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Introduction

Biochemistry can be defined as the science concerned with the chemical basis of life (Gk *bios* "life"). The cell is the structural unit of living systems. Thus, biochemistry can also be described as the science concerned with the chemical constituents of living cells and with the reactions and processes they undergo. By this definition, biochemistry encompasses large areas of cell biology, of molecular biology, and of molecular genetics. The most if not all diseases are manifestations of abnormalities of molecules, chemical reactions, or biochemical processes.

Much of biochemistry deals with the structures, functions and interactions of biological **macromolecules**, such as **proteins**, **nucleic acids**, **carbohydrates** and **lipids**, which provide the structure of cells and perform many of the functions associated with life. The chemistry of the cell also depends on the reactions of smaller molecules and ions. These can be inorganic, for example water and metal ions, or organic, for example the amino acids, which are used to synthesize proteins. The mechanisms by which cells utilize energy from their environment via chemical reactions are known as metabolism. The findings of biochemistry are applied primarily in medicine, nutrition, and agriculture. In medicine, biochemists investigate the causes and cures of diseases. In nutrition, they study how to maintain health wellness and study the effects of nutritional deficiencies. In agriculture, biochemists investigate soil and fertilizers, and try to discover ways to improve crop cultivation, crop storage and pest control.

Cell

The cell (from Latin *cella*, meaning "small room") is the basic structural, functional, and biological unit of all known living organisms. A cell is the smallest unit of life that can replicate independently, and cells are often called the "building blocks of life". It was discovered by Robert Hooke in 1665.

Cells consist of cytoplasm enclosed within a membrane, which contains many biomolecules such as proteins and nucleic acids. Organisms can be classified as unicellular (consisting of a single cell; including bacteria) or multicellular (including plants and animals). While the number of cells in plants and animals varies from species to species, humans contain more than 10 trillion (10^{13}) cells. Most plant and animal cells are visible only under a microscope, with dimensions between 1 and 100 micrometers.

Cells are of two types, **eukaryotic**, which contains a nucleus and other organelles enclosed within membranes, and **prokaryotic**, which lacks a membrane-bound nucleus, mitochondria, or any other membrane-bound organelle. Prokaryotes are single-celled organisms, while eukaryotes can be either single-celled or multicellular.

Cell components

- **Membrane**

The cell membrane, or plasma membrane, is a biological membrane that surrounds the cytoplasm of a cell. In animals, the plasma membrane is the outer boundary of the cell, while in plants and prokaryotes it is usually covered by a cell wall. This membrane serves to separate and protect a cell from its surrounding environment and is made mostly from a double layer of phospholipids, which are amphiphilic (partly hydrophobic and partly hydrophilic). Hence, the layer is called a phospholipid bilayer, or sometimes a fluid mosaic membrane. Embedded within this membrane is a variety of protein molecules that act as channels and pumps that move different molecules into and out of the cell. The membrane is semi-permeable, and selectively permeable (regulates what moves in and out). Cell surface membranes also contain receptor proteins that allow cells to detect external signaling molecules such as hormones.

- **Cytoskeleton**

It is a complex network of interlinking filaments and tubules that extend throughout the cytoplasm, from the nucleus to the plasma membrane, acts to organize and maintain the cell's shape. The cytoskeleton is composed of proteins.

- **Genetic material**

Two different kinds of genetic material exist: deoxyribonucleic acid (**DNA**) and ribonucleic acid (**RNA**). Cells use DNA for their long-term information storage. The biological information contained in an organism is encoded in its DNA sequence. RNA is used for information transport (e.g., messenger RNA "**mRNA**" convey genetic information that directs synthesis of specific proteins) and enzymatic functions (e.g., ribosomal RNA "**rRNA**" links amino acids together to form proteins). Transfer RNA (**tRNA**) molecules are used to add amino acids during protein translation.

Prokaryotic genetic material is organized in a simple circular DNA molecule (the bacterial chromosome) in the nucleoid region of the cytoplasm. Eukaryotic genetic material is divided into different linear molecules called chromosomes inside a discrete nucleus, usually with additional genetic material in some organelles like mitochondria and chloroplasts.

A human cell has genetic material contained in the cell nucleus (the nuclear genome) and in the mitochondria (the mitochondrial genome). In humans the nuclear genome is divided into 46 linear DNA molecules called chromosomes, including 22 homologous chromosome pairs and a pair of sex chromosomes. The mitochondrial genome is a circular DNA molecule distinct from the nuclear DNA.

- **Organelles**

Organelles are parts of the cell which are adapted and/or specialized for carrying out one or more vital functions. Both eukaryotic and prokaryotic cells have organelles, but prokaryotic organelles are generally simpler and are not membrane-bound. **The eukaryotic cell has the following organelles:-**

1- **Cell nucleus**: It houses the cell's chromosomes, and is the place where almost all DNA replication and RNA synthesis (transcription) occur. The nucleus is spherical and separated from the cytoplasm by a double membrane called the nuclear envelope. The nuclear envelope isolates and protects a cell's DNA from various molecules that could accidentally damage its structure or interfere with its processing. During processing, DNA is transcribed, or copied into a special RNA, called messenger RNA (mRNA). This mRNA is then transported out of the nucleus, where it is translated into a specific protein molecule. The nucleolus is a specialized region within the nucleus where ribosome subunits are assembled. In prokaryotes, DNA processing takes place in the cytoplasm.

2- **Mitochondria and Chloroplasts**: Generate energy for the cell. Mitochondria are self-replicating organelles that occur in various numbers, shapes, and sizes in the cytoplasm of all eukaryotic cells. Respiration occurs in the cell mitochondria, which generate the cell's energy by oxidative phosphorylation, using oxygen to release energy stored in cellular nutrients to generate ATP. Chloroplasts can only be found in plants and algae, and they capture the sun's energy to make carbohydrates through photosynthesis.

3- **Endoplasmic reticulum**: The endoplasmic reticulum (ER) is forms an interconnected network of flattened, membrane-enclosed sacs or tube-like structures known as cisternae. The membranes of the ER are continuous with the outer nuclear membrane. It has two forms: the **Rough ER** (**RER**) also called granular endoplasmic reticulum, which has protein-manufacturing ribosomes on its surface giving it a "rough" appearance (hence its name), and the **Smooth ER** (**SER**), which lacks ribosomes and functions in lipid manufacture and metabolism, the production of steroid hormones, and detoxification.
4- **Golgi apparatus**: The primary function of the Golgi apparatus is to process and package the macromolecules such as proteins and lipids that are synthesized by the cell.
5- **Lysosome and Peroxisome**: Lysosome is membrane-bound organelle contain digestive enzymes. They digest worn-out organelles, food particles, and engulfed viruses or bacteria. Peroxisome has enzymes that rid the cell of toxic peroxide.
6- **Centrosome**: Centrosomes are composed of two centrioles, which separate during cell division and help in the formation of the mitotic spindle.
7- **Vacuoles**: Vacuoles sequester waste products and in plant cells store water. They are often described as liquid filled space and are surrounded by a membrane. Some cells, most notably Amoeba, have contractile vacuoles, which can pump water out of the cell if there is too much water.

The organelle exists in eukaryotic cell and prokaryotic cell:-

8- **Ribosome**: The ribosome is a complex molecular machine, found within all living cells, that serves as the site of biological protein synthesis (translation). Ribosomes link amino acids together in the order specified by messenger RNA (mRNA) molecules. Ribosomes consist of two major components: the small ribosomal subunit, which reads the RNA, and the large subunit, which joins amino acids to form a polypeptide chain. Each subunit is composed of one or more ribosomal RNA (rRNA) molecules and a variety of ribosomal proteins.

Structures outside the cell membrane

Many cells also have structures which exist wholly or partially outside the cell membrane.

- **Cell wall**: Many types of prokaryotic and eukaryotic cells have a cell wall. The cell wall acts to protect the cell mechanically and chemically from its environment, and is an additional layer of protection to the cell membrane. Different types of cell have cell walls made up of different materials; plant cell walls are primarily made up of cellulose, fungi cell walls are made up of chitin and bacteria cell walls are made up of peptidoglycan.
- **Capsule**: A gelatinous capsule is present in some bacteria outside the cell membrane and cell wall. The capsule may be polysaccharide as in pneumococci, or polypeptide as *Bacillus anthracis*, or hyaluronic acid as in streptococci.
- **Flagella**: Flagella are organelles for cellular mobility. The bacterial flagellum stretches from cytoplasm through the cell membrane(s) and extrudes through the cell wall. They are long and thick thread-like appendages, protein in nature.
- **Fimbria**: A fimbria also known as a pilus is a short, thin, hair-like filament found on the surface of bacteria. Fimbriae, or pili are formed of a protein called pilin (antigenic) and are responsible for attachment of bacteria to specific receptors of human cell (cell adhesion). There are special types of specific pili involved in bacterial conjugation.

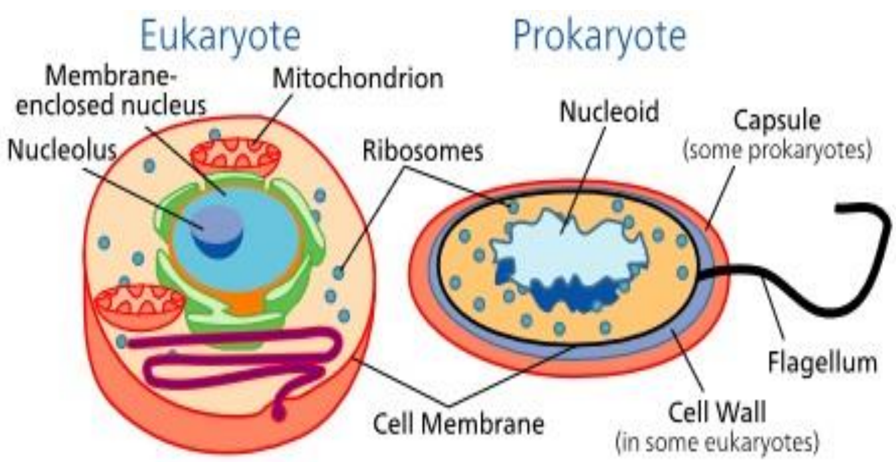

Figure 1.1: A eukaryotic cell (left) and prokaryotic cell (right)

Carbohydrates

Carbohydrates are the most abundant biomolecules on earth. Each year, photosynthesis converts more than 100 billion metric tons of CO2 and H2O into cellulose and other plant products. A carbohydrate is consisting of carbon (C), hydrogen (H) and oxygen (O) atoms, some also contain nitrogen, phosphorus, or sulfur. Usually with a hydrogen–oxygen atom ratio of 2:1 (as in water), carbohydrates have the empirical formula (**CH_2O**)*n*, some exceptions exist; for example, deoxyribose, a sugar component of DNA, has the empirical formula C5H10O4.

Carbohydrates perform numerous roles in living organisms. Polysaccharides serve for the storage of energy (e.g. starch and glycogen) and as structural components (e.g. cellulose in plants and chitin in arthropods). Certain carbohydrates (sugar and starch) are a dietary staple in most parts of the world, and the oxidation of carbohydrates is the central energy-yielding pathway in most non-photosynthetic cells. The 5-carbon monosaccharide ribose is an important component of coenzymes (e.g. ATP, FAD and NAD) and the backbone of the genetic molecule known as RNA. The related deoxyribose is a component of DNA.

Carbohydrates are found in a wide variety of foods. The important sources are cereals (wheat, maize, and rice), potatoes, sugarcane, fruits, etc.

The carbohydrates are divided into four chemical groups: **monosaccharides**, **disaccharides**, **oligosaccharides**, and **polysaccharides** (the word "saccharide" is derived from the Greek *sakcharon*, meaning "sugar").

Monosaccharide

Monosaccharides (from Greek *monos*: single), also called simple sugars, are the most basic units of carbohydrates. They are fundamental units of carbohydrates and cannot be further hydrolyzed to simpler compounds. The monosaccharides are either aldehydes or ketones with two or more hydroxyl groups; the six-carbon monosaccharides glucose and fructose have five hydroxyl groups. Many of the carbon atoms to which hydroxyl groups are attached are chiral centers, which give rise to the many sugar stereoisomers found in nature. The general formula is $C_nH_{2n}O_n$. They are the simplest form of sugar and are usually colorless, water-soluble, and crystalline solids. Some monosaccharides have a sweet taste. Examples of monosaccharides include glucose, fructose, and galactose. Monosaccharides are the building blocks of disaccharides (such as sucrose and lactose) and polysaccharides (such as cellulose and starch).

Linear-chain monosaccharides

Monosaccharides can be classified by the number x of carbon atoms they contain: triose (3), tetrose (4), pentose (5), hexose (6), heptose (7), and so on. Simple monosaccharides have a linear and unbranched carbon skeleton with one carbonyl (C=O) functional group, and one hydroxyl (OH) group on each of the remaining carbon atoms. The carbon atoms are numbered from 1 to x along the backbone, starting from the end that is closest to the C=O group. If the carbonyl is at position 1, the molecule begins with a formyl group H(C=O)− and is technically an aldehyde. In that case, the compound is termed an aldose. Otherwise, the molecule has a keto (RC(=O)R', where R and R' can be a variety of carbon-containing substituents) group, a carbonyl −(C=O)− between two carbons; then it is formally a ketone, and is termed a ketose. Ketoses of biological interest usually have the carbonyl at position 2 (Figure 1.2).

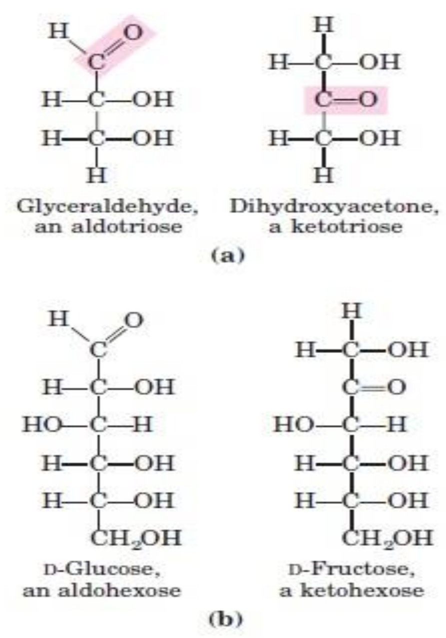

Figure 1.2: Representative monosaccharides. (a) Two trioses, an aldose and a ketose. The carbonyl group in each is shaded. (b) Two common hexoses.

The various classifications above can be combined, resulting in names such as "aldohexose" and "ketotriose".

A more general nomenclature for open-chain monosaccharides combines a Greek prefix to indicate the number of carbons (tri-, tetr-, pent-, hex-, etc.) with the suffixes "-ose" for aldoses and "-ulose" for ketoses. In the latter case, if the carbonyl is not at position 2, its position is then indicated by a numeric infix. So, for example, H(C=O)(CHOH)4H is pentose, H(CHOH)(C=O)(CHOH)3H is pentulose, and H(CHOH)2(C=O)(CHOH)2H is pent-3-ulose.

Open-chain stereoisomers

All the monosaccharides except dihydroxyacetone contain one or more asymmetric (chiral) carbon atoms (connected to four distinct molecular sub-structures). For example, the triketose H(CHOH)(C=O)(CHOH)H (glycerone, dihydroxyacetone) has no stereogenic center (chiral carbon), and therefore exists as a single stereoisomer. The other triose, the aldose H(C=O)(CHOH)2H (glyceraldehyde), has one chiral carbon (the central one, number 2) which is bonded to groups −H, −OH, −C(OH)H2, and −(C=O)H. Therefore, it exists as two stereoisomers whose molecules are mirror images of each other (like a left and a right glove). Monosaccharides with four or more carbons may contain multiple chiral carbons, so they typically have more than two stereoisomers. The **Fischer projection** is a systematic way of drawing the skeletal formula of a monosaccharide, each stereoisomer of a simple open-chain monosaccharide can be identified by the positions (right or left) in the Fischer diagram of the chiral hydroxyls (the hydroxyls attached to the chiral carbons). In the Fischer projection, two mirror-image isomers differ by having the positions of all chiral hydroxyls reversed right-to-left. Mirror-image isomers are chemically identical in non-chiral environments, but usually have very different biochemical properties and occurrences in nature (Figure 1.3). In the Fischer projection, one of the two glucose isomers has the hydroxyl at left on C3, and at right on C4 and C5; while the other isomer has the reversed pattern. Generally, a monosaccharide with *n* asymmetrical carbons has 2^n stereoisomers.

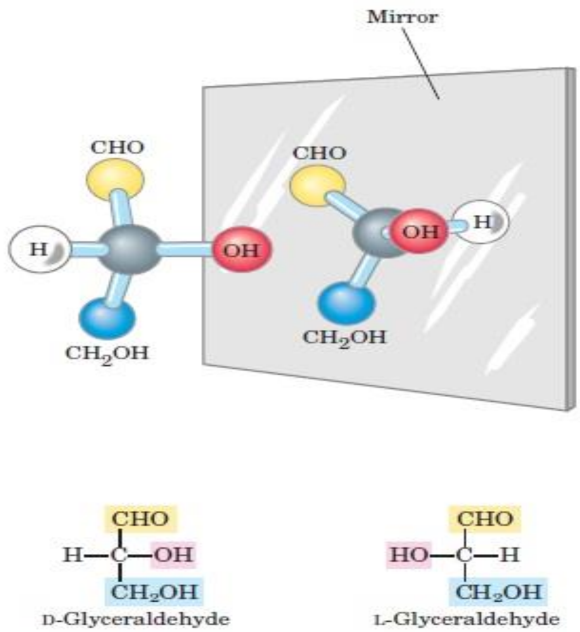

Figure 1.3: Fischer projection formulas. The stereoisomers are mirror images of each other.

Configuration of monosaccharides

The two stereoisomers are identified with the prefixes D- and L-, according to the sense of polarized light rotation: D-glyceraldehyde is dextrorotatory (rotates the polarization axis clockwise), while L-glyceraldehyde is levorotatory (rotates it counterclockwise). In the Fischer projection, the D- and L- prefixes specify the configuration at the carbon atom that is second from bottom: D- if the hydroxyl is on the right side and L- if it is on the left side (Figure 1.4).

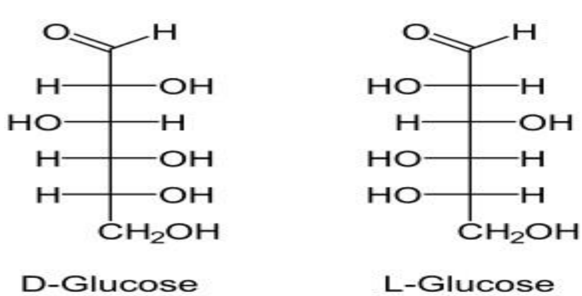

Figure 1.4: D-glucose and L-glucose

Two sugars that differ only in the configuration around one carbon atom are called **epimers**; D-glucose and D-mannose, which differ only in the stereochemistry at C-2, are epimers, as are D-glucose and D-galactose (which differ at C-4) (Figure 1.5).

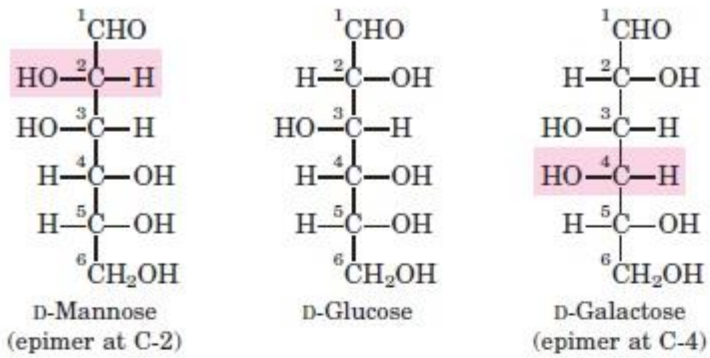

Figure 1.5: Epimers. D-Glucose and two of its epimers are shown as projection formulas. Each epimer differs from D-glucose in the configuration at one chiral center (shaded).

Cyclisation of Monosaccharides

A monosaccharide often switches from the acyclic (open-chain) form to a cyclic form, which is easily reversed, yielding the original open-chain form. In these cyclic forms, the ring usually has 5 or 6 atoms. These forms are called furanoses and pyranoses, respectively. Cyclic forms with a 7-atom ring, rarely encountered, are called heptoses.

Cyclization creates a new stereogenic center at the carbonyl-bearing carbon. Each open-chain monosaccharide yields two cyclic isomers (anomers), denoted by the prefixes α- and β-. The molecule can change between these two forms by a process called mutarotation.

Haworth projection

The stereochemical structure of a cyclic monosaccharide can be represented in a Haworth projection. In this diagram, the α-isomer for the pyranose form of a D-aldohexose has the -OH of the anomeric carbon below the plane of the carbon atoms, while the β-isomer has the -OH of the anomeric carbon above the plane (Figure 1.6).

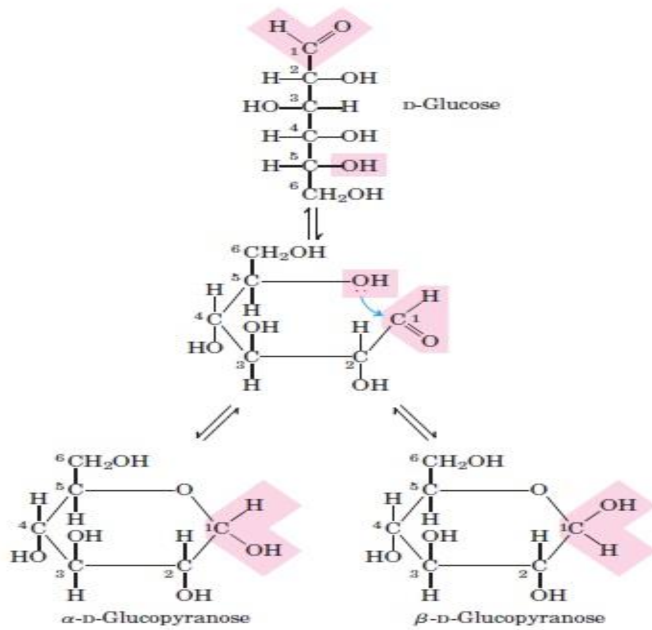

Figure 1.6: Formation of the two cyclic forms of D-glucose.

Pyranoses typically adopt a chair conformation. In this conformation, the α-isomer has the -OH of the anomeric carbon in an axial position, whereas the β-isomer has the OH- of the anomeric carbon in equatorial position (considering D-aldohexose sugars) (Figure 1.7).

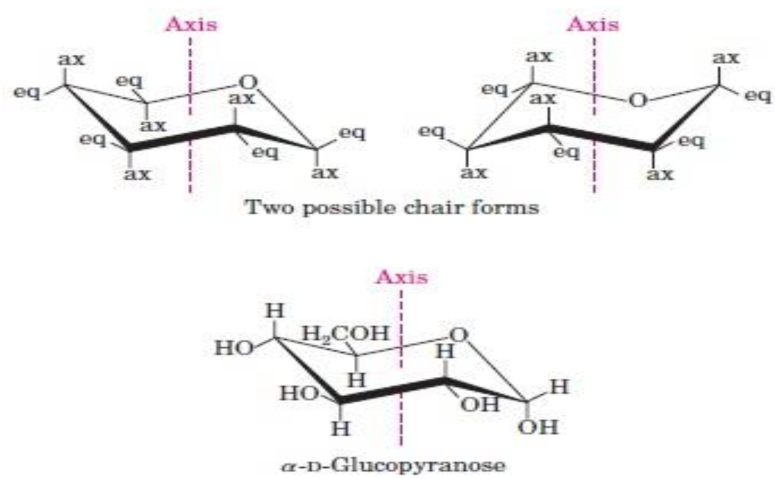

Figure 1.7: Conformational formulas of pyranoses.

Monosaccharide derivatives

A large number of biologically important modified monosaccharides exist:

- **Amino sugars**: is a sugar molecule in which a hydroxyl group has been replaced with an amine group. More than 60 amino sugars are known, such as:
  1. **Galactosamine:** is a hexosamine derived from galactose with the molecular formula $C_6H_{13}NO_5$. This amino sugar is a constituent of some glycoprotein hormones such as follicle-stimulating hormone (FSH) and luteinizing hormone (LH). Other sugar constituents of FSH and LH include glucosamine, galactose and glucose. Galactosamine is a hepatotoxic, or liver-damaging, agent.
  2. **Glucosamine** ($C_6H_{13}NO_5$): is part of the structure of the polysaccharides chitosan and chitin, which compose the exoskeletons of crustaceans and other arthropods, as well as the cell walls of fungi. Glucosamine is marketed to support the structure and function of joints, and treatment people suffering from osteoarthritis.
  3. **Sialic acid**: a monosaccharide with a nine-carbon backbone. It is also the name N-acetylneuraminic acid (NANA). Sialic acids are found widely distributed in animal tissues and to a lesser extent in other organisms, ranging from plants and fungi to yeasts and bacteria. In humans the brain has the highest sialic acid concentration, where these acids play an important role in neural transmission and ganglioside structure in synaptogenesis.
  4. **N-Acetylglucosamine** (NAG): is a monosaccharide and a derivative of glucose. It has a molecular formula of $C_8H_{15}NO_6$. It is part of a biopolymer in the bacterial and fungal cell walls. NAG is the monomeric unit of the polymer chitin, which forms the outer coverings of insects and crustaceans. It has been proposed as a treatment for autoimmune diseases.
- **Sulfosugars** such as: **Sulfoquinovose**, Sulfoquinovose is a sulfonic acid derivative of glucose.