually, to pass on their genetic material to offspring.
3. **Metabolism**: All living organisms engage in chemical processes (metabolism) to transform energy for growth, reproduction, and survival. This includes catabolic and anabolic reactions.
4. **Homeostasis**: Living organisms maintain a stable internal environment (homeostasis), such as temperature regulation and pH balance, to sustain life processes.
5. **Response to Stimuli**: Organisms react to changes in their environment (stimuli), such as light, temperature, or chemical signals, for survival and adaptation.
6. **Growth and Development**: Living organisms grow and develop in a regulated way according to genetic instructions.
7. **Adaptation Through Evolution**: Over generations, organisms undergo genetic changes that allow them to evolve and adapt to changing environments.
8. **Heredity**: Organisms pass on genetic material (DNA or RNA) to their offspring, ensuring the continuity of traits from one generation to the next.

These characteristics collectively distinguish living organisms from non-living matter.

Order

Organisms are highly organized structures that consist of one or more cells. Even very simple, single-celled organisms are remarkably complex. Inside each cell, atoms make up molecules. These in turn make up cell components or organelles. Multicellular organisms, which may consist of millions of individual cells, have an advantage over single-celled organisms in that their cells can be specialized to perform specific functions, and even sacrificed in certain situations for the good of the organism as a whole.

Levels of Organization of Living Things

Living things are highly organized and structured, following a hierarchy on a scale from small to large. The levels of organization of living things describe how biological structures and systems are organized, from the simplest to the most complex forms. Here's a breakdown of these levels:

1. Atom: The basic unit of matter, consisting of protons, neutrons, and electrons. Atoms combine to form molecules. **Example**: Carbon (C), Hydrogen (H), Oxygen (O).

2. Molecule: A group of atoms bonded together. Molecules form the building blocks of cells.

- **Example**: Water (H_2O), DNA, glucose ($C_6H_{12}O_6$).

3. Organelle: Specialized structures within cells that perform specific functions. Organelles are made up of molecules. **Example**: Mitochondria (powerhouse of the cell), nucleus, ribosomes.

4. Cell: The basic unit of life. Cells can exist independently as single-celled organisms or as part of a multicellular organism. **Example**: Red blood cell, nerve cell, muscle cell.

5. Tissue: A group of similar cells that perform a specific function. Tissues form organs in multicellular organisms. **Example**: Muscle tissue, nervous tissue, connective tissue.

6. Organ: A structure made up of different types of tissues working together to perform a specific function.: Heart, liver, lungs, brain.

7. Organ System: A group of organs that work together to perform major functions or meet physiological needs of the body. **Example**: Digestive system, respiratory system, nervous system.

8. Organism: A single, complete living being that can function independently. It may consist of a single cell (unicellular organism) or many cells (multicellular organism). **Example**: Human, tree, bacterium.

9. Population: A group of organisms of the same species that live in a specific area and interbreed.: A population of lions in the savannah.

10. Community: All the populations of different species that live and interact in a particular area.

Example: A forest community that includes trees, animals, fungi, and microorganisms.

11. Ecosystem: A community of living organisms interacting with their physical environment (non-living elements like water, soil, and air). **Example**: A coral reef ecosystem, a rainforest ecosystem.

12. Biosphere: The global sum of all ecosystems, including all living organisms and the environments they inhabit. It represents all life on Earth. **Example**: Earth's biosphere.

These levels reflect the increasing complexity of biological systems, from atoms and molecules to the biosphere, emphasizing how interconnected and interdependent life is.

MATTER

At its most fundamental level, life is made up of matter. **Matter** occupies space and has mass. All matter is composed of **elements**, substances that cannot be broken down or transformed chemically into other substances. Each element is made of atoms, each with a constant number of protons and unique properties. A total of 118 elements have been defined; however, only 92 occur naturally, and fewer than 30 are found in living cells. The remaining 26 elements are unstable and, therefore, do not exist for very long or are theoretical and have yet to be detected. Each element is designated by its chemical symbol (such as H, N, O, C, and Na), and possesses unique properties. These unique properties allow elements to combine and to bond with each other in specific ways.

Properties of Matter

1. **Physical Properties**: Characteristics that can be observed or measured without changing the identity of the substance. Examples include color, density, boiling point, melting point, and hardness.
2. **Chemical Properties**: Characteristics that describe a substance's ability to change into a different substance. These include reactivity with other chemicals, flammability, and the ability to rust or tarnish.

States of Matter

Matter exists in four primary states:

1. **Solid**:

Characteristics: Has a definite shape and volume. The particles are closely packed together and vibrate in place. **Example**: Ice, rocks, metals.

2. **Liquid**:

Characteristics: Has a definite volume but no definite shape; it takes the shape of its container. The particles are still close together but can move past one another. **Example**: Water, oil, alcohol.

3. **Gas**:

Characteristics: Has neither a definite shape nor volume. Gas expands to fill the shape and volume of its container. The particles are far apart and move freely. **Example**: Oxygen, nitrogen, carbon dioxide.

4. **Plasma**:

Characteristics: A high-energy state where atoms lose their electrons. It is found in stars, including the sun, and in lightning. **Example**: The sun, neon lights, plasma TVs.

COMPOSITION OF MATTER

Matter is made up of elements, compounds, and mixtures.

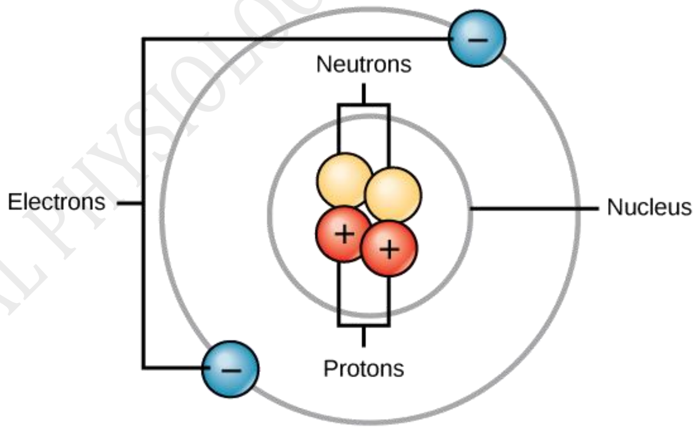
1. **Elements**: The simplest form of matter that cannot be broken down into simpler substances by chemical means. Each element is composed of one type of atom.
   Example: Oxygen (O), Hydrogen (H), Carbon (C).
2. **Compounds**: Substances composed of two or more elements chemically bonded in fixed proportions. Compounds can be broken down into simpler substances through chemical reactions. **Example**: Water (H_2O), Carbon dioxide (CO_2), Sodium chloride (NaCl).
3. **Mixtures**: A combination of two or more substances that are not chemically bonded and can be separated by physical means. Mixtures can be:
   - **Homogeneous** (uniform composition throughout): Examples include air, saltwater.
   - **Heterogeneous** (non-uniform composition): Examples include salad, sand in water.

The Atomic Structure of Matter

Matter is composed of atoms, the smallest unit of an element that retains the properties of that element. Atoms consist of three fundamental particles:

1. **Protons**: Positively charged particles found in the nucleus.
2. **Neutrons**: Neutral particles found in the nucleus.
3. **Electrons**: Negatively charged particles that orbit the nucleus.

The number of protons in an atom defines the element (atomic number), and the arrangement of electrons determines how atoms interact in chemical reactions.



	Charge	Mass (amu)	Location
Proton	+1	1	nucleus
Neutron	0	1	nucleus
Electron	–1	0	orbitals

Key concepts like **isotopes**, **ions**, **atomic number**, and **atomic mass** help explain the properties and behavior of atoms.

1. Atomic Number

The **atomic number** of an element is the number of protons found in the nucleus of its atoms. It is denoted by the symbol **Z.** The atomic number defines the identity of an element, meaning each element has a unique atomic number. **Example**:

- Hydrogen has an atomic number of **1**, meaning every hydrogen atom has **1 proton**.
- Carbon has an atomic number of **6**, meaning every carbon atom has **6 protons**.

Since atoms are electrically neutral, the number of **electrons** in an atom equals the number of protons, meaning the atomic number also determines the number of electrons in a neutral atom.

2. Atomic Mass (Mass Number)

The **atomic mass**, or **mass number**, is the total number of protons and neutrons in an atom's nucleus. It is denoted by the symbol **A.**

- **Mass Number (A)** = Number of **protons** + Number of **neutrons**

Electrons have very little mass compared to protons and neutrons, so they are not included in the calculation of atomic mass. **Example**:

- Carbon-12 (^{12}C) has **6 protons** and **6 neutrons**, so its mass number is **12.**
- Oxygen-16 (^{16}O) has **8 protons** and **8 neutrons**, giving it a mass number of **16.**

The mass number is typically an integer, but the **atomic mass** found on the periodic table is a weighted average of all isotopes of an element and may include decimals.

3. Isotopes are atoms of the same element that have the same number of protons but different numbers of **neutrons**. This difference in neutron number results in different mass numbers for isotopes of the same element.

- Isotopes of an element have the same atomic number (**Z**) but different mass numbers (**A**).
- While isotopes have nearly identical chemical properties, their nuclear properties (e.g., stability) can differ. **Example**: Carbon has several isotopes, including:
  - **Carbon-12 (^{12}C)**: 6 protons and 6 neutrons (stable).
  - **Carbon-13 (^{13}C)**: 6 protons and 7 neutrons (stable).
  - **Carbon-14 (^{14}C)**: 6 protons and 8 neutrons (radioactive, used in carbon dating).
    - Hydrogen isotopes include:

- **Protium (^1H)**: 1 proton, 0 neutrons.
- **Deuterium (^2H)**: 1 proton, 1 neutron.
- **Tritium (^3H)**: 1 proton, 2 neutrons (radioactive).

Some isotopes are **stable**, while others are **radioactive** and decay over time, emitting radiation.

4. Ions

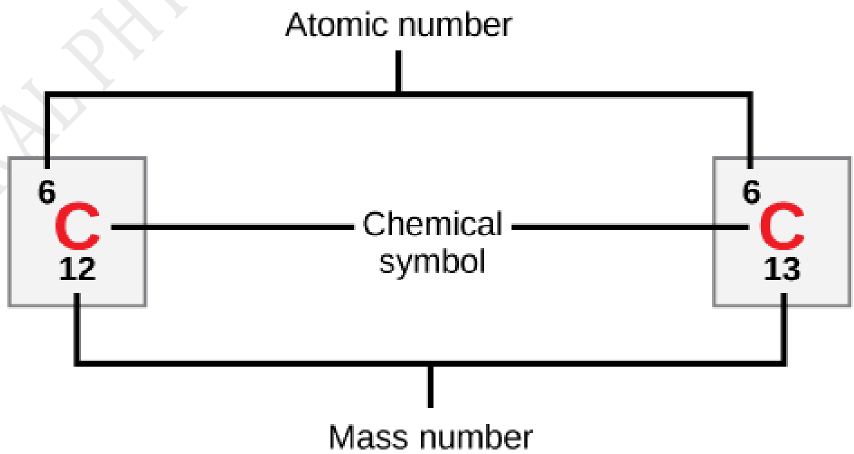
Ions are atoms or molecules that have gained or lost one or more electrons, resulting in a net electrical charge. Ions are formed when an atom does not have an equal number of protons and electrons.

- **Cations**: Positively charged ions, formed when an atom **loses** electrons.
  - **Example**: Sodium (Na) loses one electron to become a sodium ion (**Na^+**).
- **Anions**: Negatively charged ions, formed when an atom **gains** electrons.
  - **Example**: Chlorine (Cl) gains one electron to become a chloride ion (**Cl^-**).

Ions play important roles in chemical reactions, electrical conductivity, and biological processes (e.g., nerve impulses, muscle contractions).

Key Differences and Relationships

- **Atomic Number (Z)** determines the element and the number of protons.
- **Mass Number (A)** is the total number of protons and neutrons.
- **Isotopes** are atoms of the same element with different numbers of neutrons and thus different mass numbers.
- **Ions** are atoms or molecules that have gained or lost electrons, resulting in a net charge.



Chemical Changes in Matter

Matter can undergo chemical changes, resulting in new substances being formed. A chemical change involves breaking and forming chemical bonds, and it is often irreversible.

Examples: Rusting of iron, burning of wood, digestion of food.

PHYSICAL CHANGES IN MATTER

Matter can also undergo physical changes that do not alter its chemical composition. These changes typically involve changes in state or shape.

- **Examples**: Melting of ice, boiling of water, tearing of paper.

Law of Conservation of Matter

The **Law of Conservation of Matter** states that matter cannot be created or destroyed in a closed system. In any chemical reaction or physical change, the total mass of the substances involved remains constant, though the substances may change forms.

THE ROLE OF MATTER IN LIFE PROCESSES

Matter is crucial for biological processes. Living organisms require matter to build structures (such as proteins, carbohydrates, and fats), generate energy, and carry out cellular functions. The biochemical cycles, like the carbon cycle and nitrogen cycle, demonstrate how matter moves through the environment, allowing life to thrive.

In summary, matter is the foundation of all physical substances in the universe, making up everything from the tiniest particles to the largest celestial bodies, and it plays a key role in both the physical world and biological systems.

1. 2 WATER: COMPOSITION, PROPERTIES, AND BIOLOGICAL IMPORTANCE

Water (H_2O) is one of the most essential substances for life. It is a simple molecule made of two hydrogen atoms covalently bonded to one oxygen atom, yet its properties and significance are profound. Water covers approximately 71% of the Earth's surface and constitutes 60-70% of the human body. Its unique characteristics make it vital for both the environment and living organisms.

STRUCTURE AND COMPOSITION OF WATER

The water molecule consists of **Two hydrogen atoms** covalently bonded to **one oxygen atom**. The oxygen atom is more **electronegative** than the hydrogen atoms, which causes the shared electrons to spend more time near the oxygen. This gives oxygen a partial negative charge (δ^-) and hydrogen a partial positive charge (δ^+), resulting in a **polar molecule**. This polarity enables water molecules to form **hydrogen bonds** with each other, where the partially positive hydrogen atom of one water molecule is attracted to the partially negative oxygen atom of another water molecule.

PROPERTIES OF WATER

Water's unique properties stem from its polar nature and its ability to form hydrogen bonds. These properties are critical to life and the environment.

A. Cohesion and Adhesion

- **Cohesion**: Water molecules are attracted to each other due to hydrogen bonding. This cohesive property allows water to form droplets and gives rise to **surface tension**, which makes the surface of water behave like an elastic sheet.

Surface Tension: Water has high surface tension due to hydrogen bonding, allowing certain organisms, like insects, to walk on water.

- **Adhesion**: Water molecules can also adhere to other polar or charged surfaces. This property is essential for processes like **capillary action**, where water moves up narrow tubes against gravity.

Capillary Action: Crucial for the movement of water from plant roots to leaves, allowing plants to transport nutrients and maintain turgor pressure.

B. High Specific Heat Capacity

Water has a high specific heat capacity, meaning it can absorb a lot of heat without a significant rise in temperature. This property helps regulate the Earth's climate and provides a stable environment for aquatic life.

Biological Importance: The high specific heat of water allows organisms to maintain a stable internal temperature, buffering against temperature fluctuations in the environment. It also stabilizes ocean temperatures, benefiting marine ecosystems.

C. High Heat of Vaporization

Water requires a large amount of energy to change from a liquid to a gas, which is known as its **heat of vaporization**. This property is important for cooling mechanisms in living organisms.

Evaporative Cooling: When water evaporates, it removes heat from the surface, a process used in **sweating** and **panting** in animals to maintain body temperature.

D. Density and Expansion Upon Freezing

Water behaves unusually as it freezes. Most substances contract when they freeze, but water expands. Ice is less dense than liquid water due to the hydrogen bonds forming a crystalline structure that takes up more space. This is why ice floats on water.

Biological Importance:

- Ice forming on the surface of lakes and ponds insulates the water below, allowing aquatic life to survive during freezing temperatures.
- If ice were denser than water and sank, aquatic ecosystems would freeze solid, severely disrupting life.

E. Universal Solvent

Water is known as the **"universal solvent"** because it can dissolve more substances than any other liquid. Its polarity allows it to interact with a wide range of molecules, especially other polar molecules and ionic compounds.

Hydrophilic Substances: Polar molecules (e.g., salts, sugars) dissolve easily in water because they form hydrogen bonds or ionic interactions with water molecules.

Hydrophobic Substances: Nonpolar molecules (e.g., oils, fats) do not dissolve in water because they cannot form hydrogen bonds with it.

Biological Importance:

- Water dissolves nutrients, gases (like oxygen and carbon dioxide), and waste products, enabling their transport in living organisms.
- In blood, water acts as the medium for transporting dissolved substances like glucose, electrolytes, and hormones.
- Within cells, water dissolves and transports essential ions, molecules, and enzymes for biochemical reactions.

F. pH and Ionization

Water undergoes slight ionization, producing equal amounts of hydrogen ions (H^+) and hydroxide ions (OH^-), giving it a **neutral pH of 7**. Water can act as both an **acid** (donating H^+) and a **base** (accepting H^+), allowing it to participate in a variety of chemical reactions. It helps maintain the pH balance in organisms, which is crucial for enzyme activity and overall biochemical stability.

BIOLOGICAL IMPORTANCE OF WATER

Water plays an indispensable role in biological processes and is critical to life on Earth. Some of its key biological roles include:

A. Solvent for Biochemical Reactions

Water is the medium in which most biochemical reactions occur. The ability to dissolve ions, gases, and biomolecules allows water to:

- Facilitate the transport of nutrients and wastes in cells and organisms.
- Act as a solvent for enzymes and substrates in metabolic reactions.

B. Transport of Substances

- **In Animals**: Water is a key component of blood, lymph, and other fluids, allowing the transport of oxygen, carbon dioxide, nutrients, hormones, and waste products.
- **In Plants**: Water moves from roots to leaves through **xylem** via transpiration, carrying dissolved minerals and nutrients necessary for plant growth.

C. Thermoregulation

Water's high specific heat capacity allows organisms to maintain stable internal temperatures despite external temperature changes. Evaporation of water from the skin (sweating) or from plant leaves (transpiration) helps cool the organism or plant.

D. Structural Support

Water provides turgidity and structural support to plant cells. The **turgor pressure** in plant cells, which is the pressure exerted by water against the cell wall, helps maintain the plant's rigidity and upright posture.

E. Role in Metabolic Processes

Water is involved in both **catabolic** and **anabolic** reactions.

- **Hydrolysis**: Water is used to break down complex molecules into simpler ones (e.g., in digestion).
- **Dehydration Synthesis**: Water is released when smaller molecules are joined to form larger molecules (e.g., during the formation of proteins and carbohydrates).

F. Cellular Function and Homeostasis

- **Cytoplasm**: Water makes up the bulk of the cytoplasm, where organelles are suspended and many cellular processes take place.
- **Osmosis**: Water movement across cell membranes via osmosis is crucial for maintaining cell shape and volume, as well as regulating concentrations of solutes in cells and tissues.
- **pH Balance**: Water helps buffer changes in pH, ensuring that biochemical processes occur within the optimal pH range.

4. Water Cycle in Nature

Water continuously cycles between the atmosphere, land, and oceans in a process known as the **hydrological cycle** or **water cycle.** This cycle includes processes like:

- **Evaporation**: Water from oceans, lakes, and rivers turns into vapor.
- **Condensation**: Water vapor forms clouds.
- **Precipitation**: Water returns to the Earth's surface as rain, snow, sleet, or hail.
- **Infiltration and Runoff**: Water seeps into the ground to replenish aquifers or flows into water bodies.
- The water cycle ensures that water is available in various forms to support ecosystems and human activities.

5. Water in Human Life and Society

- **Drinking Water**: Essential for hydration and survival. Humans need to consume water regularly to maintain bodily functions.
- **Agriculture**: Water is essential for irrigation and the production of crops.
- **Industry**: Water is used in a variety of industrial processes, including cooling, manufacturing, and power generation.
- **Sanitation**: Clean water is necessary for hygiene and preventing waterborne diseases.

Water's unique physical and chemical properties make it essential for life on Earth. Its roles as a solvent, transport medium, temperature buffer, and participant in biochemical reactions underscore its importance in maintaining life processes. In addition to its biological significance, water is integral to the environment, shaping weather patterns, ecosystems, and human activities. Its importance cannot be overstated, making it one of the most critical molecules for life.

MODULE 2 CARBOHYDRATES AND THEIR BIOLOGICAL IMPORTANCE

Carbohydrates are one of the four major macromolecules essential for life, primarily serving as a source of energy and structural materials in living organisms. They are organic compounds composed of carbon, hydrogen, and oxygen, generally in a 1:2:1 ratio (CH_2O). Carbohydrates can be classified into **simple sugars** and **complex carbohydrates**, based on the number of sugar units they contain and they play crucial roles in various biological processes.

A. Monosaccharides (Simple Sugars)

Monosaccharides are the simplest form of carbohydrates and consist of a single sugar unit. They are the building blocks for more complex carbohydrates. Monosaccharides may exist as a linear chain or as ring-shaped molecules; in aqueous solutions, they are usually found in the ring form.

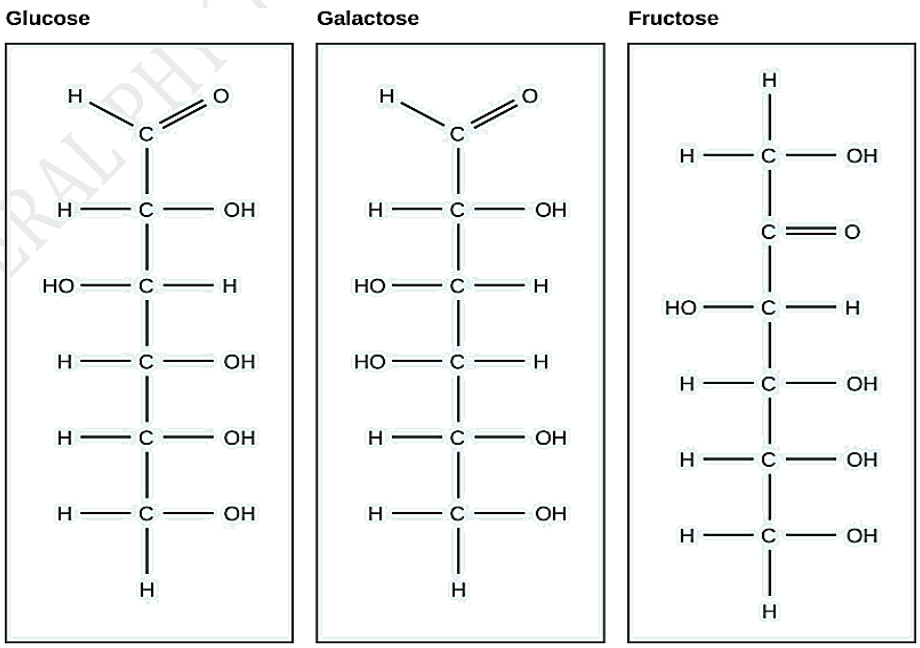
Galactose (part of lactose, or milk sugar) and fructose (found in fruit) are other common monosaccharides. Although glucose, galactose, and fructose all have the same chemical formula ($C_6H_{12}O_6$), they differ structurally and chemically (and are known as isomers) because of differing arrangements of atoms in the carbon chain. **Examples**: Glucose, fructose, galactose

Structure: They typically have a backbone of 3-7 carbon atoms. Glucose ($C_6H_{12}O_6$) is the most common monosaccharide and is a primary energy source for cells.

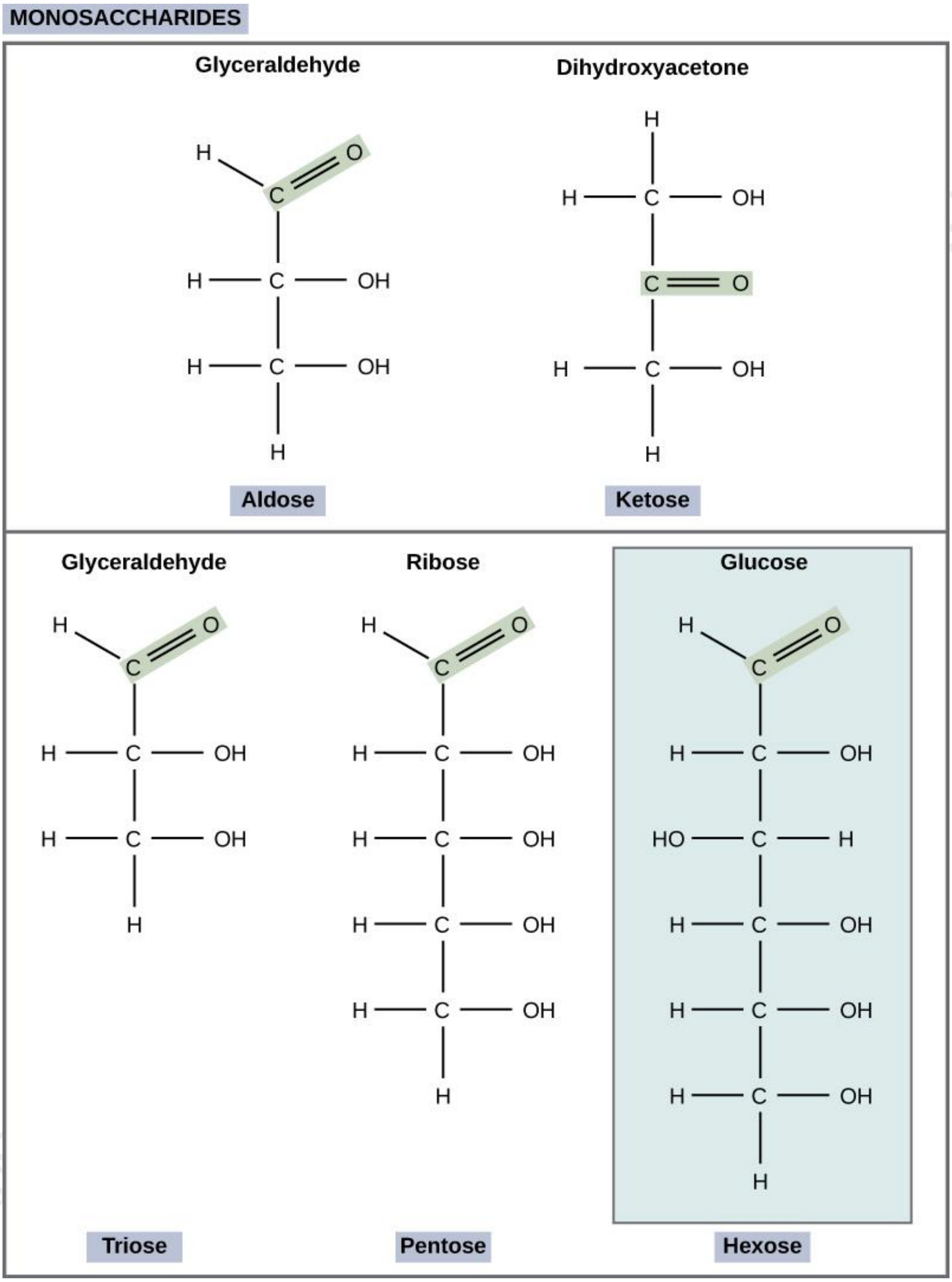
Function:

Energy source: Monosaccharides are directly used in cellular respiration to produce ATP.

Building blocks: Monosaccharides are used to form disaccharides and polysaccharides.



Glucose, galactose, and fructose are all hexoses. They are structural isomers, meaning they have the same chemical formula ($C_6H_{12}O_6$) but a different arrangement of atoms



B. Disaccharides

Disaccharides are formed when two monosaccharides are linked by a glycosidic bond, a type of covalent bond formed during dehydration synthesis. form when two monosaccharides undergo a dehydration reaction (also known as a condensation reaction or dehydration synthesis). During this process, the hydroxyl group of one monosaccharide combines with the hydrogen of another monosaccharide, releasing a molecule of water and forming a covalent bond. A covalent bond formed between a carbohydrate molecule and another molecule (in this case, between two monosaccharides) is known as a glycosidic bond. Glycosidic bonds (also called glycosidic linkages) can be of the alpha or the beta type.

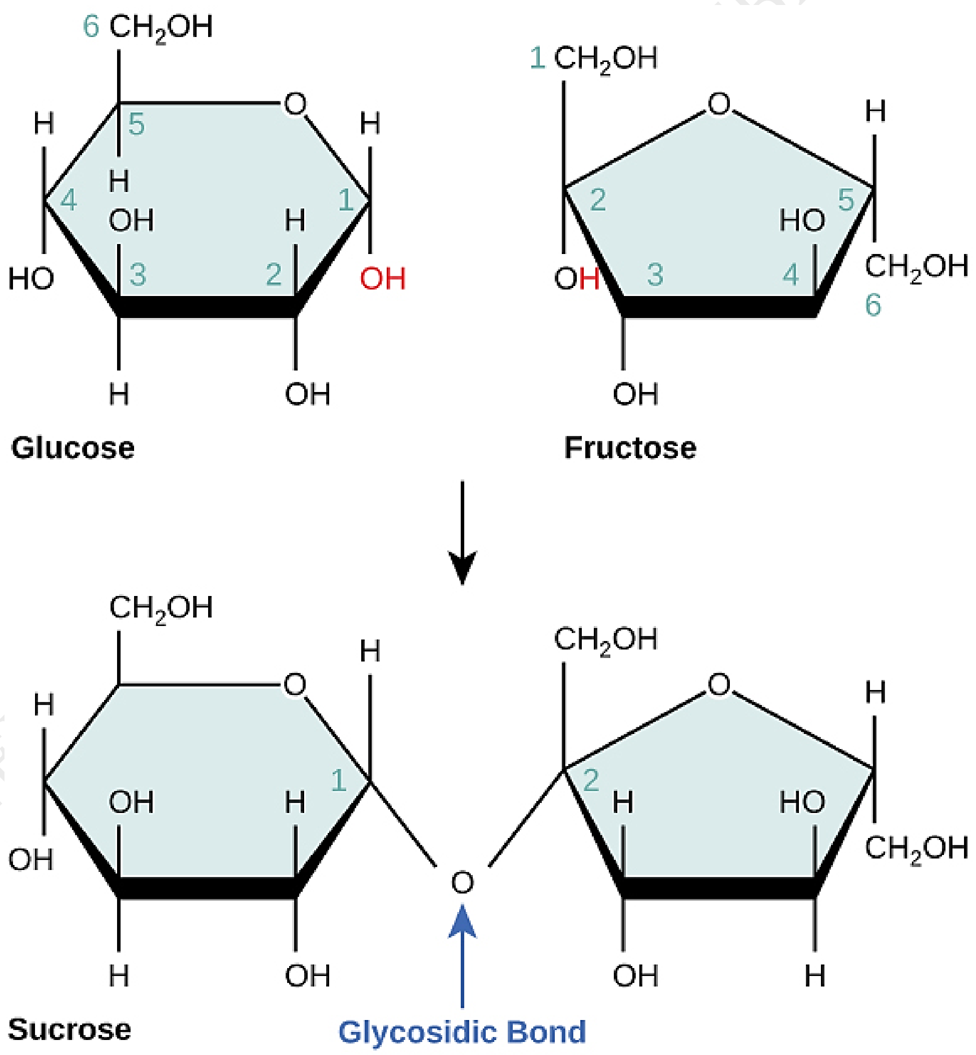
Examples:

Sucrose (glucose + fructose): Table sugar, used for energy.

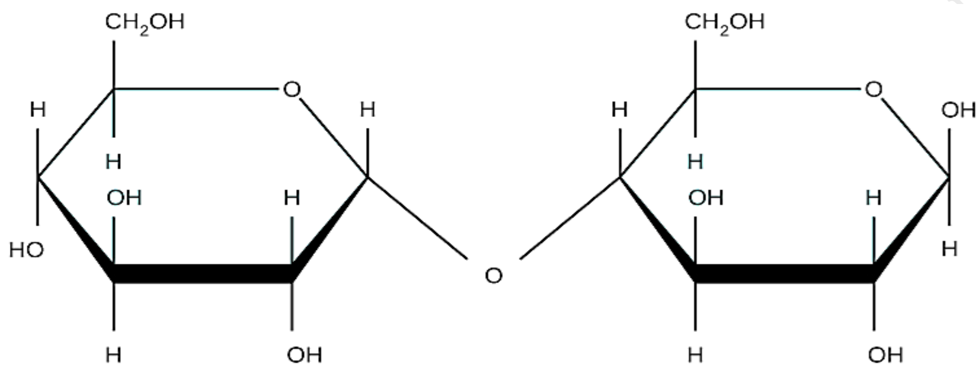
Lactose (glucose + galactose): Found in milk, providing energy to infants.

Maltose (glucose + glucose): Found in germinating seeds.

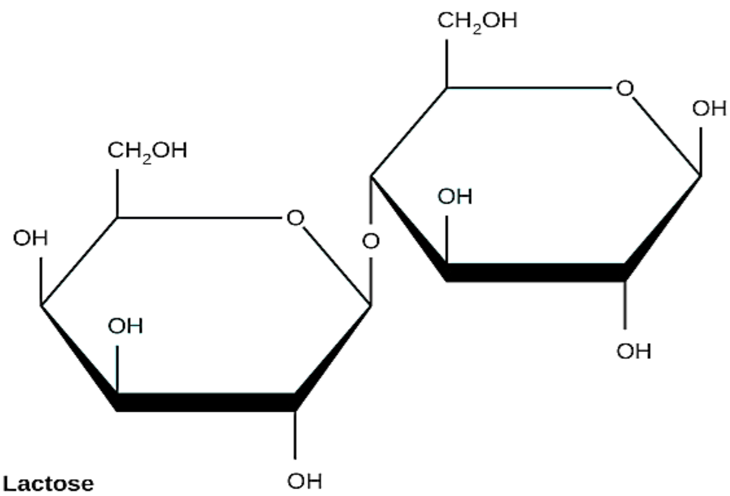
Function: Disaccharides serve as energy sources and are often broken down into monosaccharides before absorption in the body.



Sucrose is formed when a monomer of glucose and a monomer of fructose are joined in a dehydration reaction to form a glycosidic bond. In the process, a water molecule is lost. By convention, the carbon atoms in a monosaccharide are numbered from the terminal carbon closest to the carbonyl group. In sucrose, a glycosidic linkage is formed between carbon 1 in glucose and carbon 2 in fructose. Common disaccharides include lactose, maltose, and sucrose. Lactose is a disaccharide consisting of the monomers glucose and galactose. It is found naturally in milk. Maltose, or malt sugar, is a disaccharide formed by a dehydration reaction between two glucose molecules. The most common disaccharide is sucrose, or table sugar, which is composed of the monomers glucose and fructose.



Maltose



Lactose

C. Oligosaccharides

Oligosaccharides contain 3 to 10 monosaccharide units. They are less common but are often found on the surface of cells.

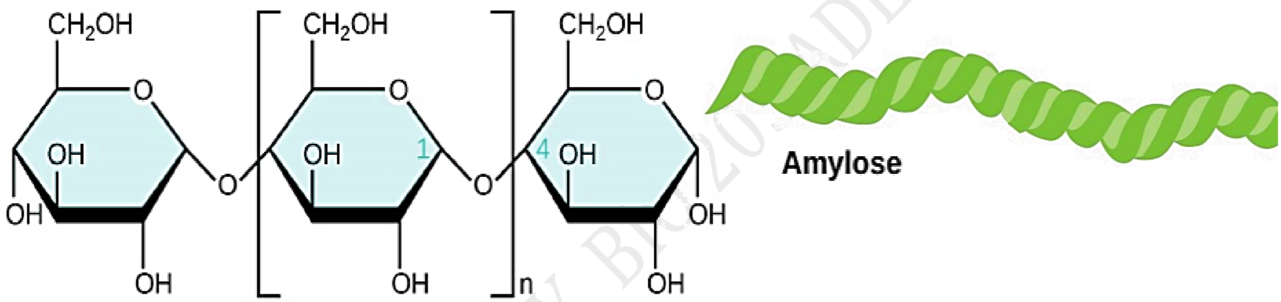
Function:

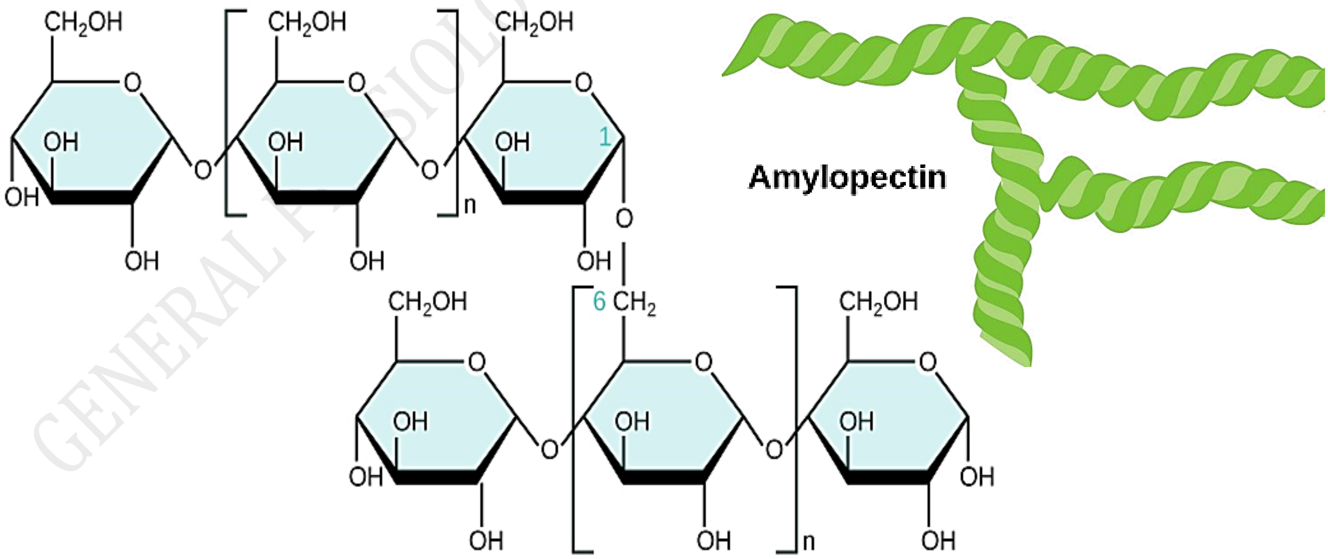
Cell recognition: Oligosaccharides attached to proteins and lipids on cell membranes play a role in cell signaling and immune responses.

D. Polysaccharides (Complex Carbohydrates)

Polysaccharides are long chains of monosaccharides (typically glucose) linked together. They can be branched or unbranched and serve as energy storage or structural molecules. A long chain of monosaccharides linked by glycosidic bonds is known as a polysaccharide (poly- = "many"). The chain may be branched or unbranched, and it may contain different types of monosaccharides. The molecular weight may be 100,000 daltons or more depending on the number of monomers joined. Starch, glycogen, cellulose, and chitin are primary examples of polysaccharides.

Starch is the stored form of sugars in plants and is made up of amylose and amylopectin (both polymers of glucose). Plants are able to synthesize glucose, and the excess glucose is stored as starch in different plant parts, including roots and seeds. The starch that is consumed by animals is broken down into smaller molecules, such as glucose. The cells can then absorb the glucose. Starch is made up of glucose monomers that are joined by α 1-4 or α 1-6 glycosidic bonds. The numbers 1-4 and 1-6 refer to the carbon number of the two residues that have joined to form the bond.

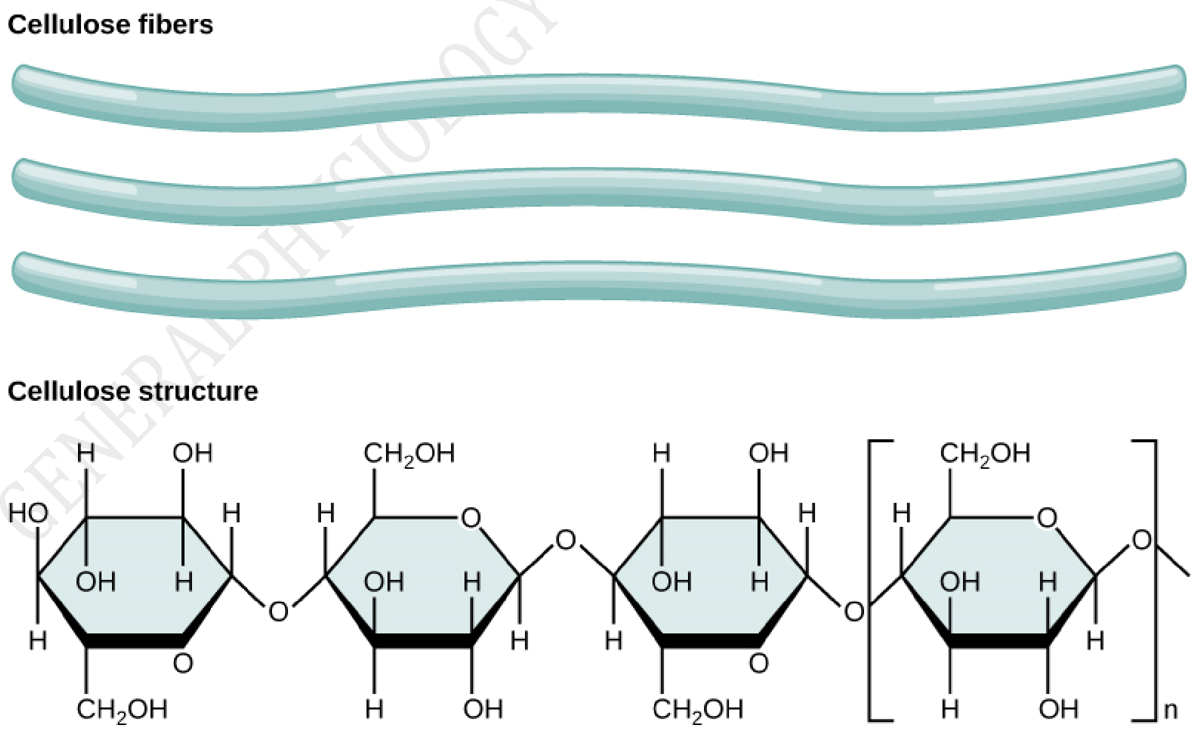




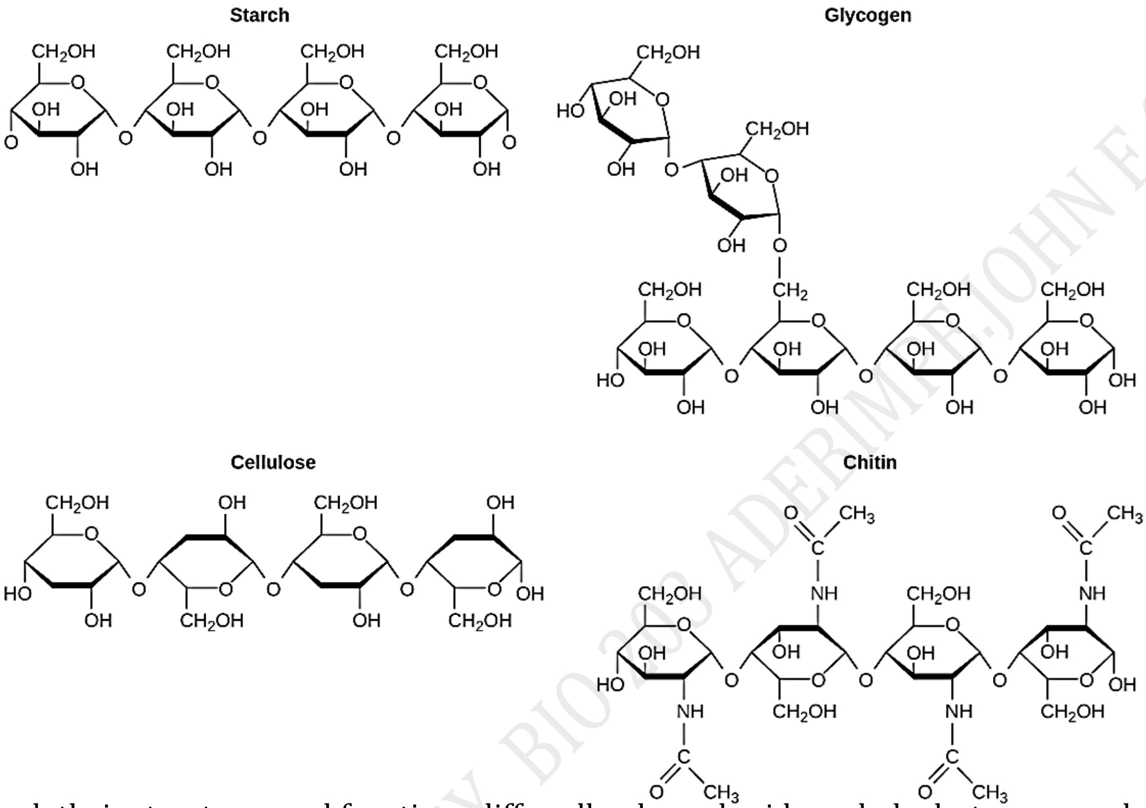
Glycogen Glycogen is the storage form of glucose in humans and other vertebrates and is made up of monomers of glucose. Glycogen is the animal equivalent of starch and is a highly branched molecule usually stored in liver and muscle cells. Whenever blood glucose levels decrease, glycogen is broken down to release glucose in a process known as glycogenolysis.

Cellulose is one of the most abundant natural biopolymers. The cell walls of plants are mostly made of cellulose, which provides structural support to the cell. Wood and paper are mostly cellulosic in nature. Cellulose is made up of glucose monomers that are linked by bonds between particular carbon atoms in the glucose molecule. Cellulose is made up of glucose monomers that are linked by β 1-4 glycosidic bonds

Every other glucose monomer in cellulose is flipped over and packed tightly as extended long chains. This gives cellulose its rigidity and high tensile strength—which is so important to plant cells. Cellulose passing through our digestive system is called dietary fiber. While the glucose-glucose bonds in cellulose cannot be broken down by human digestive enzymes, herbivores such as cows, buffalos, and horses are able to digest grass that is rich in cellulose and use it as a food source. In these animals, certain species of bacteria reside in the digestive system of herbivores and secrete the enzyme cellulase. The appendix also contains bacteria that break down cellulose, giving it an important role in the digestive systems of some ruminants. Cellulases can break down cellulose into glucose monomers that can be used as an energy source by the animal.



Chitin Carbohydrates serve other functions in different animals. Arthropods, such as insects, spiders, and crabs, have an outer skeleton, called the exoskeleton, which protects their internal body parts. This exoskeleton is made of the biological macromolecule **chitin**, which is a nitrogenous carbohydrate. It is made of repeating units of a modified sugar containing nitrogen



Although their structures and functions differ, all polysaccharide carbohydrates are made up of monosaccharides and have the chemical formula $(CH_2O)n$.

2. Biological Importance of Carbohydrates

Carbohydrates are vital for a variety of biological processes and functions in both plants and animals.

A. Energy Production

Carbohydrates are the primary source of energy for most organisms. Monosaccharides, particularly glucose, are central to metabolism and are used in cellular respiration to produce ATP (adenosine triphosphate), the energy currency of the cell.

- **Glycolysis**: The breakdown of glucose in the cytoplasm of cells to produce pyruvate, ATP, and NADH.
- **Krebs Cycle and Electron Transport Chain**: Pyruvate enters the mitochondria and is further oxidized to produce more ATP. This process provides the energy needed for cellular processes.

- **ATP Production**: One molecule of glucose can produce up to 38 ATP molecules through aerobic respiration.

B. Energy Storage

- **In Plants**: Carbohydrates are stored as **starch**, primarily in seeds, tubers, and roots. Plants use stored starch during periods of low photosynthetic activity (e.g., nighttime or winter).
- **In Animals**: Excess glucose is stored as **glycogen** in the liver and muscles. When blood glucose levels drop, glycogen is broken down into glucose to maintain energy supply.

C. Structural Roles

Carbohydrates serve as structural components in both plants and animals.

- **Cellulose**: A major component of plant cell walls, cellulose provides rigidity and strength. Humans cannot digest cellulose because they lack the enzyme cellulase, but it aids in digestion by acting as dietary fiber.
- **Chitin**: Found in the exoskeletons of arthropods (e.g., insects, crustaceans) and the cell walls of fungi. It provides protection and structural support.

D. Cell Recognition and Signalling

Carbohydrates attached to proteins (glycoproteins) and lipids (glycolipids) on the surface of cell membranes are essential for cell-cell recognition, signaling, and immune responses.

- **Glycoproteins and Glycolipids**: These molecules are involved in cellular recognition processes, such as the immune system's ability to recognize foreign invaders or the ability of cells to communicate with one another.
- **Blood Types**: The different blood types (A, B, AB, O) are determined by specific carbohydrate structures on the surface of red blood cells.

E. Dietary Fiber

- **Soluble Fiber**: Found in foods like oats, legumes, and some fruits, soluble fiber dissolves in water and can help lower blood cholesterol and glucose levels.
- **Insoluble Fiber**: Found in whole grains, vegetables, and wheat bran, insoluble fiber adds bulk to stool and aids in the movement of material through the digestive tract, promoting healthy bowel movements and preventing constipation.

F. Role in Brain Function

The brain relies almost entirely on glucose as its energy source. A constant supply of glucose is essential for cognitive function, concentration, and memory. Hypoglycemia (low blood sugar) can lead to impaired brain function, dizziness, and confusion.

3. Carbohydrate Metabolism

The metabolism of carbohydrates is a tightly regulated process that involves multiple steps for the production, storage, and utilization of glucose.

- **Insulin**: A hormone produced by the pancreas, insulin facilitates the uptake of glucose into cells and promotes glycogen storage in the liver and muscles.
- **Glucagon**: When blood sugar levels are low, glucagon stimulates the breakdown of glycogen into glucose, maintaining normal blood sugar levels.
- **Diabetes**: A metabolic disorder in which the body either does not produce enough insulin (Type 1) or becomes resistant to insulin's effects (Type 2), leading to elevated blood glucose levels.

4. Carbohydrates in Nutrition

Carbohydrates are a major component of the human diet, providing about 45-65% of daily caloric intake.

- **Simple Carbohydrates**: These include sugars found in fruits, milk, and sweeteners. While they provide quick energy, excessive intake can lead to spikes in blood sugar and potential health problems such as obesity and diabetes.
- **Complex Carbohydrates**: Found in whole grains, vegetables, and legumes, complex carbohydrates are digested more slowly, providing a steady source of energy and contributing to long-term health.

Carbohydrates are essential macromolecules that provide energy, structural support, and contribute to cell communication and function. Their role in energy production, storage, and regulation is critical for the survival of living organisms. Additionally, carbohydrates play an important part in human nutrition, with a balance between simple and complex carbohydrates being vital for maintaining health.

MODULE 3 LIPIDS AND THEIR FUNCTIONS IN BIOLOGY

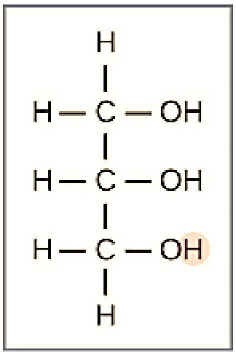
Lipids include a diverse group of compounds that are united by a common feature. **Lipids** are hydrophobic ("water-fearing"), or insoluble in water, because they are nonpolar molecules. This is because they are hydrocarbons that include only nonpolar carbon-carbon or carbon-hydrogen bonds. Lipids perform many different functions in a cell. Cells store energy for long-term use in the form of lipids called fats. Lipids also provide insulation from the environment for plants and animals. For example, they help keep aquatic birds and mammals dry because of their water-repelling nature. Lipids are also the building blocks of many hormones and are an important constituent of the plasma membrane. Lipids include fats, oils, waxes, phospholipids, and steroids.

Hydrophobic lipids in the fur of aquatic mammals, such as this river otter, protect them from the elements.

Fats and Oils

A fat molecule consists of two main components—glycerol and fatty acids. Glycerol is an organic compound (alcohol) with three carbons, five hydrogens, and three hydroxyl (OH) groups. Fatty acids have a long chain of hydrocarbons to which a carboxyl group is attached, hence the name "fatty acid." The number of carbons in the fatty acid may range from 4 to 36; most common are those containing 12–18 carbons. In a fat molecule, the fatty acids are attached to each of the three carbons of the glycerol molecule with an ester bond through an oxygen atom A **fat** molecule, such as a triglyceride, consists of two main components—glycerol and fatty acids. Glycerol is an organic compound with three carbon atoms, five hydrogen atoms, and three hydroxyl (–OH) groups. Fatty acids have a long chain of hydrocarbons to which an acidic carboxyl group is attached, hence the name "fatty acid."

Glycerol



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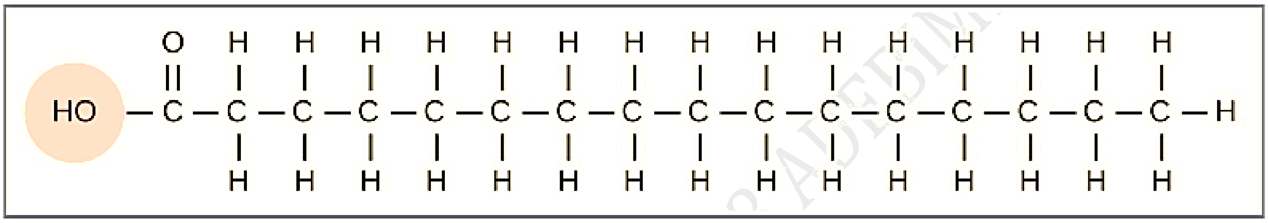
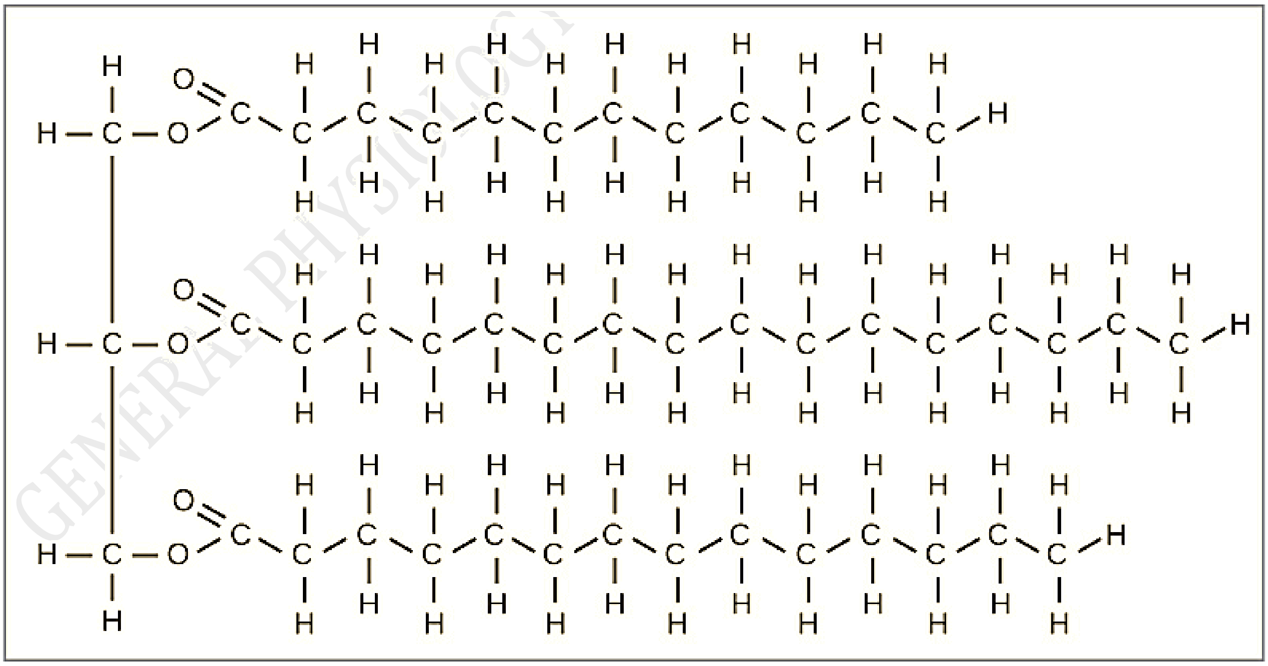
Fatty Acid

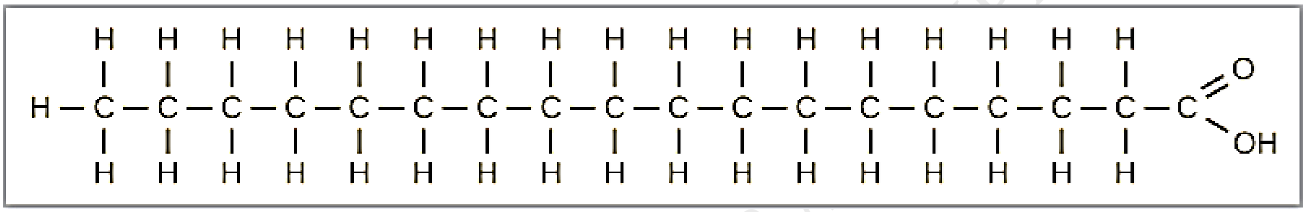


Triacylglycerol



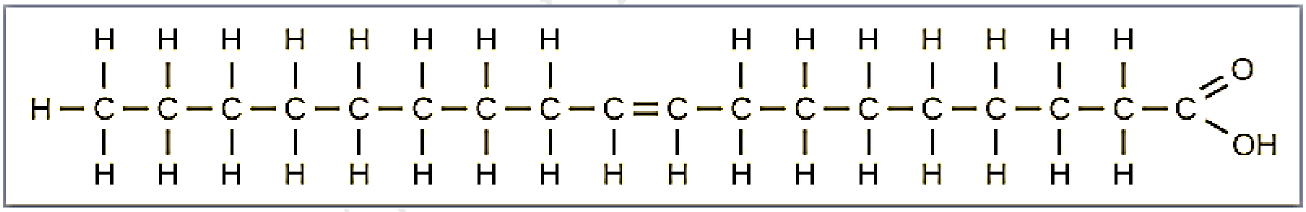
Triacylglycerol is formed by the joining of three fatty acids to a glycerol backbone in a dehydration reaction.

Three molecules of water are released in the process. During this ester bond formation, three water molecules are released. The three fatty acids in the triacylglycerol may be similar or dissimilar. Fats are also called triacylglycerols or triglycerides because of their chemical structure. Some fatty acids have common names that specify their origin. For example, palmitic acid, a saturated fatty acid, is derived from the palm tree. Arachidic acid is derived from *Arachis hypogea,* the scientific name for groundnuts or peanuts. Fatty acids may be saturated or unsaturated. In a fatty acid chain, if there are only single bonds between neighbouring carbons in the hydrocarbon chain, the fatty acid is said to be saturated. Saturated fatty acids are saturated with hydrogen; in other words, the number of hydrogen atoms attached to the carbon skeleton is maximized. Stearic acid is an example of a saturated fatty acid.



Stearic acid is a common saturated fatty acid.

When the hydrocarbon chain contains a double bond, the fatty acid is said to be unsaturated. Oleic acid is an example of an unsaturated fatty acid



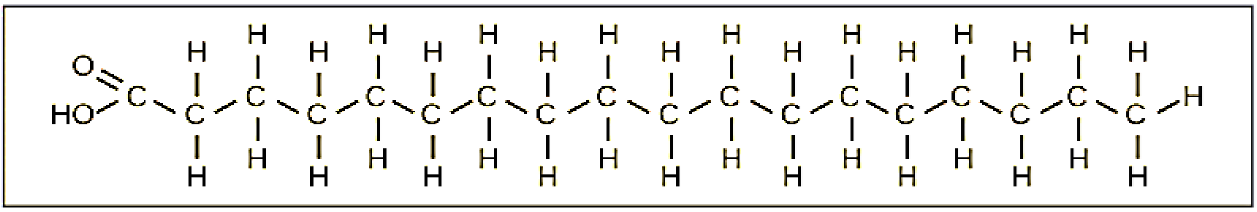
Oleic acid is a common unsaturated fatty acid.

Most unsaturated fats are liquid at room temperature and are called oils. If there is one double bond in the molecule, then it is known as a monounsaturated fat (e.g., olive oil), and if there is more than one double bond, then it is known as a polyunsaturated fat (e.g., canola oil).

When a fatty acid has no double bonds, it is known as a saturated fatty acid because no more hydrogen may be added to the carbon atoms of the chain. A fat may contain similar or different fatty acids attached to glycerol. Long straight fatty acids with single bonds tend to get packed tightly and are solid at room temperature. Animal fats with stearic acid and palmitic acid (common in meat) and the fat with butyric acid (common in butter) are examples of saturated fats. Mammals store fats in specialized cells called adipocytes, where globules of fat occupy most of the cell's volume. In plants, fat or oil is stored in many seeds and is used as a source of energy during seedling development. Unsaturated fats or oils are usually of plant origin and contain *cis* unsaturated fatty acids. *Cis* and *trans* indicate the configuration of the molecule around the double bond. If hydrogens are present in the same plane, it is referred to as a cis fat; if the hydrogen atoms are on two different planes, it is referred to as a trans fat. The *cis* double bond causes a bend or a “kink” that prevents the fatty acids from packing tightly, keeping them liquid at room temperature. Olive oil, corn oil, canola oil, and cod liver oil are examples of unsaturated fats. Unsaturated fats help to lower blood cholesterol levels whereas saturated fats contribute to plaque formation in the arteries.

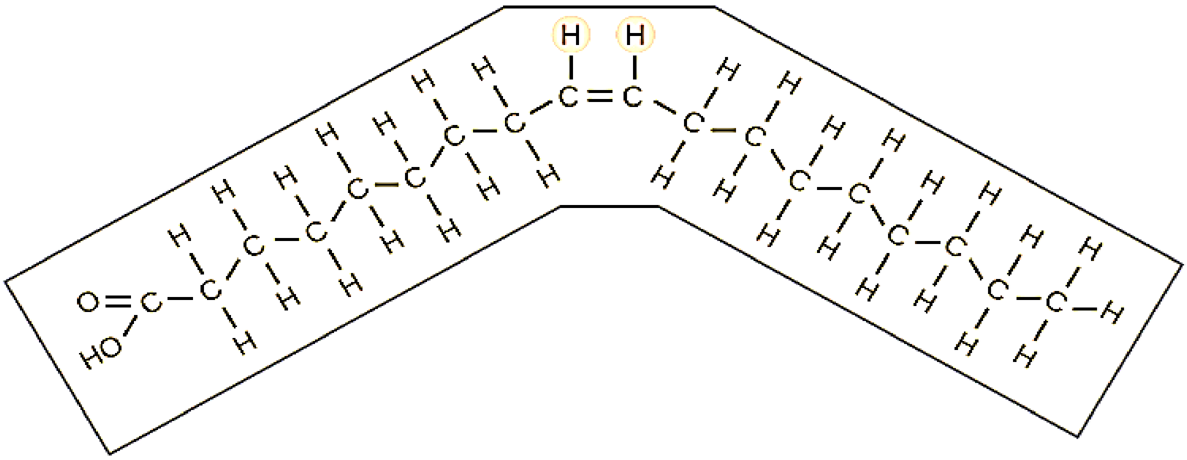
Saturated fatty acid

Stearic acid

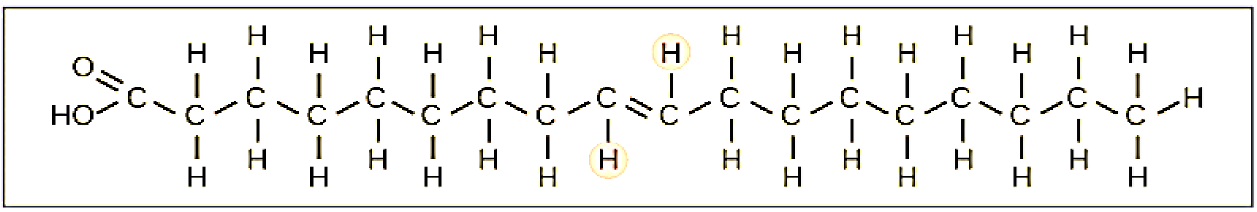


Unsaturated fatty acids

Cis oleic acid



Trans oleic acid



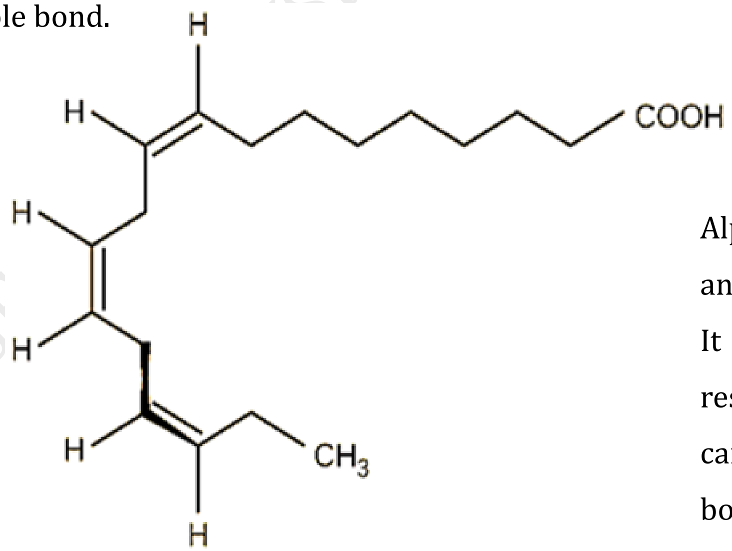
Saturated fatty acids have hydrocarbon chains connected by single bonds only. Unsaturated fatty acids have one or more double bonds. Each double bond may be in a *cis* or *trans* configuration. In the *cis* configuration, both hydrogens are on the same side of the hydrocarbon chain. In the *trans* configuration, the hydrogens are on opposite sides. A *cis* double bond causes a kink in the chain.

Trans Fats

In the food industry, oils are artificially hydrogenated to make them semi-solid and of a consistency desirable for many processed food products. Simply speaking, hydrogen gas is bubbled through oils to solidify them. During this hydrogenation process, double bonds of the *cis*- conformation in the hydrocarbon chain may be converted to double bonds in the trans-conformation. Margarine, some types of peanut butter, and shortening are examples of artificially hydrogenated trans fats. Recent studies have shown that an increase in trans fats in the human diet may lead to an increase in levels of low-density lipoproteins (LDL), or "bad" cholesterol, which in turn may lead to plaque deposition in the arteries, resulting in heart disease. Many fast food restaurants have recently banned the use of trans fats, and food labels are required to display the trans fat content.

Omega Fatty Acids

Essential fatty acids are fatty acids required but not synthesized by the human body. Consequently, they have to be supplemented through ingestion via the diet. Omega-3 fatty acids fall into this category and are one of only two known for humans (the other being omega-6 fatty acid). These are polyunsaturated fatty acids and are called omega-3 because the third carbon from the end of the hydrocarbon chain is connected to its neighbouring carbon by a double bond.



Alpha-linolenic acid is an example of an omega-3 fatty acid.

It has three *cis* double bonds and, as a result, a curved shape. For clarity, the carbons are not shown. Each singly bonded carbon has two hydrogens associated with it, also not shown.

The farthest carbon away from the carboxyl group is numbered as the omega (ω) carbon, and if the double bond is between the third and fourth carbon from that end, it is known as an omega-3 fatty acid. Nutritionally important because the body does not make them, omega-3 fatty acids include alpha-linoleic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), all of which are polyunsaturated. Salmon, trout, and tuna are good sources of omega-3 fatty acids. Research indicates that omega-3 fatty acids reduce the risk of sudden death from heart attacks, reduce triglycerides in the blood, lower blood pressure, and prevent thrombosis by inhibiting blood clotting. They also reduce inflammation, and may help reduce the risk of some cancers in animals.

Like carbohydrates, fats have received a lot of bad publicity. It is true that eating an excess of fried foods and other "fatty" foods leads to weight gain. However, fats do have important functions. Many vitamins are fat soluble, and fats serve as a long-term storage form of fatty acids: a source of energy. They also provide insulation for the body. Therefore, "healthy" fats in moderate amounts should be consumed on a regular basis.

Waxes

Wax covers the feathers of some aquatic birds and the leaf surfaces of some plants. Because of the hydrophobic nature of waxes, they prevent water from sticking on the surface Waxes are made up of long fatty acid chains esterified to long-chain alcohols.

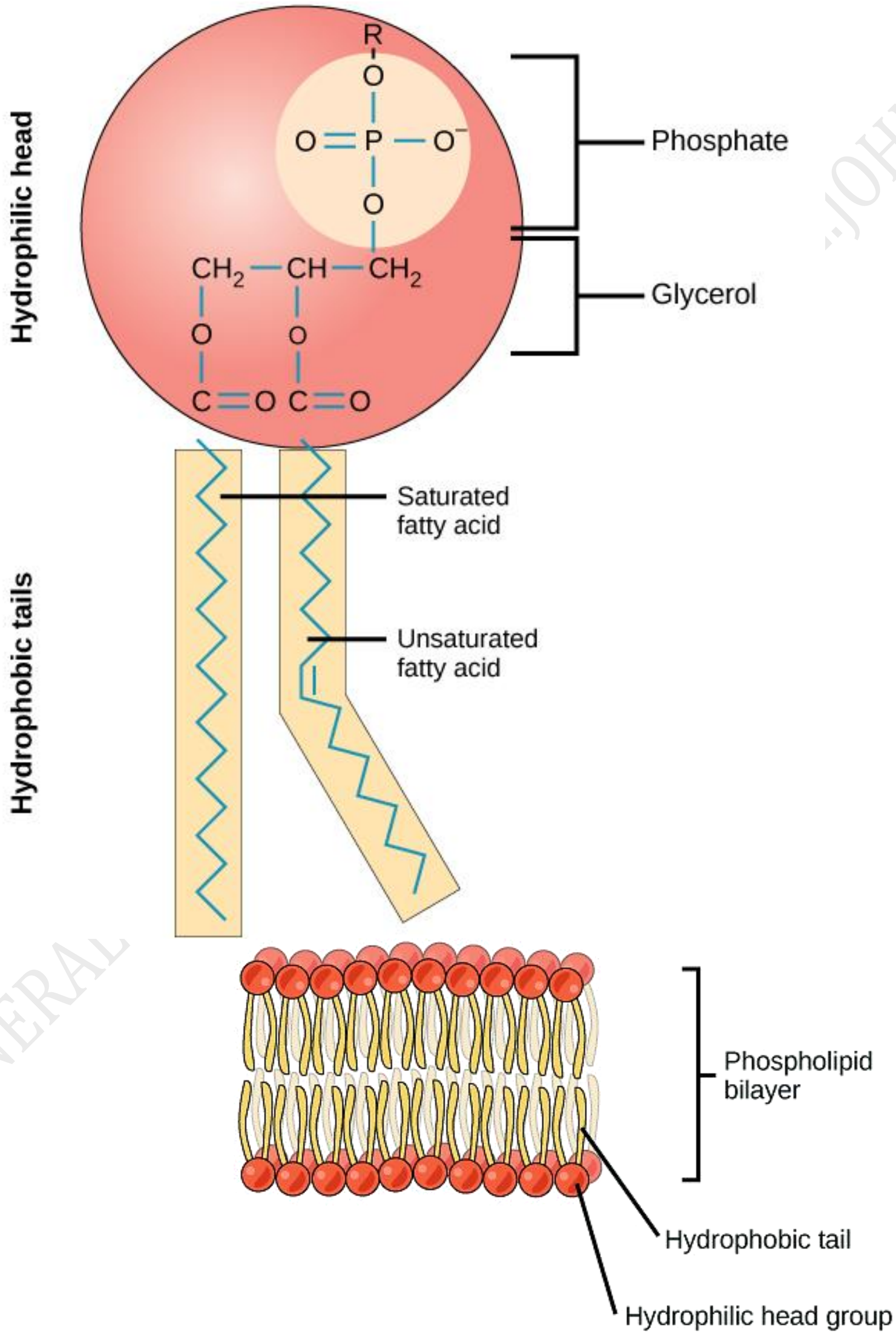
Phospholipids

Phospholipids are major constituents of the plasma membrane, the outermost layer of animal cells. Like fats, they are composed of fatty acid chains attached to a glycerol or sphingosine backbone. Instead of three fatty acids attached as in triglycerides, however, there are two fatty acids forming diacylglycerol, and the third carbon of the glycerol backbone is occupied by a modified phosphate group (Figure 3.3.83.3.8). A phosphate group alone attached to a diaglycerol does not qualify as a phospholipid; it is phosphatidate (diacylglycerol 3-phosphate), the precursor of phospholipids. The phosphate group is modified by an alcohol. Phosphatidylcholine and phosphatidylserine are two important phospholipids that are found in plasma membranes.

Figure 3.3.83.3.8: A phospholipid is a molecule with two fatty acids and a modified phosphate group attached to a glycerol backbone. The phosphate may be modified by the addition of charged or polar chemical groups. Two chemical groups that may modify the phosphate,

choline and serine, are shown here. Both choline and serine attach to the phosphate group at the position labelled R via the hydroxyl group indicated in green.

A phospholipid is an amphipathic molecule, meaning it has a hydrophobic and a hydrophilic part. The fatty acid chains are hydrophobic and cannot interact with water, whereas the phosphate-containing group is hydrophilic and interacts with water

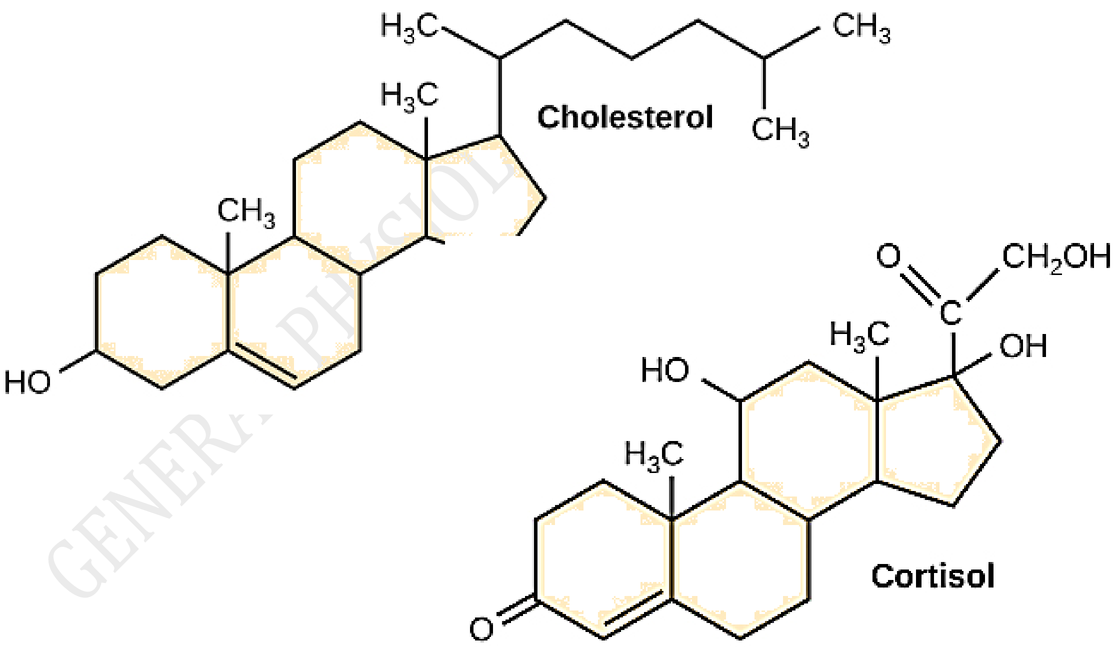


The Phospholipid Bilayer is the major component of all cellular membranes. The hydrophilic head groups of the phospholipids face the aqueous solution. The hydrophobic tails are sequestered in the middle of the bilayer.

The head is the hydrophilic part, and the tail contains the hydrophobic fatty acids. In a membrane, **a bilayer of phospholipids** forms the matrix of the structure, the fatty acid tails of phospholipids face inside, away from water, whereas the phosphate group faces the outside, aqueous side. Phospholipids are responsible for the dynamic nature of the plasma membrane. If a drop of phospholipids is placed in water, it spontaneously forms a structure known as a micelle, where the hydrophilic phosphate heads face the outside and the fatty acids face the interior of this structure.

Steroids

Unlike the phospholipids and fats discussed earlier, steroids have a fused ring structure. Although they do not resemble the other lipids, they are grouped with them because they are also hydrophobic and insoluble in water. All steroids have four linked carbon rings and several of them, like cholesterol, have a short tail. Many steroids also have the –OH functional group, which puts them in the alcohol classification (sterols).



Steroids such as cholesterol and cortisol are composed of four fused hydrocarbon rings.

Cholesterol is the most common steroid. Cholesterol is mainly synthesized in the liver and is the precursor to many steroid hormones such as testosterone and estradiol, which are secreted by the gonads and endocrine glands. It is also the precursor to Vitamin D. Cholesterol is also the precursor of bile salts, which help in the emulsification of fats and their subsequent absorption by cells. Although cholesterol is often spoken of in negative terms by lay people, it is necessary for proper functioning of the body. It is a component of the plasma membrane of animal cells and is found within the phospholipid bilayer. Being the outermost structure in animal cells, the plasma membrane is responsible for the transport of materials and cellular recognition and it is involved in cell-to-cell communication.