Unit 3: Biochemical Molecules

3.1 Biochemical Molecules

Biological Molecules: Definition and Classification

Biological molecules are the compounds that are essential for the structure and function of living organisms. They are involved in various biological processes and contribute to the makeup of cells and tissues. These molecules can be classified into two main categories:

1. **Inorganic Molecules**: These do not contain carbon and are not derived from biological processes. Common examples include:
   - **Water** (H_2O)
   - **Mineral ions** (e.g., sodium ions, potassium ions, calcium ions)
2. **Organic Molecules**: These contain carbon and are often associated with living organisms. Examples include:
   - **Carbohydrates** (e.g., glucose, starch)
   - **Proteins** (e.g., enzymes, antibodies)
   - **Lipids** (e.g., fats, oils)
   - **Nucleic Acids** (e.g., DNA, RNA)

Effect on Cell Structure and Function

- **Inorganic Molecules**: Inorganic molecules like water and ions play crucial roles in maintaining cell structure and function. Water provides a medium for biochemical reactions and helps in maintaining cell turgor. Ions are essential for nerve impulse transmission, muscle contraction, and maintaining osmotic balance.
- **Organic Molecules**: Organic molecules are fundamental to cellular processes. Carbohydrates provide energy, proteins perform various functions including structural roles and catalysis, lipids contribute to membrane structure and energy storage, and nucleic acids store and transmit genetic information.

3.1.1 Inorganic Molecule: Water

Properties and Importance of Water

Water is a fundamental inorganic molecule with the chemical formula H_2O. It consists of two hydrogen atoms covalently bonded to one oxygen atom. Its unique properties are essential for life:

1. **Solvent Properties**: Water is a versatile solvent for ions and polar molecules. This ability is crucial for biochemical reactions and nutrient transport within and between cells.
2. **High Specific Heat Capacity**: Water requires a significant amount of heat to raise its temperature, which helps to stabilize temperature in organisms and environments.
3. **High Latent Heat of Vaporization**: Water absorbs a lot of heat before it evaporates. This property is vital for cooling mechanisms like sweating and for regulating temperature in organisms.
4. **Density and Freezing Properties**: Water is less dense as ice than as a liquid, allowing ice to float and insulate bodies of water, which helps to sustain life in cold environments.
5. **High Surface Tension and Cohesion**: Water molecules exhibit strong cohesion and surface tension, which are important for processes like water transport in plants and the ability of small organisms to walk on water.
6. **Boiling and Freezing Points**: Water has a high boiling point (100°C) and freezing point (0°C), which ensures that it remains in a liquid state under most environmental conditions, supporting aquatic life and various biological functions.

3.1.2 Inorganic Ions

Classification and Functions of Inorganic Ions

Inorganic ions are charged atoms or molecules crucial for various physiological processes. They are classified into:

- **Macro-nutrients**: Required in larger quantities (e.g., Sodium, Phosphorus, Magnesium).
- **Micro-nutrients**: Required in smaller quantities (e.g., Iron, Copper, Iodine).

Key Inorganic Ions and Their Roles

1. **Hydrogen Ions (H^+)**: Maintain pH balance and are involved in various metabolic processes. pH levels influence enzyme activity and overall cellular function.
2. **Sodium Ions (Na^+)**: Found in extracellular fluids, crucial for maintaining fluid balance and nerve function. Excessive intake can lead to hypertension.

3. **Potassium Ions (K^+)**: Predominantly intracellular, essential for cell function, nerve transmission, and muscle contraction. Deficiency or excess can affect heart rhythm.
4. **Calcium Ions (Ca^{2+})**: Important for bone and teeth formation, muscle contraction, and blood clotting. Deficiency can lead to bone disorders, while excess can cause kidney stones.
5. **Phosphate Ions (PO_4^{3-})**: Found in bones and teeth, vital for energy transfer (ATP) and nucleic acid structure. Imbalances can affect bone health and energy metabolism.
6. **Chloride Ions (Cl^-)**: Help maintain fluid balance and are essential for producing hydrochloric acid in the stomach. Deficiency can affect digestion and fluid balance.
7. **Iron Ions (Fe^{2+}/Fe^{3+})**: Crucial for oxygen transport in hemoglobin. Deficiency causes anemia, while excess can lead to conditions like hemochromatosis.
8. **Copper Ions (Cu^{2+})**: Involved in enzyme function and iron metabolism. Deficiency can lead to anemia and developmental issues, while excess can cause Wilson's disease.
9. **Iodine Ions (I^-)**: Essential for thyroid hormone production, which regulates metabolism. Deficiency causes goiter and hypothyroidism, while excess can lead to thyroid dysfunction.

Organic Molecules

Definition: Organic molecules are compounds that contain carbon and are essential to life. Carbon is central to organic chemistry because of its ability to form diverse and complex structures through covalent bonding. The four major groups of organic molecules crucial for life are carbohydrates, lipids, proteins, and nucleic acids.

Monomers and Polymers

Monomers are small molecular units that bond together to form **polymers**, which are long chains of repeating units. The major organic molecules are formed from different monomers:

- **Proteins**: Monomers are amino acids (containing carbon, hydrogen, oxygen, and nitrogen).
- **Lipids**: Monomers include glycerol and fatty acids (containing carbon, hydrogen, and oxygen).
- **Carbohydrates**: Monomers are monosaccharides like glucose, galactose, and fructose (containing carbon, hydrogen, and oxygen).
- **Nucleic Acids**: Monomers are nucleotides (containing carbon, hydrogen, oxygen, nitrogen, and phosphorus).

Carbohydrates

Definition: Carbohydrates are organic compounds made of carbon, hydrogen, and oxygen, with hydrogen and oxygen in a 2:1 ratio. They are key sources of energy and structural components in living organisms.

Types of Carbohydrates:

1. **Monosaccharides:**
   - Simple sugars with one sugar unit.
   - Examples: Glucose, galactose, and fructose.
   - Formula: $(CH_2O)n$, where n represents the number of carbon atoms.
2. **Disaccharides:**
   - Composed of two monosaccharides.
   - Examples: Maltose (glucose + glucose), lactose (glucose + galactose), sucrose (glucose + fructose).
3. **Polysaccharides:**
   - Long chains of monosaccharide units.
   - Examples: Starch, glycogen, cellulose.

Functions:

- Provide energy (e.g., glucose, starch).
- Store energy (e.g., starch in plants, glycogen in animals).
- Serve as structural components (e.g., cellulose in plant cell walls).

Laboratory Test for Reducing Sugars:

- **Benedict's Test:**
  - Reducing sugars reduce blue copper(II) ions in Benedict's reagent to form a brick-red precipitate.
  - Procedure: Add Benedict's reagent to the solution and heat. Observe the color change.

Lipids

Definition: Lipids are hydrophobic organic molecules made of carbon, hydrogen, and oxygen. They include fats, oils, and cholesterol.

Types of Lipids:

1. **Fatty Acids:**
   - Long hydrocarbon chains with a carboxyl group.
   - Types: Saturated (no double bonds, solid at room temperature) and unsaturated (one or more double bonds, liquid at room temperature).

2. **Phospholipids:**
    - Have a hydrophilic phosphate head and hydrophobic fatty acid tails.
    - Essential for forming cell membranes.

Functions:

- Store energy (e.g., fat in animals).
- Serve as structural components of cell membranes (e.g., phospholipids).
- Provide insulation and protection.

Proteins

Definition: Proteins are complex molecules made of carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur. They are composed of amino acids.

Amino Acids:

- Monomers with a general formula $RCH(NH_2)COOH$.
- Differ in their R group.

Functions:

- Structural (e.g., collagen, keratin).
- Enzymatic (e.g., digestive enzymes).
- Hormonal (e.g., insulin).
- Transport (e.g., hemoglobin).
- Storage (e.g., casein in milk).

Laboratory Test for Proteins:

- **Biuret Test:**
    - Proteins react with copper ions in alkaline solution to produce a purple color.
    - Procedure: Mix food sample with Biuret reagent and observe color change.
- **Xanthoproteic Test:**
    - Identifies proteins containing aromatic amino acids (phenylalanine, tyrosine, tryptophan).
    - Procedure: Add nitric acid to the sample, cool, then add sodium hydroxide. Observe color change.

This overview covers the essential aspects of organic molecules and their roles in living organisms, including their structures, functions, and methods of testing in the laboratory.

Nucleic Acids: Structure and Function

Nucleic acids are crucial biomolecules that carry genetic information and play a central role in protein synthesis. The two primary types of nucleic acids are Deoxyribonucleic Acid (DNA) and Ribonucleic Acid (RNA).

Structure of Nucleic Acids

1. **Basic Units: Nucleotides**
   - **Components**:
     - **Nitrogenous Base**: Adenine (A), Thymine (T), Guanine (G), Cytosine (C) in DNA; Adenine (A), Uracil (U), Guanine (G), Cytosine (C) in RNA.
     - **Pentose Sugar**: Ribose in RNA; Deoxyribose in DNA (lacks an oxygen atom at the 2nd carbon compared to ribose).
     - **Phosphate Group**: Links the sugar of one nucleotide to the sugar of the next, forming a backbone for the nucleic acid strand.
2. **DNA vs. RNA Structure**
   - **DNA**:
     - **Form**: Double-stranded, forming a double helix.
     - **Strands**: Two complementary strands running in opposite directions.
     - **Stability**: Very stable; preserves genetic information across generations.
   - **RNA**:
     - **Form**: Single-stranded.
     - **Types**:
       - **mRNA (Messenger RNA)**: Carries genetic code from DNA to ribosomes.
       - **tRNA (Transfer RNA)**: Delivers amino acids to ribosomes during protein synthesis.
       - **rRNA (Ribosomal RNA)**: Combines with proteins to form ribosomes.
     - **Stability**: Less stable; degrades quickly to allow for rapid regulation of protein synthesis.

Functions of Nucleic Acids

1. **DNA (Deoxyribonucleic Acid)**
   - **Genetic Information Storage**: Contains the genetic blueprint for an organism's development and function.
   - **Replication**: Can make copies of itself, ensuring genetic information is passed to daughter cells during cell division.
   - **Protein Synthesis**: DNA sequences are transcribed into mRNA, which is then translated into proteins.

2. **RNA (Ribonucleic Acid)**
   - **Genetic Material in Some Viruses**: Certain viruses use RNA to carry genetic information.
   - **Enzymatic Activity**: Some RNA molecules, known as ribozymes, can catalyze chemical reactions.
   - **Protein Synthesis**:
     - **mRNA**: Transfers genetic information from DNA to ribosomes.
     - **tRNA**: Provides amino acids to ribosomes for protein assembly.
     - **rRNA**: Forms ribosomes, the site of protein synthesis.

Summary

Nucleic acids, DNA and RNA, are essential for storing and transmitting genetic information. DNA's double-stranded structure and stability make it ideal for long-term information storage and replication, while RNA's single-stranded form and various types allow it to play diverse roles in protein synthesis and regulation. Both types of nucleic acids are fundamental to life, directing the synthesis of proteins and ensuring the continuity of genetic information across generations.