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:

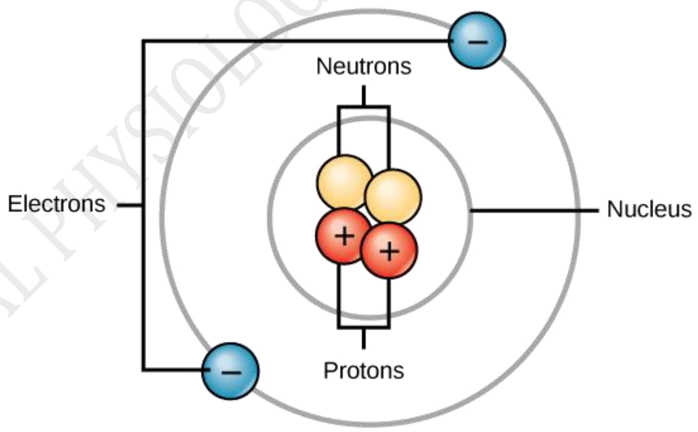
- **Homogeneous** (uniform composition throughout): Examples include air, saltwater.
- **Heterogeneous** (non-uniform composition): Examples include salad, sand in water.

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

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

4. Ions

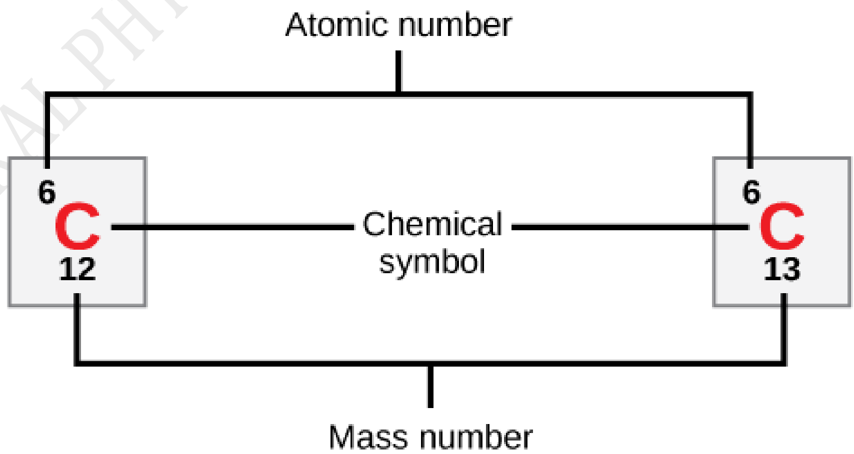
Ions are atoms or molecules that have gained or lost one or more electrons, resulting in a net electrical charge. Ions are formed when an atom does not have an equal number of protons and electrons.

- **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.

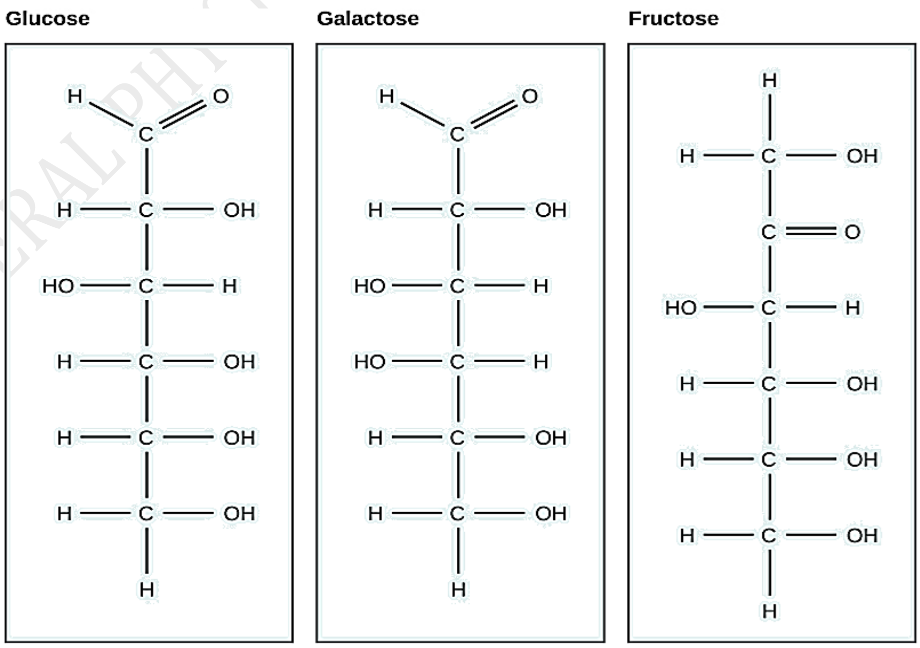
Galactose (part of lactose, or milk sugar) and fructose (found in fruit) are other common monosaccharides. Although glucose, galactose, and fructose all have the same chemical formula ($C_6H_{12}O_6$), they differ structurally and chemically (and are known as isomers) because of differing arrangements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

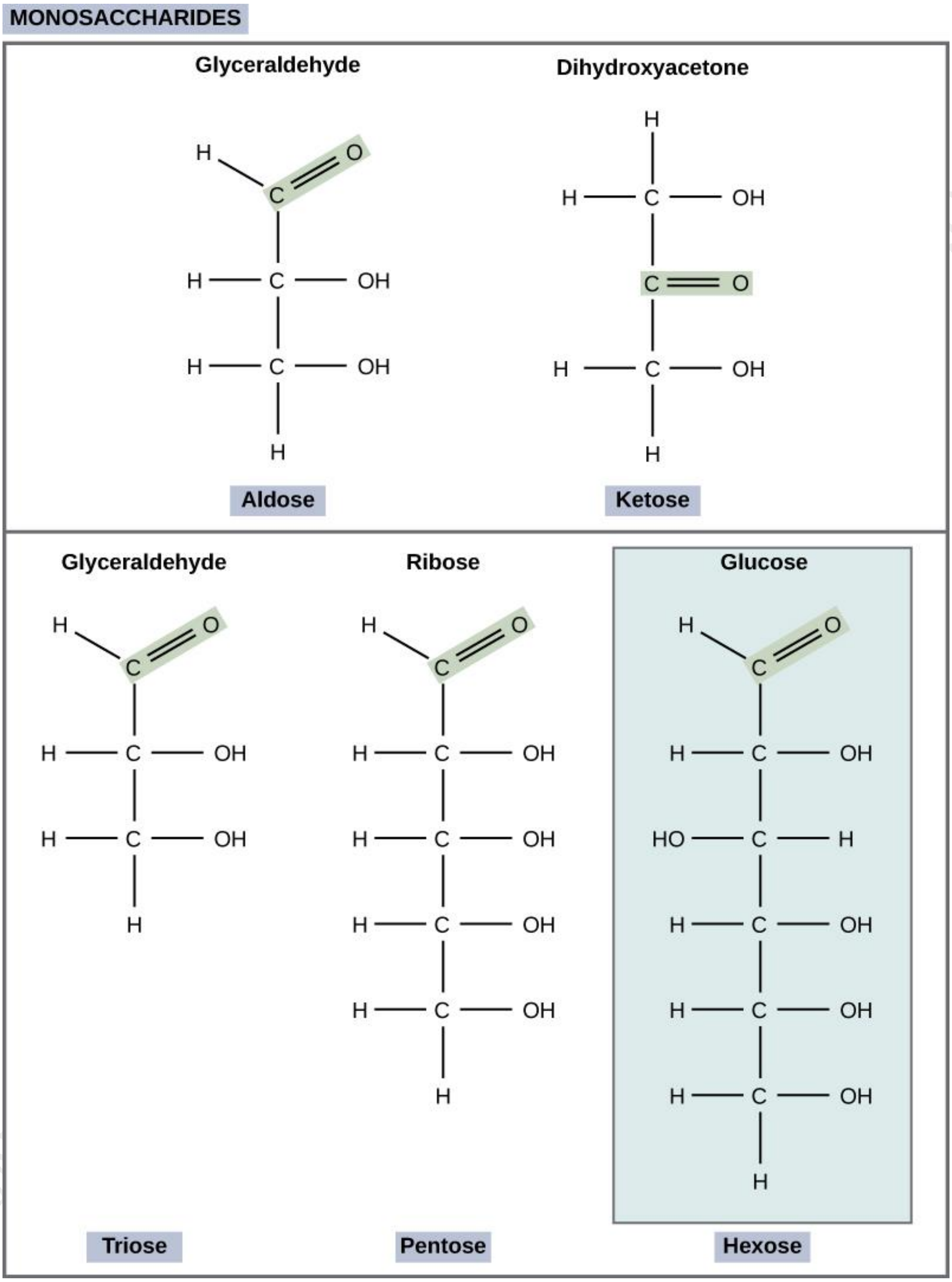
Function:

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.

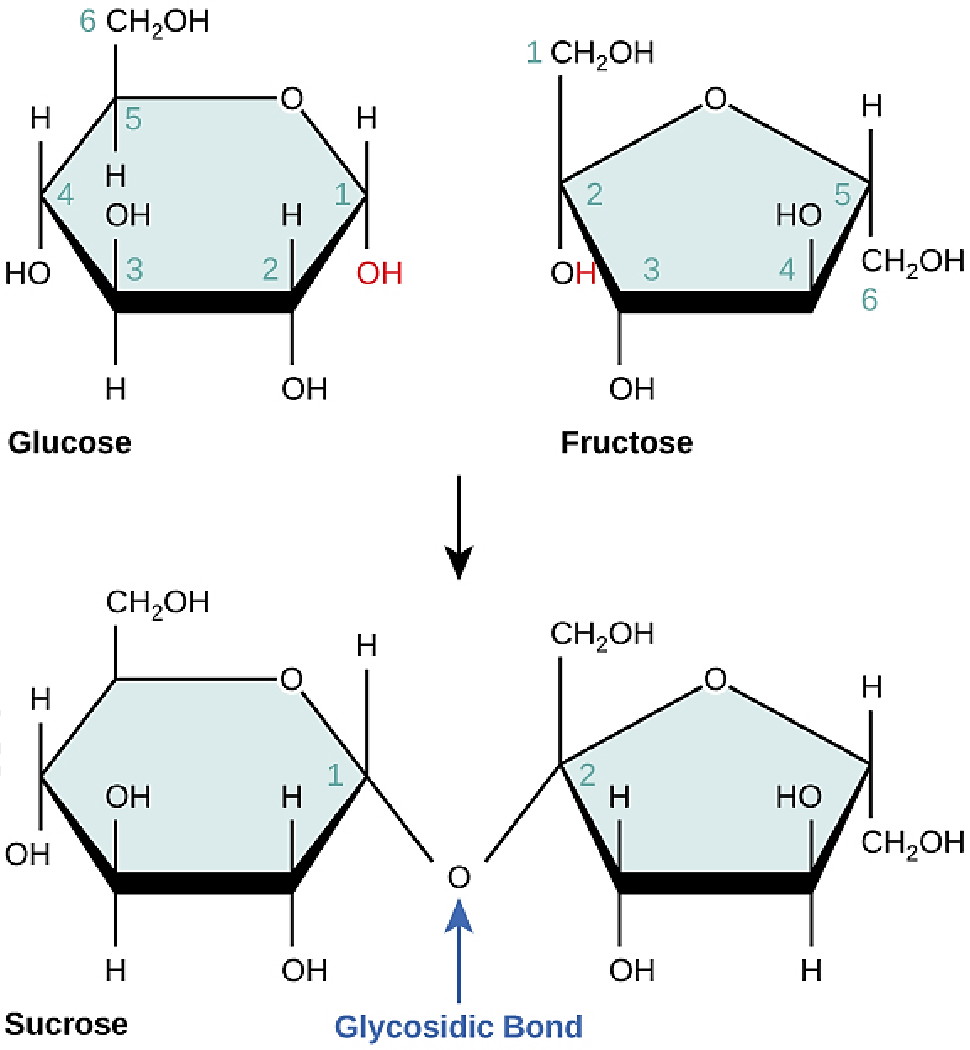
Examples:

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

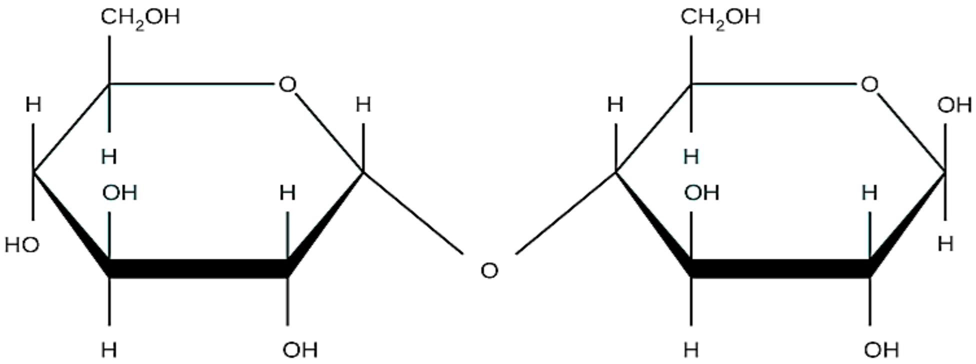
Lactose (glucose + galactose): Found in milk, providing energy to infants.

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

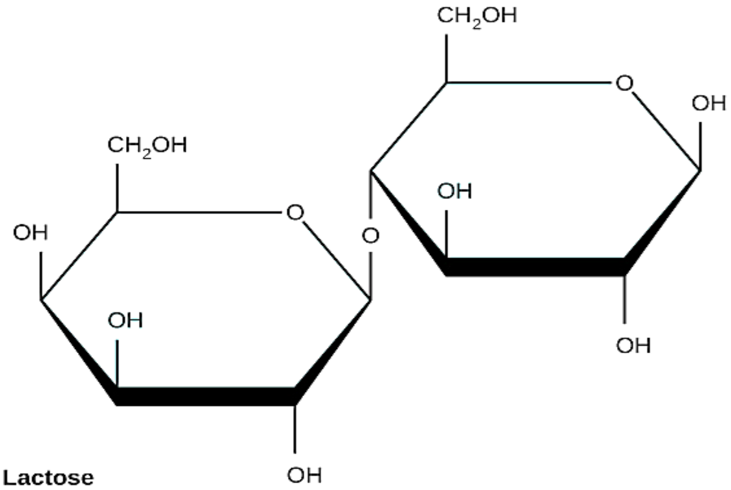
Function: Disaccharides serve as energy sources and are often broken down into monosaccharides before absorption in the body.



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.

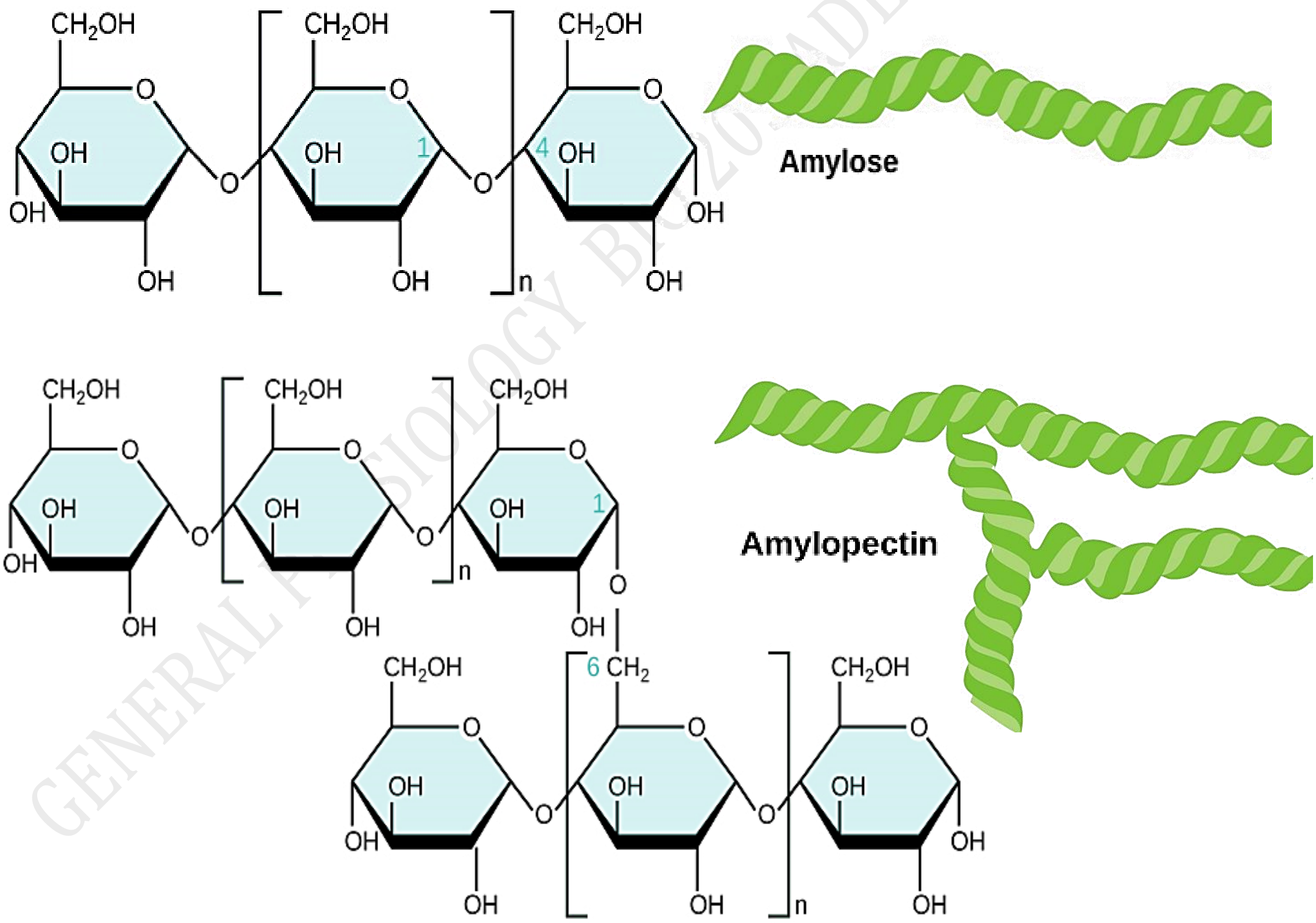
Function:

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.

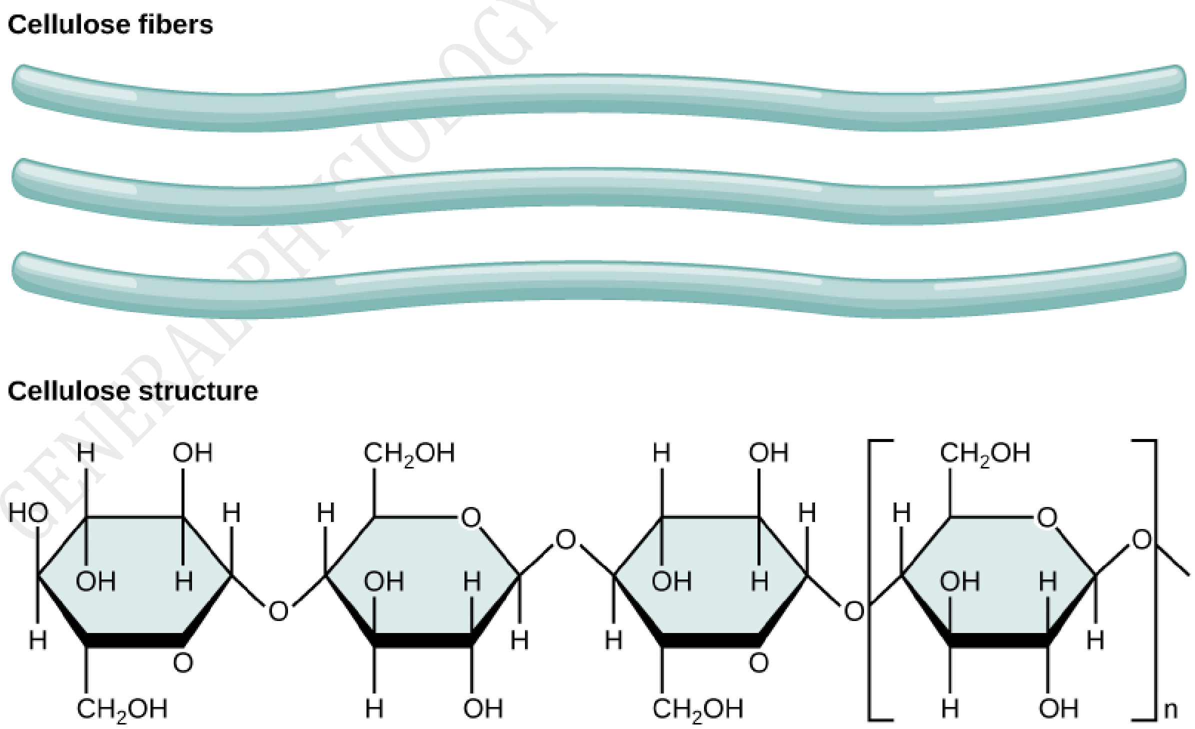
Starch is the stored form of sugars in plants and is made up of amylose and amylopectin (both polymers of glucose). Plants are able to synthesize glucose, and the excess glucose is stored as starch in different plant parts, including roots and seeds. The starch that is consumed by animals is broken down 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.



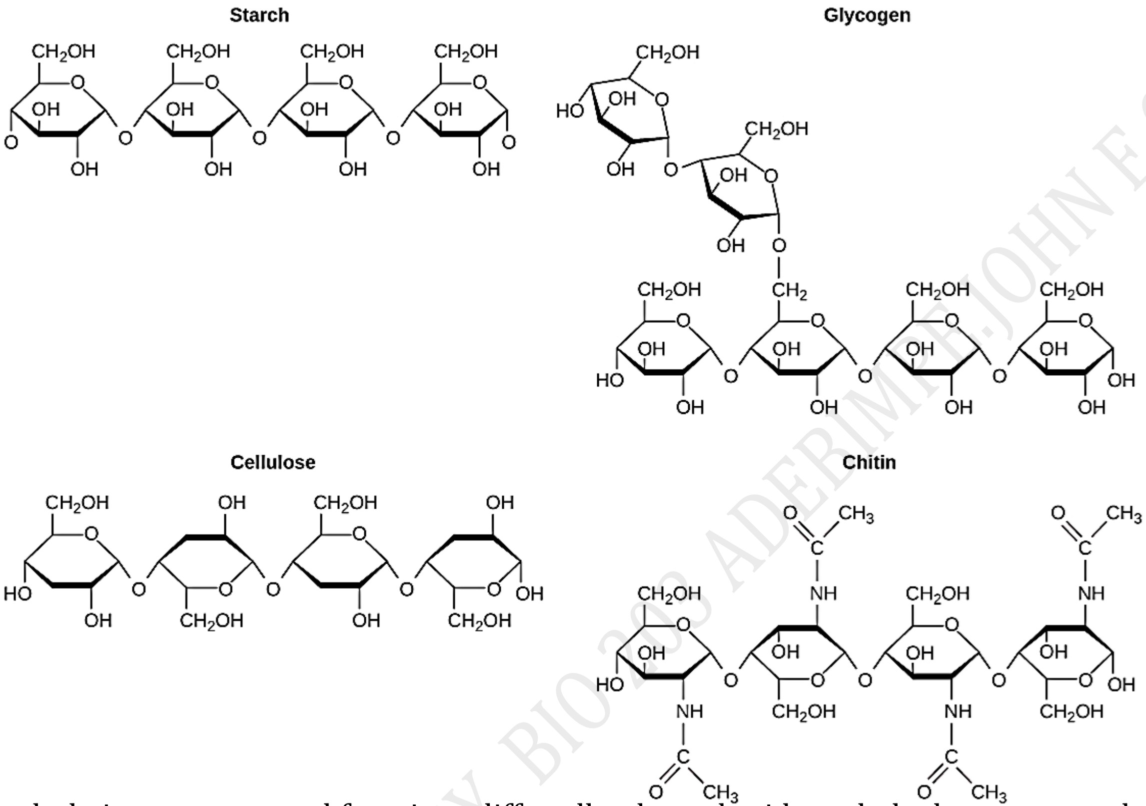
Glycogen Glycogen is the storage form of glucose in humans and other vertebrates and is made up of monomers of glucose. Glycogen is the animal equivalent of starch and is a highly branched molecule usually stored in liver and muscle cells. Whenever blood glucose levels decrease, glycogen is broken down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

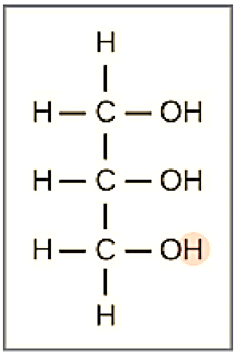
Lipids include a diverse group of compounds that are united by a common feature. **Lipids** are hydrophobic (“water-fearing”), or insoluble in water, because they are nonpolar molecules. This is because they are hydrocarbons that include only nonpolar carbon-carbon or carbon-hydrogen bonds. Lipids perform 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

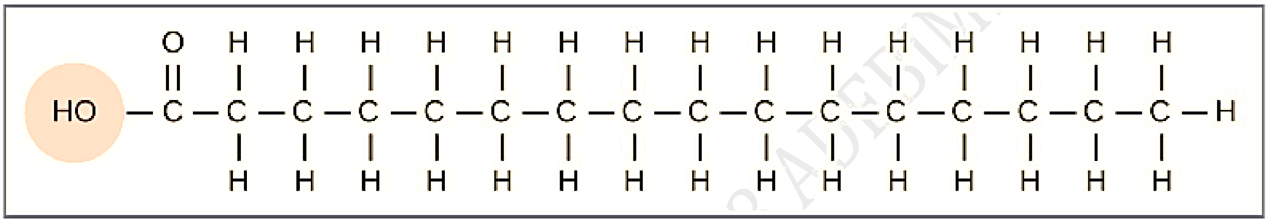
A fat molecule consists of two main components—glycerol and fatty acids. Glycerol is an organic compound (alcohol) with three carbons, five hydrogens, and three hydroxyl (OH) groups. Fatty acids have a long chain of hydrocarbons to which a carboxyl group is attached, hence the name “fatty acid.” The 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

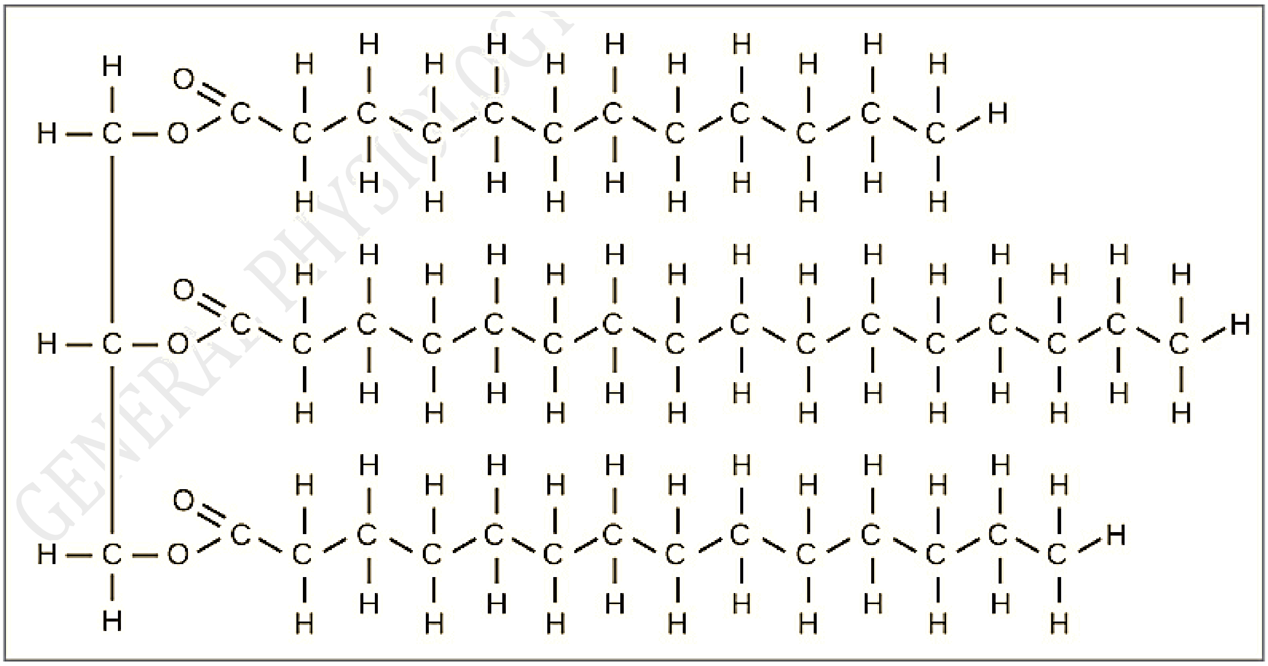


+

Fatty Acid

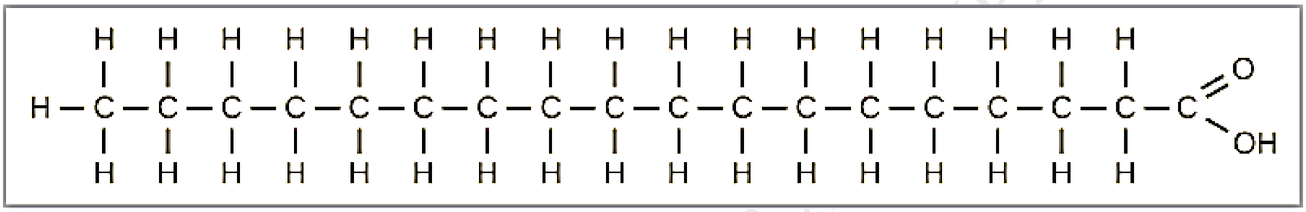


Triacylglycerol



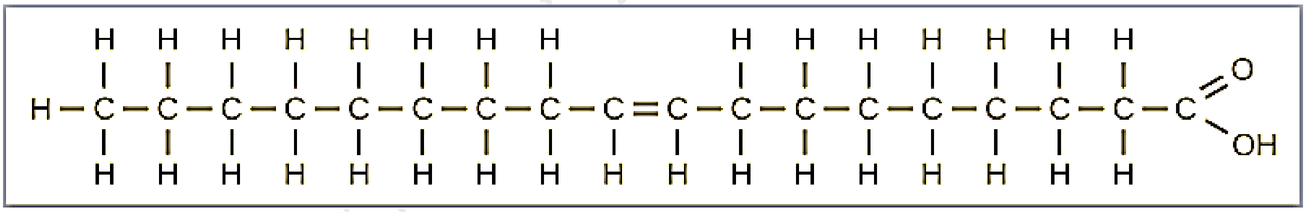
Triacylglycerol is formed by the joining of three fatty acids to a glycerol backbone in a dehydration reaction.

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



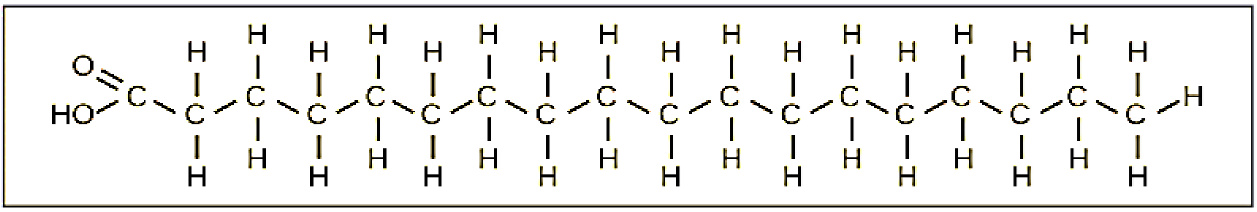
Oleic acid is a common unsaturated fatty acid.

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.

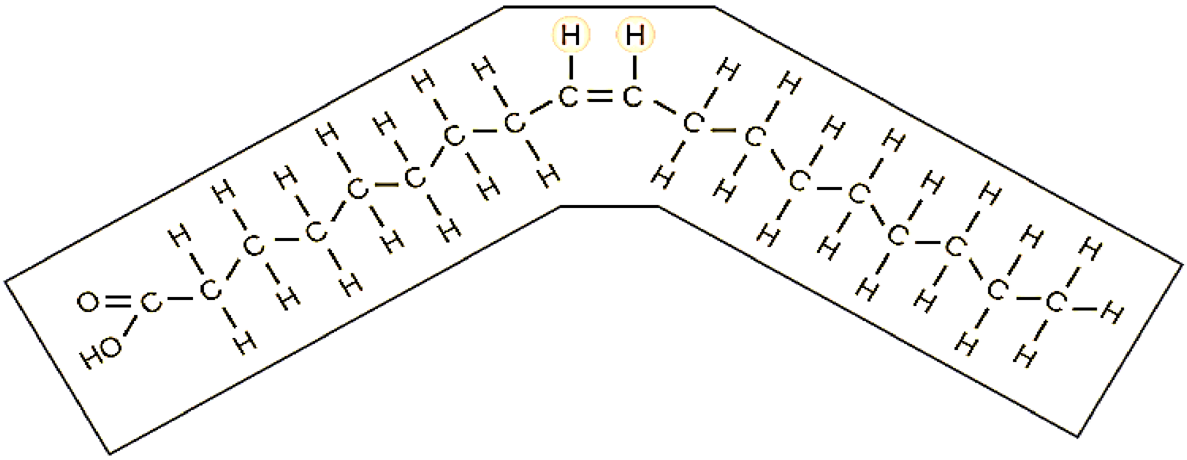
Saturated fatty acid

Stearic acid

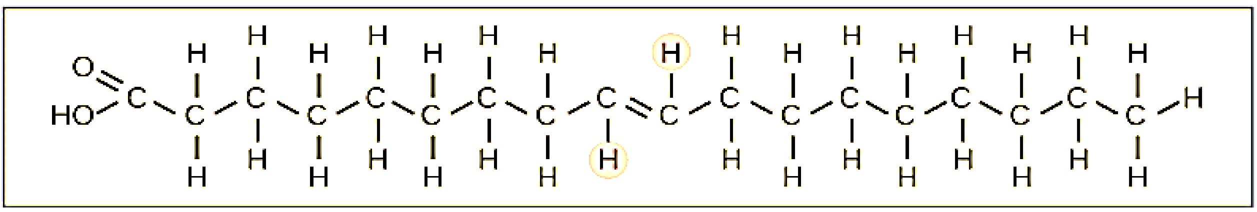


Unsaturated fatty acids

Cis oleic acid



Trans oleic acid



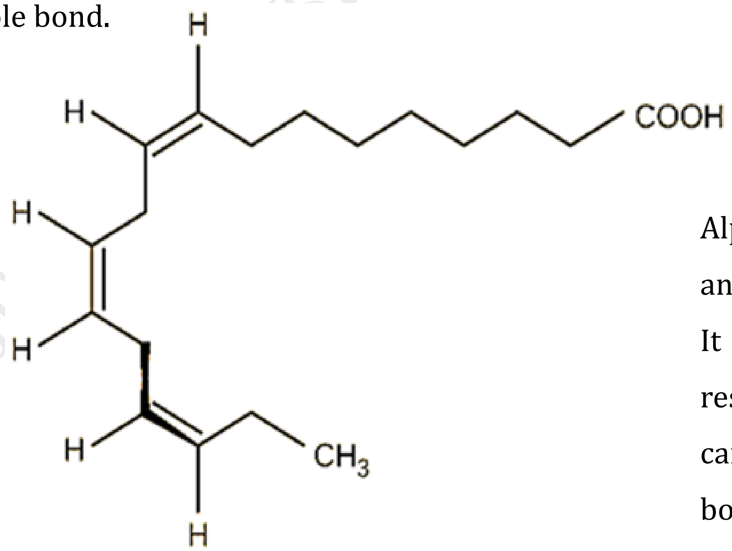
Saturated fatty acids have hydrocarbon chains connected by single bonds only. Unsaturated fatty acids have one or more double bonds. Each double bond may be in a *cis* or *trans* configuration. In the *cis* configuration, both hydrogens are on the same side of the hydrocarbon chain. In the *trans* configuration,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

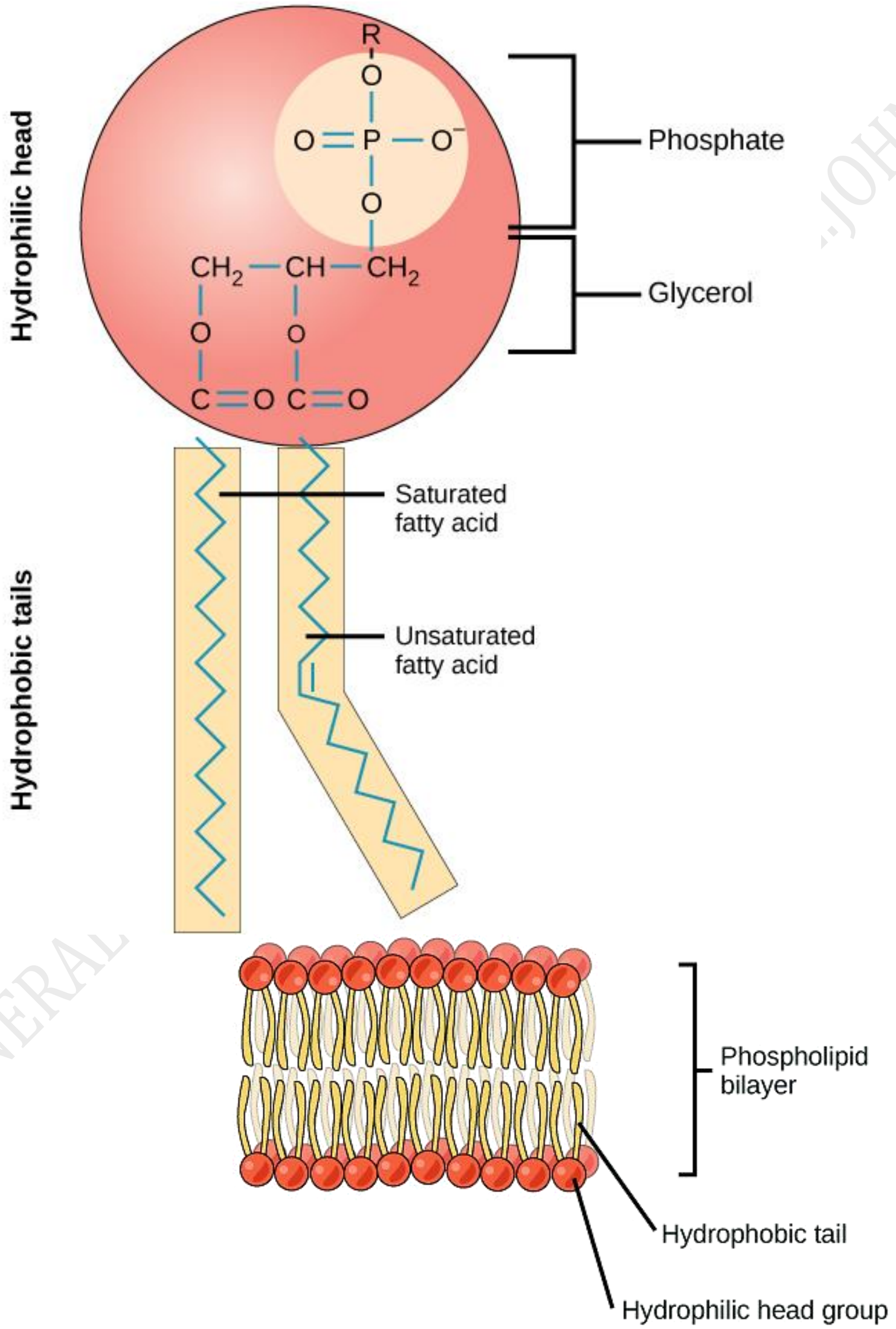
Phospholipids

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

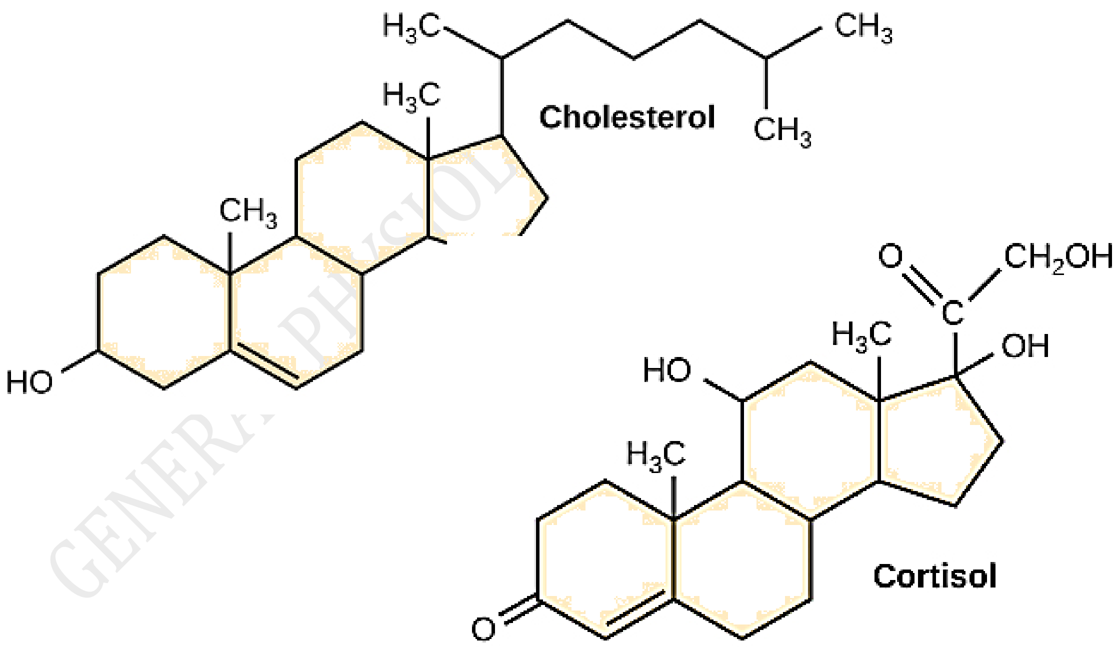


The Phospholipid Bilayer is the major component of all cellular membranes. The hydrophilic head groups of the phospholipids face the aqueous solution. The hydrophobic tails are sequestered in the middle of the bilayer.

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.

MODULE 4 PROTEINS – STRUCTURE AND FUNCTION

Proteins are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. Proteins may be structural, regulatory, contractile, or protective; they may serve in transport, storage, or membranes; or they may be toxins or enzymes. Each cell in a living system may contain thousands of different proteins, each with a unique function. Their structures, like their functions, vary greatly. They are all, however, polymers of amino acids, arranged in a linear sequence.

Types and Functions of Proteins

Protein Types and Functions

Type	Examples	Functions
Digestive Enzymes	Amylase, lipase, pepsin, trypsin	Help in digestion of food by catabolizing nutrients into monomeric units
Transport	Haemoglobin, albumin	Carry substances in the blood or lymph throughout the body
Structural	Actin, tubulin, keratin	Construct different structures, like the cytoskeleton
Hormones	Insulin, thyroxine	Coordinate the activity of different body systems
Defense	Immunoglobulins	Protect the body from foreign pathogens
Contractile	Actin, myosin	Effect muscle contraction
Storage	Legume storage proteins, egg white (albumin)	Provide nourishment in early development of the embryo and the seedling

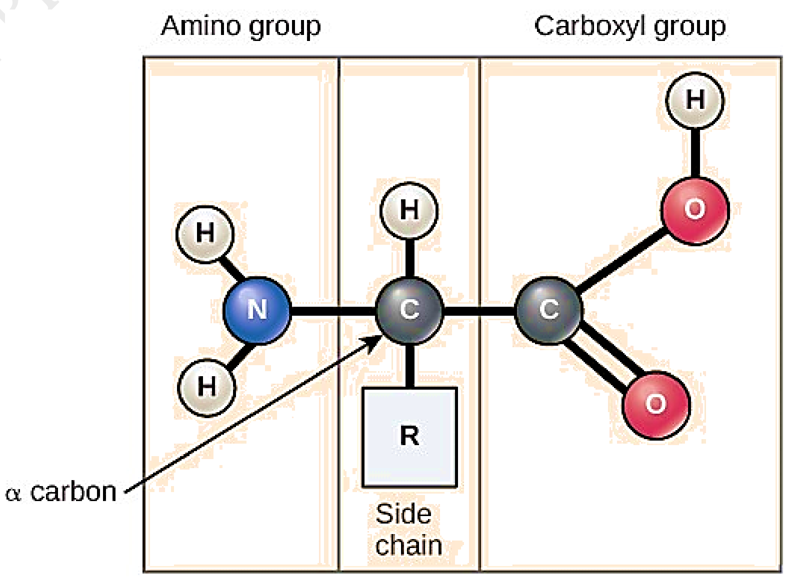
Proteins have different shapes and molecular weights; some proteins are globular in shape whereas others are fibrous in nature. For example, haemoglobin is a globular protein, but collagen, found in our skin, is a fibrous protein. Protein shape is critical to its function, and this shape is maintained by many different types of chemical bonds. Changes in temperature, pH, and exposure to chemicals may lead to permanent changes in the shape of the protein, leading to loss of function, known as denaturation. All proteins are made up of different arrangements of the same 20 types of amino acids. The functions of proteins are very diverse because there are 20 different chemically distinct amino acids that form long chains, and the amino acids can be in any order. For example, proteins can function as enzymes or hormones.

Enzymes, which are produced by living cells, are catalysts in biochemical reactions (like digestion) and are usually proteins. Each enzyme is specific for the substrate (a reactant that binds to an enzyme) upon which it acts. Enzymes can function to break molecular bonds, to rearrange bonds, or to form new bonds. An example of an enzyme is salivary amylase, which breaks down amylose, a component of starch.

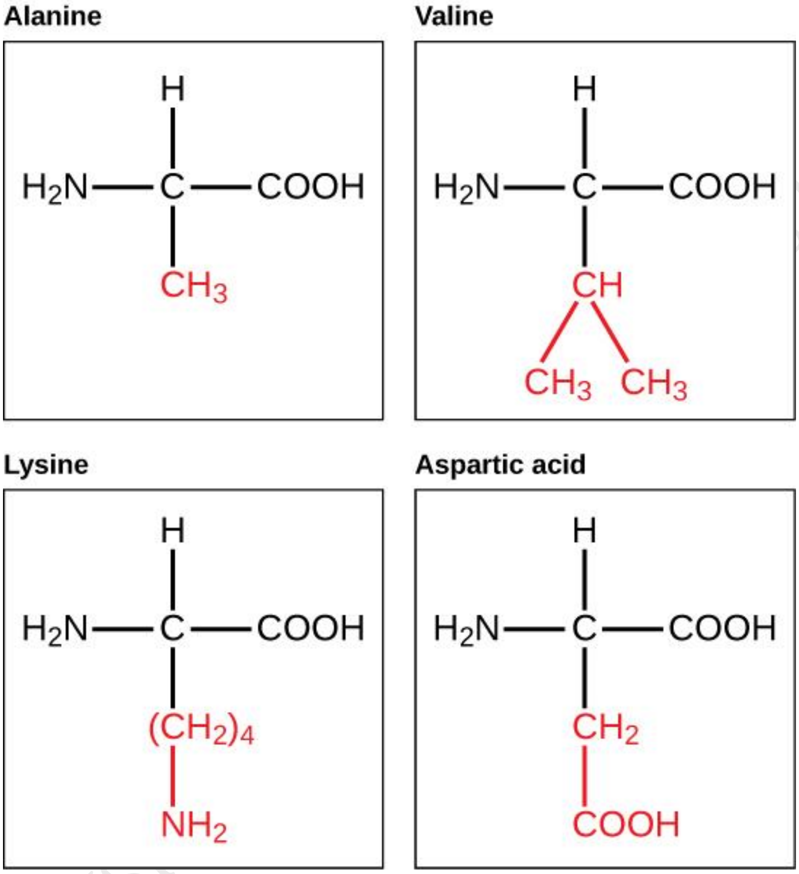
Hormones are chemical signalling molecules, usually proteins or steroids, secreted by an endocrine gland or group of endocrine cells that act to control or regulate specific physiological processes, including growth, development, metabolism, and reproduction. For example, insulin is a protein hormone that maintains blood glucose levels. Proteins have different shapes and molecular weights; some proteins are globular in shape whereas others are fibrous in nature. For example, haemoglobin is a globular protein, but collagen, found in our skin, is a fibrous protein. Protein shape is critical to its function. Changes in temperature, pH, and exposure to chemicals may lead to permanent changes in the shape of the protein, leading to a loss of function or **denaturation** (to be discussed in more detail later). All proteins are made up of different arrangements of the same 20 kinds of amino acids.

AMINO ACIDS

Amino acids are the monomers that make up proteins. Each amino acid has the same fundamental structure, which consists of a central carbon atom, also known as the alpha (α) carbon, bonded to an amino group (NH_2), a carboxyl group (COOH), and to a hydrogen atom. Every amino acid also has another atom or group of atoms bonded to the central atom known as the R group



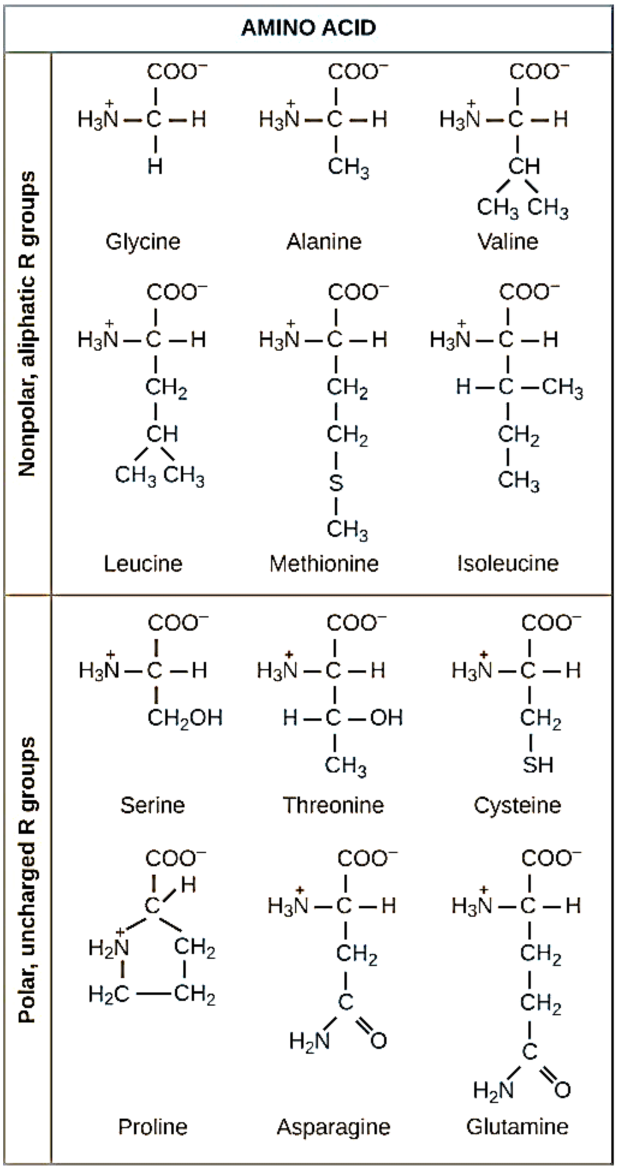
Amino acids have a central asymmetric carbon to which an amino group, a carboxyl group, a hydrogen atom, and a side chain (R group) are attached. The name "amino acid" is derived from the fact that they contain both amino group and carboxyl-acid-group in their basic structure. As mentioned, there are 20 amino acids present in proteins. Ten of these are considered essential amino acids in humans because the human body cannot produce them and they are obtained from the diet. For each amino acid, the R group (or side chain) is different

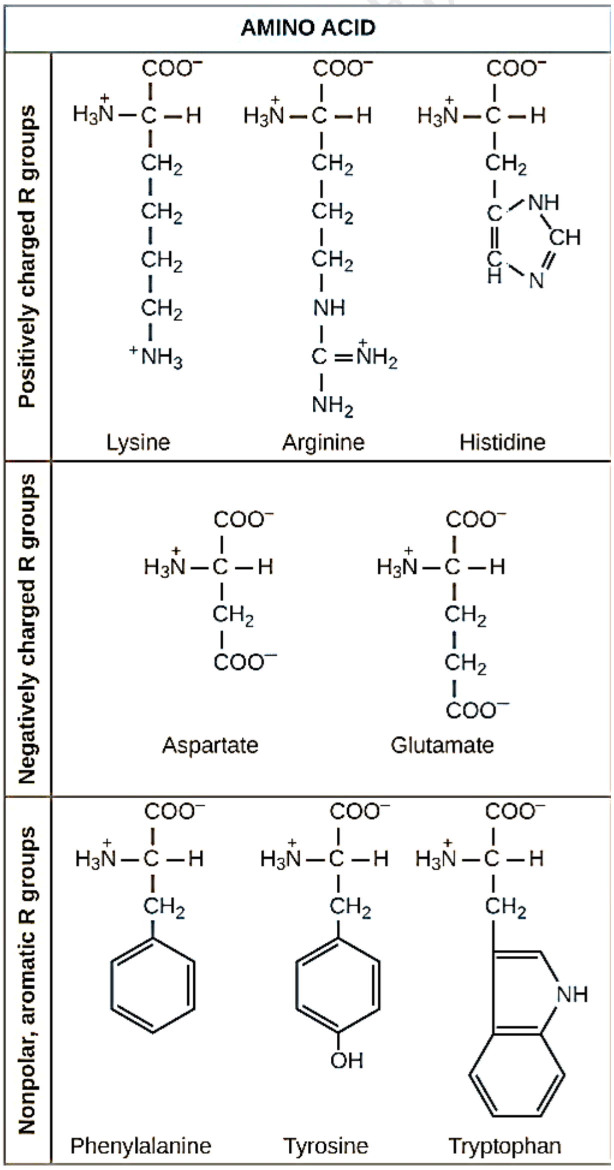


Amino acids are made up of a central carbon bonded to an amino group (–NH_2), a carboxyl group (–COOH), and a hydrogen atom. The central carbon's fourth bond varies among the different amino acids, as seen in these examples of alanine, valine, lysine, and aspartic acid. The chemical nature of the R group determines the chemical nature of the amino acid within its protein (that is, whether it is acidic, basic, polar, or nonpolar).

Essential Amino Acids (must be obtained from the diet)	**Non-Essential Amino Acids (can be synthesized by the body)**
Histidine (His, H)	Alanine (Ala, A)
Isoleucine (Ile, I)	Arginine (Arg, R) (conditionally essential, especially during growth)
Leucine (Leu, L)	Asparagine (Asn, N)

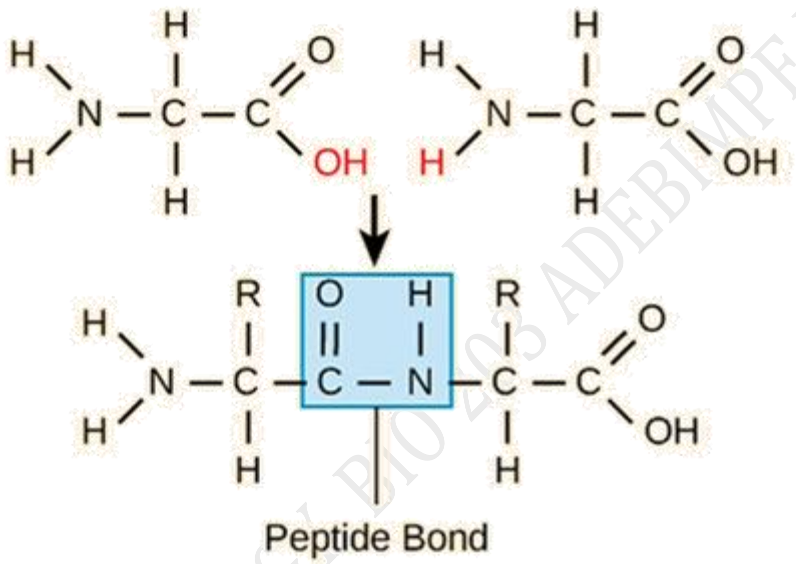
Lysine (Lys, K)	Aspartic acid (Asp, D)
Methionine (Met, M)	Cysteine (Cys, C) (conditionally essential)
Phenylalanine (Phe, F)	Glutamic acid (Glu, E)
Threonine (Thr, T)	Glutamine (Gln, Q) (conditionally essential)
Tryptophan (Trp, W)	Glycine (Gly, G)
Valine (Val, V)	Proline (Pro, P)
	Serine (Ser, S)
	Tyrosine (Tyr, Y) (conditionally essential, derived from phenylalanine)





Each amino acid has a unique side chain that defines its characteristics and roles in proteins.

The sequence and number of amino acids ultimately determine a protein's shape, size, and function. Each amino acid is attached to another amino acid by a covalent bond, known as a peptide bond, which is formed by a dehydration reaction. The carboxyl group of one amino acid and the amino group of a second amino acid combine, releasing a water molecule. The resulting bond is the peptide bond. The products formed by such a linkage are called polypeptides. While the terms polypeptide and protein are sometimes used interchangeably, a **polypeptide** is technically a polymer of amino acids, whereas the term protein is used for a polypeptide or polypeptides that have combined together, have a distinct shape, and have a unique function.



Cytochrome c

Cytochrome c is an important component of the molecular machinery that harvests energy from glucose. Because this protein's role in producing cellular energy is crucial, it has changed very little over millions of years. Protein sequencing has shown that there is a considerable amount of sequence similarity among cytochrome c molecules of different species; evolutionary relationships can be assessed by measuring the similarities or differences among various species' protein sequences.

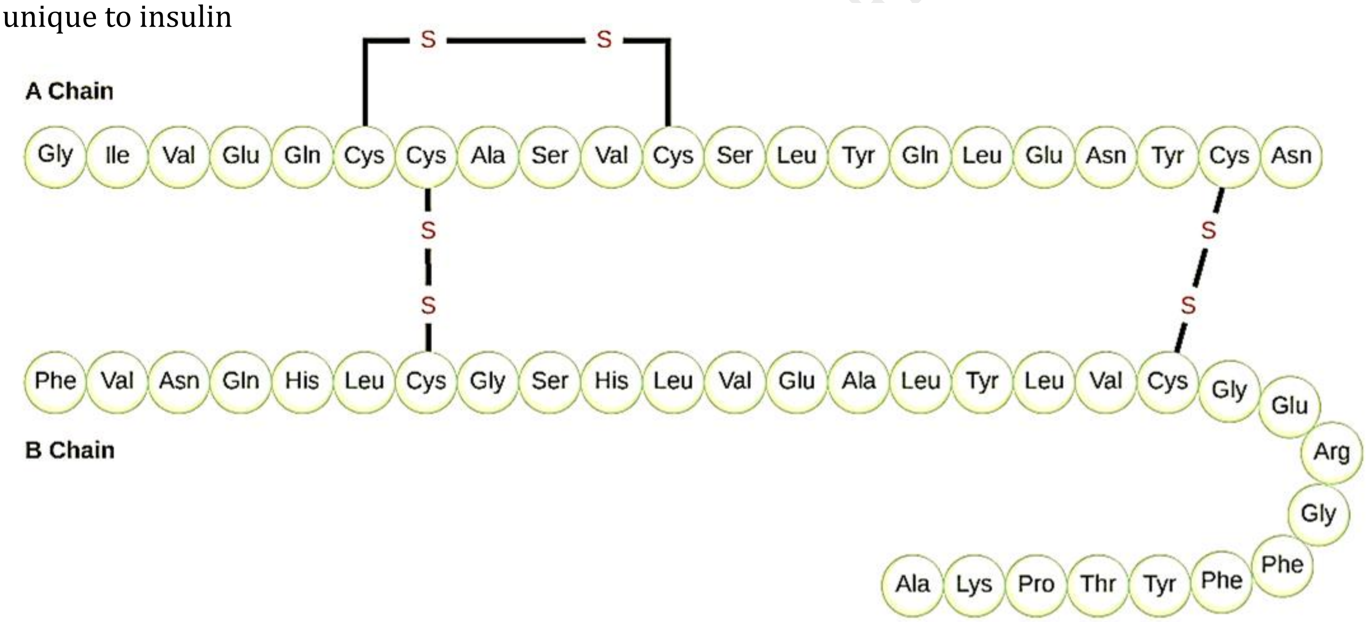
For example, scientists have determined that human **cytochrome c contains 104 amino acids**. For each cytochrome c molecule that has been sequenced to date from different organisms, 37 of these amino acids appear in the same position in each cytochrome c. This indicates that all of these organisms are descended from a common ancestor. On comparing the human and chimpanzee protein sequences, no sequence difference was found. When human and rhesus monkey sequences were compared, a single difference was found in one amino acid. In contrast, human-to-yeast comparisons show a difference in 44 amino acids, suggesting that humans and chimpanzees have a more recent common ancestor than humans and the rhesus monkey, or humans and yeast.

Protein Structure

As discussed earlier, the shape of a protein is critical to its function. To understand how the protein gets its final shape or conformation, we need to understand the four levels of protein structure: **Primary, Secondary, Tertiary, and Quaternary.**

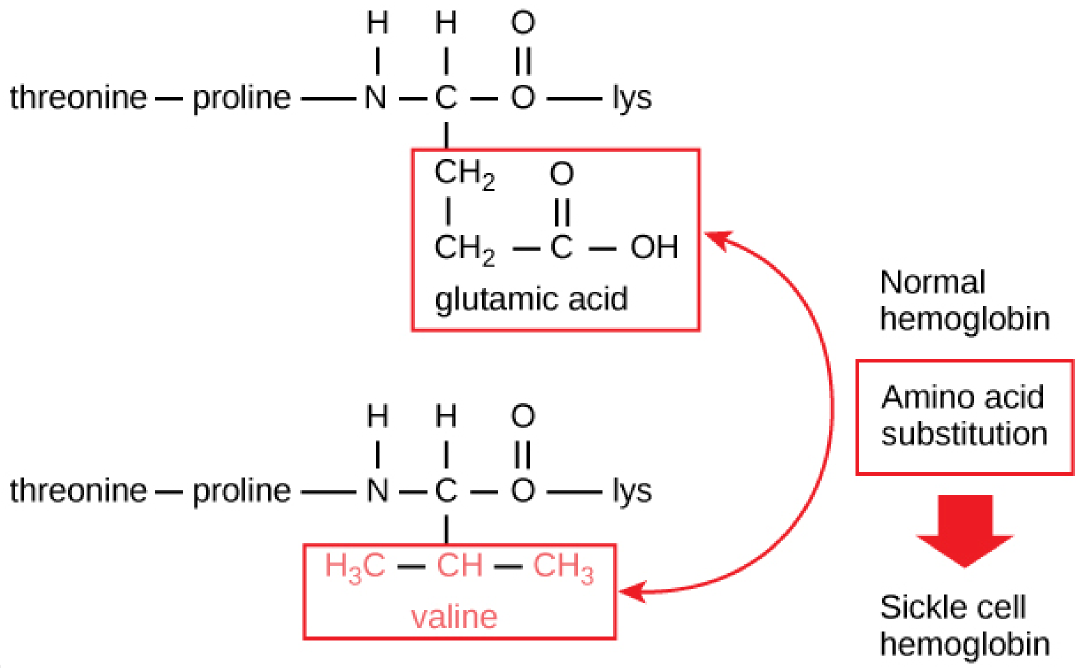
Primary Structure

The unique sequence of amino acids in a polypeptide chain is its primary structure. For example, the pancreatic hormone insulin has two polypeptide chains, A and B, and they are linked together by disulfide bonds. The N terminal amino acid of the A chain is glycine, whereas the C terminal amino acid is asparagine. The sequences of amino acids in the A and B chains are unique to insulin



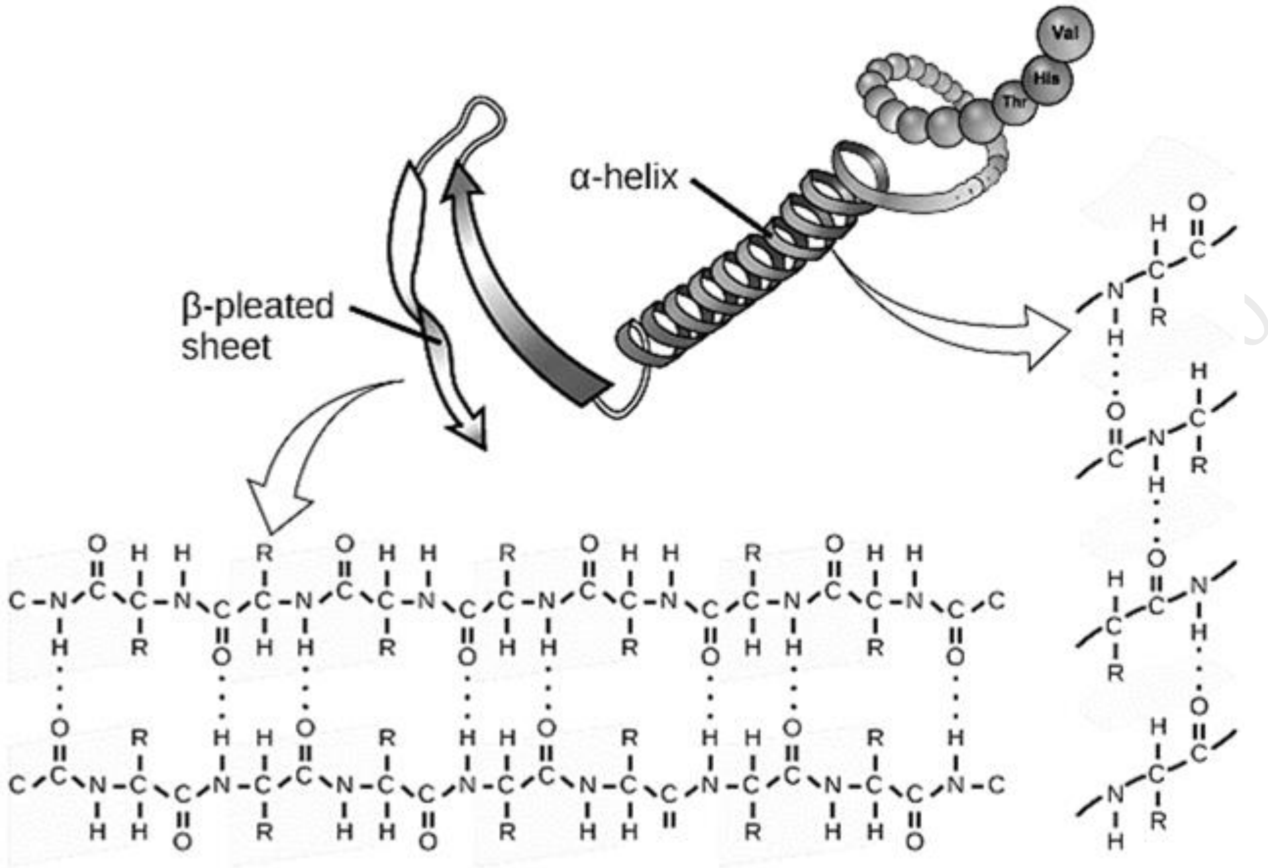
Bovine serum insulin is a protein hormone made of two peptide chains, A (21 amino acids long) and B (30 amino acids long). In each chain, primary structure is indicated by three-letter abbreviations that represent the names of the amino acids in the order they are present. The amino acid cysteine (cys) has a sulfhydryl (SH) group as a side chain. Two sulfhydryl groups can react in the presence of oxygen to form a disulfide (S-S) bond. Two disulfide bonds connect the A and B chains together, and a third helps the A chain fold into the correct shape. Note that all disulfide bonds are the same length, but are drawn different sizes for clarity.

The unique sequence and number of amino acids in a polypeptide chain is its primary structure. The unique sequence for every protein is ultimately determined by the gene that encodes the protein. Any change in the gene sequence may lead to a different amino acid being added to the polypeptide chain, causing a change in protein structure and function. **William Warrick Cardozo** showed that sickle-cell anaemia is caused by a change in protein structure as a result of gene encoding, meaning that it is an inherited disorder. In sickle cell anaemia, the haemoglobin β chain has a single amino acid substitution, causing a change in both the structure and function of the protein. What is most remarkable to consider is that a haemoglobin molecule is made up of two alpha chains and two beta chains that each consist of about 150 amino acids. The molecule, therefore, has about 600 amino acids. The structural difference between a normal hemoglobin molecule and a sickle cell molecule—that dramatically decreases life expectancy in the affected individuals—is a single amino acid of the 600.



Secondary Structure

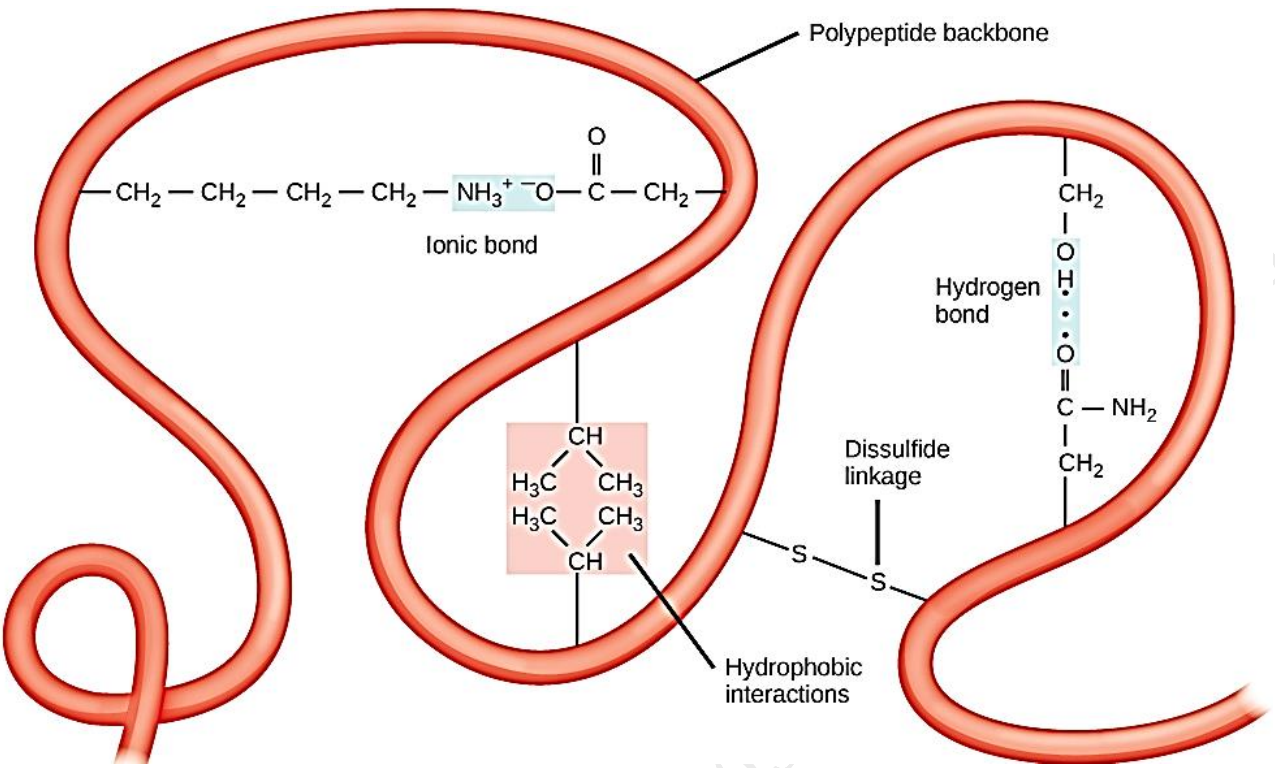
The local folding of the polypeptide in some regions gives rise to the secondary structure of the protein. The most common are the α-helix and β-pleated sheet structures (Figure 3.4.7). Both structures are the α-helix structure—the helix held in shape by hydrogen bonds. The hydrogen bonds form between the oxygen atom in the carbonyl group in one amino acid and another amino acid that is four amino acids farther along the chain.



The α-helix and β-pleated sheet are secondary structures of proteins that form because of hydrogen bonding between carbonyl and amino groups in the peptide backbone. Certain amino acids have a propensity to form an α-helix, while others have a propensity to form a β-pleated sheet.

Tertiary Structure

The unique three-dimensional structure of a polypeptide is its tertiary structure (Figure 3.4.8). This structure is in part due to chemical interactions at work on the polypeptide chain. Primarily, the interactions among R groups creates the complex three-dimensional tertiary structure of a protein. The nature of the R groups found in the amino acids involved can counteract the formation of the hydrogen bonds described for standard secondary structures. For example, R groups with like charges are repelled by each other and those with unlike charges are attracted to each other (ionic bonds). When protein folding takes place, the hydrophobic R groups of nonpolar amino acids lay in the interior of the protein, whereas the hydrophilic R groups lay on the outside. The former types of interactions are also known as hydrophobic interactions. Interaction between cysteine side chains forms disulfide linkages in the presence of oxygen, the only covalent bond forming during protein folding.



The tertiary structure of proteins is determined by a variety of chemical interactions. These include hydrophobic interactions, ionic bonding, hydrogen bonding and disulfide linkages.

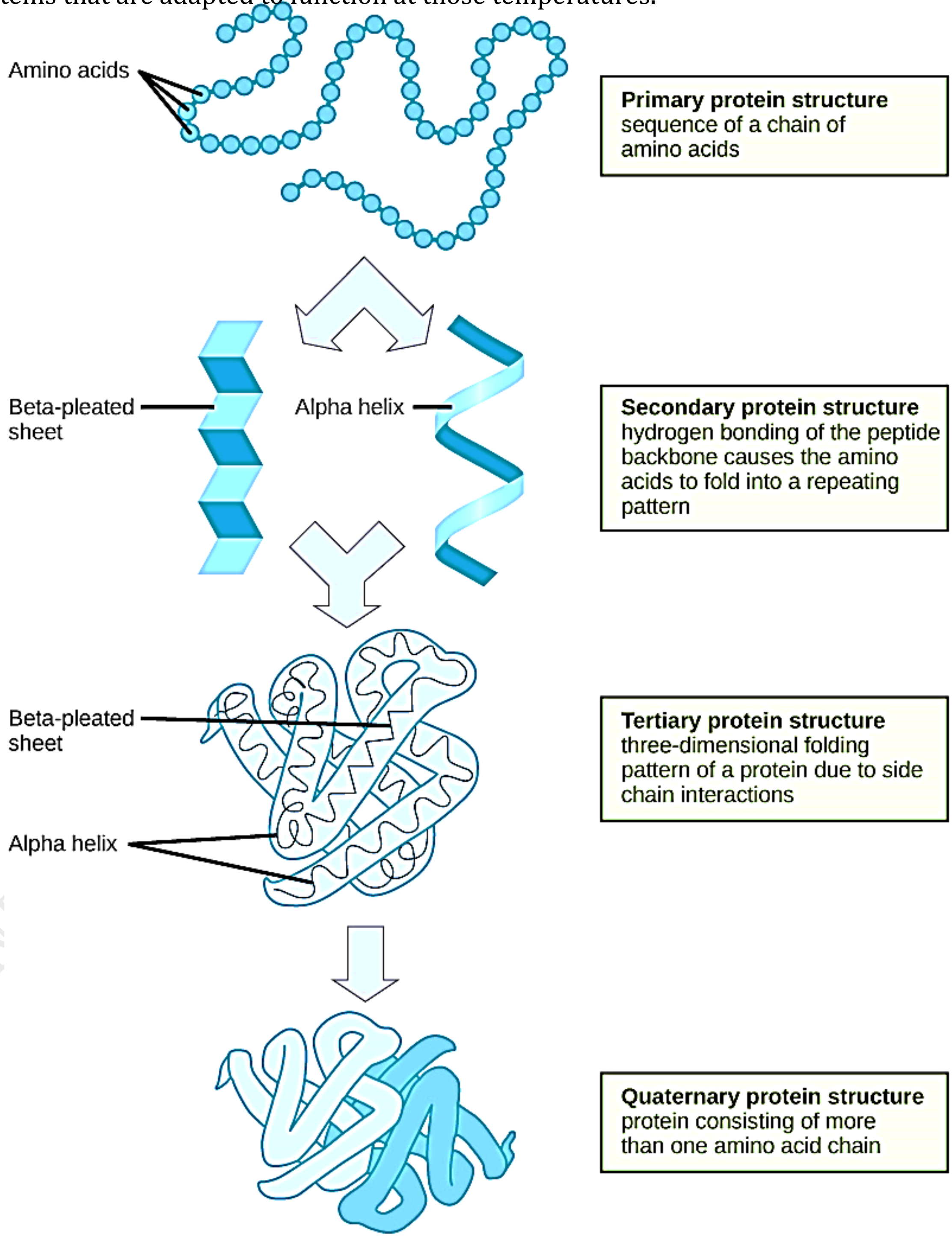
All of these interactions, weak and strong, determine the final three-dimensional shape of the protein. When a protein loses its three-dimensional shape, it may no longer be functional

Quaternary Structure

In nature, some proteins are formed from several polypeptides, also known as subunits, and the interaction of these subunits forms the quaternary structure. Weak interactions between the subunits help to stabilize the overall structure. For example, insulin (a globular protein) has a combination of hydrogen bonds and disulfide bonds that cause it to be mostly clumped into a ball shape. Insulin starts out as a single polypeptide and loses some internal sequences in the presence of post-translational modification after the formation of the disulfide linkages that hold the remaining chains together. Silk (a fibrous protein), however, has a β-pleated sheet structure that is the result of hydrogen bonding between different chain.

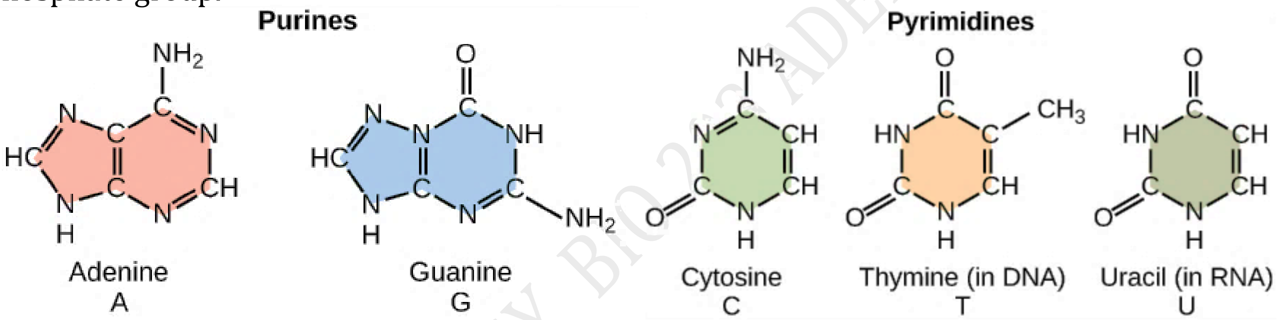
Each protein has its own unique sequence and shape held together by chemical interactions. If the protein is subject to changes in temperature, pH, or exposure to chemicals, the protein structure may change, losing its shape in what is known as denaturation as discussed earlier.

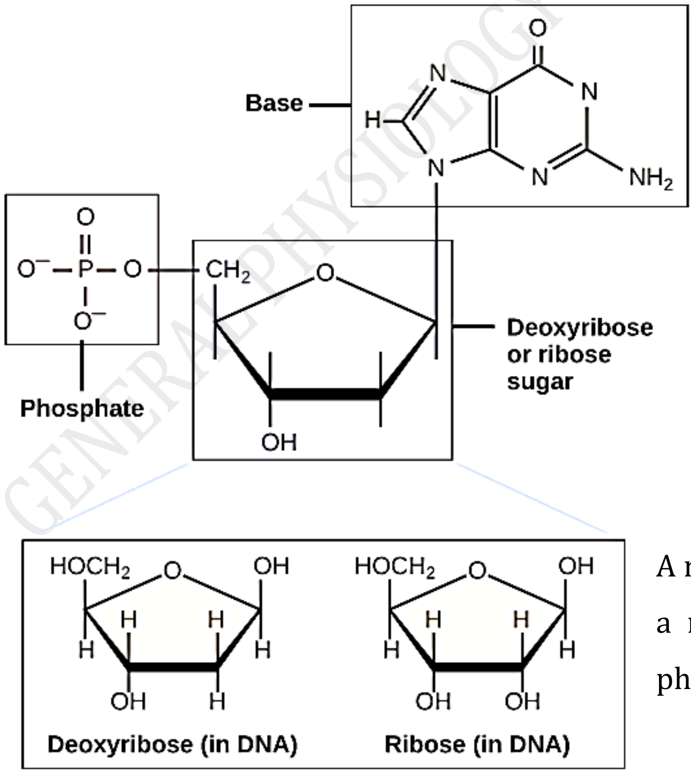
Denaturation is often reversible because the primary structure is preserved if the denaturing agent is removed, allowing the protein to resume its function. Sometimes denaturation is irreversible, leading to a loss of function. One example of protein denaturation can be seen when an egg is fried or boiled. The albumin protein in the liquid egg white is denatured when placed in a hot pan, changing from a clear substance to an opaque white substance. Not all proteins are denatured at high temperatures; for instance, bacteria that survive in hot springs have proteins that are adapted to function at those temperatures.

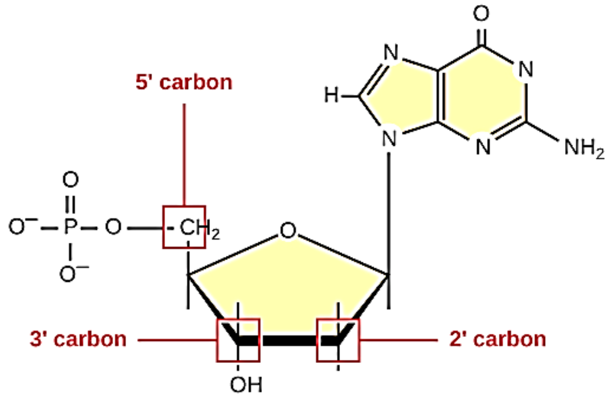


MODULE 5 NUCLEIC ACIDS – DNA AND RNA

Nucleic acids are key macromolecules in the continuity of life. They carry the genetic blueprint of a cell and carry instructions for the functioning of the cell. The two main types of **nucleic acids** are **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. DNA is the genetic material found in all living organisms, ranging from single-celled bacteria to multicellular mammals. The other type of nucleic acid, RNA, is mostly involved in protein synthesis. The DNA molecules never leave the nucleus, but instead use an RNA intermediary to communicate with the rest of the cell. Other types of RNA are also involved in protein synthesis and its regulation. DNA and RNA are made up of monomers known as **nucleotides**. The nucleotides combine with each other to form a polynucleotide, DNA or RNA. Each nucleotide is made up of three components: a nitrogenous base, a pentose (five-carbon) sugar, and a phosphate group (Each nitrogenous base in a nucleotide is attached to a sugar molecule, which is attached to a phosphate group.



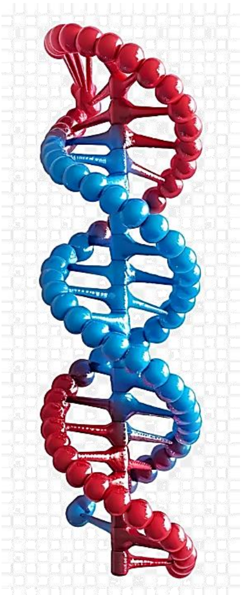


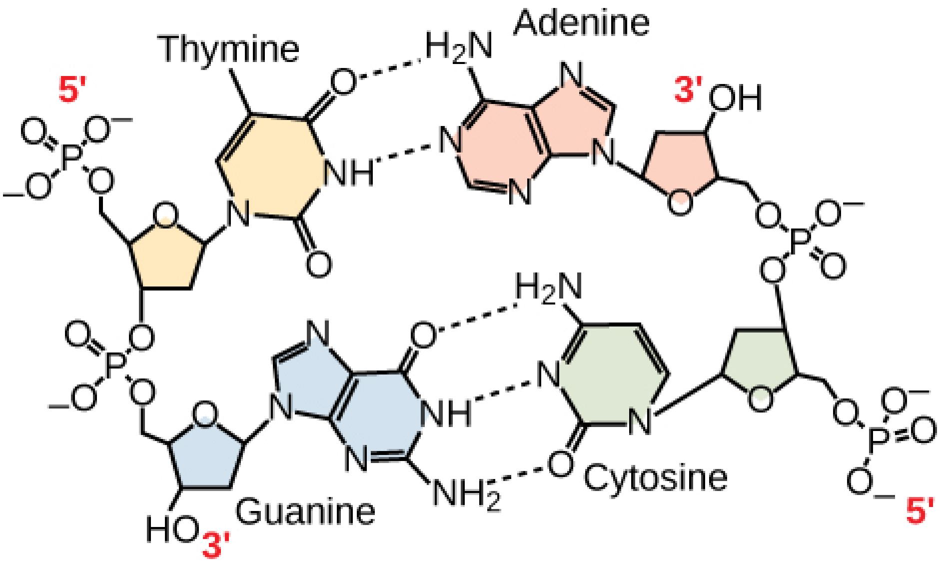


A nucleotide is made up of three components: a nitrogenous base, a pentose sugar, and a phosphate group.

DNA Double-Helical Structure

DNA has a double-helical structure. It is composed of two strands, or polymers, of nucleotides. The strands are formed with bonds between phosphate and sugar groups of adjacent nucleotides. The strands are bonded to each other at their bases with hydrogen bonds, and the strands coil about each other along their length, hence the “double helix” description, which means a double spiral.





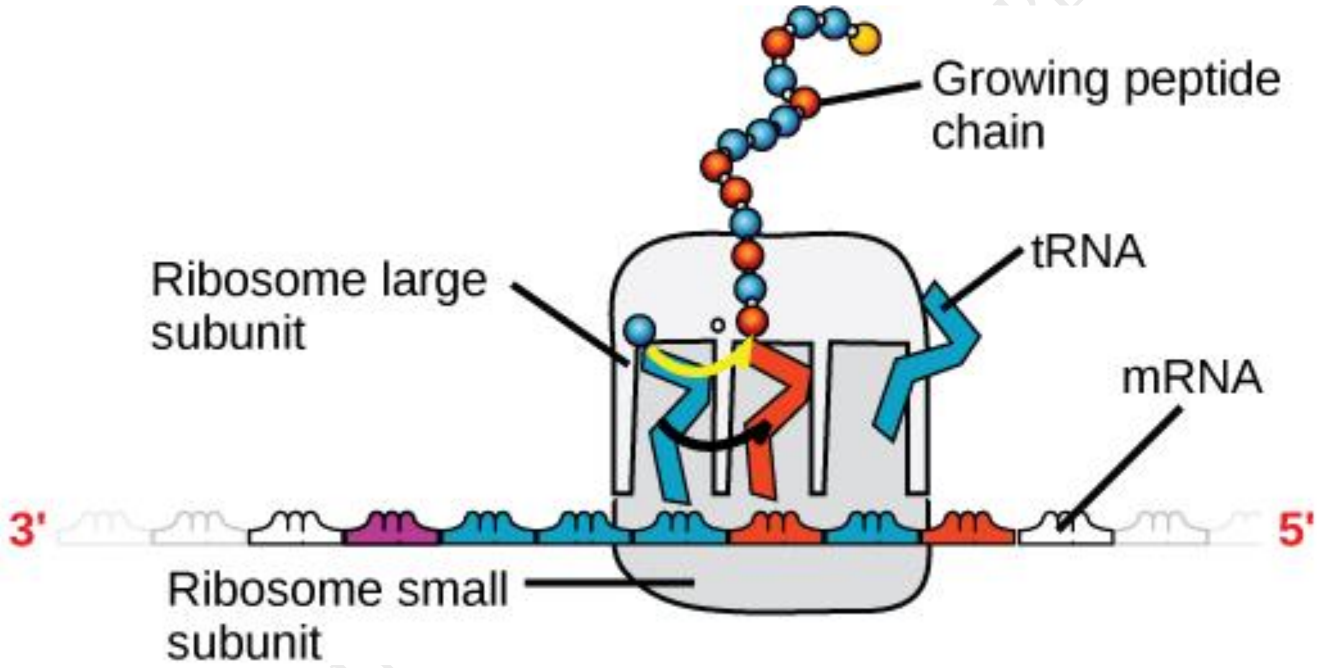
The double-helix model shows DNA as two parallel strands of intertwining molecules. In a double stranded DNA molecule, the two strands run antiparallel to one another so that one strand runs 5′ to 3′ and the other 3′ to 5′. The phosphate backbone is located on the outside, and the bases are in the middle. Adenine forms hydrogen bonds (or base pairs) with thymine, and guanine base pairs with cytosine.

The alternating sugar and phosphate groups lie on the outside of each strand, forming the backbone of the DNA. The nitrogenous bases are stacked in the interior, like the steps of a staircase, and these bases pair; the pairs are bound to each other by hydrogen bonds. The bases pair in such a way that the distance between the backbones of the two strands is the same all along the molecule.

RNA (Ribonucleic acid)

Ribonucleic acid, or RNA, is mainly involved in the process of protein synthesis under the direction of DNA. RNA is usually single-stranded and is made of ribonucleotides that are linked by phosphodiester bonds. A ribonucleotide in the RNA chain contains ribose (the pentose sugar), one of the four nitrogenous bases (A, U, G, and C), and the phosphate group.

There are four major types of RNA: messenger RNA (mRNA), ribosomal RNA (rRNA), transfer RNA (tRNA), and microRNA (miRNA). The first, mRNA, carries the message from DNA, which controls all of the cellular activities in a cell. If a cell requires a certain protein to be synthesized, the gene for this product is turned "on" and the messenger RNA is synthesized in the nucleus. The RNA base sequence is complementary to the coding sequence of the DNA from which it has been copied. However, in RNA, the base T is absent and U is present instead. If the DNA strand has a sequence AATTGCGC, the sequence of the complementary RNA is UUAACGCG. In the cytoplasm, the mRNA interacts with ribosomes and other cellular machinery



A ribosome has two parts: a large subunit and a small subunit. The mRNA sits in between the two subunits. A tRNA molecule recognizes a codon on the mRNA, binds to it by complementary base pairing, and adds the correct amino acid to the growing peptide chain.

The mRNA is read in sets of three bases known as codons. Each codon codes for a single amino acid. In this way, the mRNA is read and the protein product is made. Ribosomal RNA (rRNA) is a major constituent of ribosomes on which the mRNA binds. The rRNA ensures the proper alignment of the mRNA and the ribosomes; the rRNA of the ribosome also has an enzymatic activity (peptidyl transferase) and catalyzes the formation of the peptide bonds between two aligned amino acids. Transfer RNA (tRNA) is one of the smallest of the four types of RNA, usually 70–90 nucleotides long. It carries the correct amino acid to the site of protein synthesis.

It is the base pairing between the tRNA and mRNA that allows for the correct amino acid to be inserted in the polypeptide chain. microRNAs are the smallest RNA molecules and their role involves the regulation of gene expression by interfering with the expression of certain mRNA messages.

Features of DNA and RNA.

	DNA	RNA
Function	Carries genetic information	Involved in protein synthesis
Location	Remains in the nucleus	Leaves the nucleus
Structure	Double helix	Usually single-stranded
Sugar	Deoxyribose	Ribose
Pyrimidines	Cytosine, thymine	Cytosine, uracil
Purines	Adenine, guanine	Adenine, guanine

Even though the RNA is single stranded, most RNA types show extensive intramolecular base pairing between complementary sequences, creating a predictable three-dimensional structure essential for their function.

As you have learned, information flow in an organism takes place from DNA to RNA to protein. DNA dictates the structure of mRNA in a process known as transcription, and RNA dictates the structure of protein in a process known as translation. This is known as the Central Dogma of Life, which holds true for all organisms; however, exceptions to the rule occur in connection with viral infections.