AP: Biology
Self-Study, Richardson HS, Fall 2024 & Spring 2025

1 Chemistry of Life

1.1 Structure of Water and Hydrogen Bonding

Most organisms and their environments are made of water. Water has unique properties compared to other molecules. Water is "weird".

Water is **polar**. This means that the overall charge is not evenly distributed. Water is therefore partially positive on one side and partially negative on the other.

This fact allows water to form hydrogen bonds. This is an attraction between different water molecules. Hydrogen bonds are different because they are more like interactions between molecules themselves. The water molecules are constantly interaction with each other and are attracting and repelling each other. Hydrogen bonds break and reform easily.

Water has many unique properties as a result of this - Cohesion, Adhesion, and Surface Tension.

Cohesion is the property that water molecules stick to each other because of hydrogen bonding. Essentially, water is sticky because of its polarity and hydrogen bonds.

Adhesion is the property that water sticks to other polar surfaces.

Water's stickiness allows trees and other plants to transport it upward from the ground because they are able to adhere to the walls of water-conducting cells and water also water molecules cohere together.

Surface tension is a measure of how difficult it is to break the surface of a liquid. Hydrogen bonds keep the liquid intact. Water has a high surface tension compared to other liquids.

1.2 Elements of Life

All living things and the environment are all made of the same elements. Living things need to constantly exchange matter with the environment.

Chemicals that make up living things are carbon-based (except water). Carbon can form a variety of complex organic compounds. Each carbon atom can form four covalent bonds, which means four valence electrons. Hydrocarbons only have carbon and hydrogen.

There are four main classes of biomolecules. These are carbohydrates (C,H,O), proteins (C,H,O,N,S), lipids (C,H,O), and nucleic acids (C,H,N,O,P). Configurations of atoms make biomolecules even more varied. Isomers are compounds with same numbers and types of atoms, but with a different structure.

A structural isomer has a different arrangement of atoms. Cis-trans isomers have a different arrangement of atoms due to double bonds. Enantiomers are "mirror images" of one another due to one carbon being bonded to four different things.

1.3 Introduction to Biological Macromolecules

As mentioned previously, there are four classes of macromolecules - carbohydrates, proteins, lipids, and nucleic acids. Macromolecules are called this because they are big for molecules.

Complex carbohydrates, proteins, and nucleic acids are polymers, which are long molecules made of many building blocks linked by covalent bonds. The building blocks of polymers are monomers.

Monomers and smaller polymers link together to form bigger polymers through dehydration synthesis. Bigger polymers can break down into smaller polymers or monomers through hydrolysis.

Dehydration Synthesis causes a new covalent bond to form with the loss of a water molecule. One molecule gives an -OH, the other -H to form H_2O. Essentially, we are removing a water molecule to form a new covalent bond.

Hydrolysis breaks a covalent bond by adding a water molecule to a polymer. It is the opposite of dehydration synthesis.

1.4 Properties of Biological Macromolecules

The monomers that make up macromolecules determine the properties of the macromolecule. The monomers of carbohydrates are monosaccharides. Monomers of proteins are amino acids. Monomers of lipids are fatty acids. Monomers of nucleic acids are nucleotides.

Complex carbohydrates are made of monosaccharides. They usually end with "-ose" as a suffix. Each monosaccharide is 3-6 carbons in a ring with O and H atoms. Examples of monosaccharides are glucose, fructose, and galactose. Monosaccharides are a major source of celluar energy.

If we take monosaccharides and link them together, we make a disaccharide, which is two monosaccharides joined by a glycosidic linkage.

Proteins are made up of monomers called amino acids. The order of amino acids in a chain determines the protein's properties. All amino acids have a NH_2 (amino) group, a COOH (carboxyl) group and each of these form peptide bonds with each other. All amino acids have a different "R" group (a side chain), which has different properties that affect the structure of the protein. All 20 amino acids have different R-groups.

Lipids are a diverse group of nonpolar molecules that do not interact with water (fats, phospholipids, steroids). Fats and phospholipids have fatty acids. Fats are also known as triglycerides because triglycerides are made up of 3 fatty acids. Phospholipids are made up of a polar head with a phosphate group within it and two fatty acid chains.

Triglycerides can be unsaturated or saturated depending on the structure of fatty acids. Unsaturated fatty acids have at least one double bond. Unsaturated fatty acids usually are liquid and have a different shape. Saturated fatty acids only have single bonds. They are usually solid at room temperature.

Nucleic acids are chains of monomers called nucleotides. Nucleotides have a five carbon ring, a phosphate, and a nitrogen base.

Nucleotides differ by their nitrogen base - A, T, C, G, or adenine, thymine, cytosine, and guanine. DNA's five-carbon sugar is called deoxyribose and RNA's five-carbon sugar is called ribose.

1.5 Structure and Function of Biological Macromolecules

In 1.4, we focused on the monomers of the macromolecules. In 1.5, we talk about the structures themselves.

Many monosaccharides make up polysaccharides, bonded together by glycosidic linkages. Chains of polysaccharides can be linear or branched. Some polysaccharides are for energy storage, others are for structure.

Many amino acids in a linear chain make up a polypeptide. A protein is made up of one or more polypeptides. Peptide bonds are formed at the carboxyl end of each amino acid.

The structure of proteins can be broken down into four levels. Protein function is determined by interactions at each of these levels.

Primary structure is a protein's sequence of amino acids. R groups or side chains of amino acids determine structure at other levels.

Amino acid chains fold and coil in its secondary structure. Folding and coiling are the result of hydogen bonds between amino acid backbones. α-helix is formed by coiling, and β-helix is formed by folding.

Tertiary structure refers to the shape of a polypeptide from interactions of side chains (combinations of α-helices and β-sheets). Some examples of side chain interactions that we might find in a tertiary protein:

- Hydrophobic interactions between two nonpolar side chains
- Disulfide bridges between two side chains with sulfur

When these interactions of side chains are broken, the protein has been denatured.

Quaternary structure refers to multiple polypeptide subunits forming one macromolecule. Hemoglobin consists of four polypeptides. All four levels of structure determine the function of the protein.

DNA is made up of two polynucleotide strands in a double helix. Each strand is oriented in opposite directions. Each nucleotide matches with its complementary nucleotide on the other strand and DNA is antiparallel. Adenine always pairs with thymine and cytosine always pairs up with guanine.

Adenine, guanine are purines, which are nucleotides with two nitrogen rings in base. Cytosine, thymine, uracil are pyrimidines, which have one nitrogen ring in base.

5' and 3' in DNA refers to individual carbon atoms in the ribose sugar of a nucleotide. The phosphate of one nucleotide binds to the 3' carbon of another nucleotide to form a chain. DNA nucleotides are complementary and antiparallel and covalent bonds form between matching nucleotides.

1.6 Nucleic Acids

DNA has two antiparallel polynucleotide strands. Nitrogenous bases run perpendicular to the sugar-phosphate backbone.

DNA and RNA have differences. DNA is deoxyribose, it has A, T, C, G, and two strands. RNA is robose, it has A, T, C, U, and one strand.

DNA has a deoxyribose sugar. It has no -OH on 2' carbon, hence the "de". RNA has a ribose sugar and has -OH on 2' carbon.

DNA is usually double-stranded and RNA is usually single-stranded. RNA has uracil (U) nucleotides that complement adenine (A).

2 Cell Structure and Function

2.1 Cell Structure: Subcelluar Components

All life is made of one or more cells. There are two groups:

- Eukaryotic cells contain DNA in the nucleus and have membrane-bound organelles.
- Prokaryotic cells do not keep DNA in an organelle and do not have membrane-bound organelles.

All cells have:

- Cytosol - jellylike substance that holds subcelluar components
- Ribosomes - complexes made of RNA and protein; synthesizes protein
- Plasma Membrane - selective barrier of the cell, controls what goes in and out

Eukaryotic cells contain organelles, which are membrane-enclosed structures. The first organelle is the endoplasmic reticulum. It is an extensive membrane network continuous with the membrane of the nucleus (the nuclear envelope).

The smooth endoplasmic reticulum (ER) has no ribosomes attached and it synthesizes lipids and detoxifies poisons. The rough ER is studded with ribosomes. It labels proteins and packages them in vesicles to transport out.

The golgi complex are flattened membrane sacs and it ensures correct folding and packaging of new proteins. It receives vesicles from the ER and sends them to the plasma membrane or other parts of the cell.

The mitochondrion is the site of celluar respiration and ATP production. The mitochondria has two membranes, an inner membrane with many folds (cristae) and an outer membrane.

The lysosome is a sac of hydrolytic enzymes that break down macromolecules.

A vacuole is a large vesicle that can serve a variety of functions. The central vacuole in a plant enables growth and stores ions.

Chloroplasts are the sites of photosynthesis in plants and algae. This is where solar energy is converted to chemical energy.

2.2 Cell Structure and Function

Each subcelluar component of a cell's structure contributes to serving its function.

Lysosomes digest and break down macromolecules. The ER synthesizes proteins and lipids and transports them and also provides mechanical support. Vacuoles are surrounded by a membrane and stores molecules, waste products, and water.

Mitochondria carry out metabolic reactions, including ATP synthesis. Different reactions take place in different compartments. Mitochondria have their own DNA and ribosomes. Aerobic celluar respiration occurs within the mitochondria. Oxidative phosphorylation (electron transport chain) occurs the inner membrane. The Krebs/citric acid cycle occurs in the matrix.

Chloroplasts also have inner membrane systems and are the sites of photosynthesis. Different reactions take place in different compartments of the chloroplast. A granum is a stack of thylakoids within the inner membrame. The fluid outside the granum is the stroma. Light-dependent photosynthesis reactions occur in the grana. The Calvin Cycle occurs in the stroma. Thylakoid membranes contain chlorophyll and "photosystem" proteins.

2.3 Cell Size

All cells are dependent on exchange of materials with their environment in order to obtain nutrients, eliminate waste, and to gain/lose energy.

A cell's size plays a big factor in its ability to exchange with the environment.

Cells rely upon diffusion (movement of substance from high to low concentration) to exchange with their environment. This process can be slow - in a large cell, nutrients may not reach the place they need to be. A cell with a smaller volume will be better equipped to exchange materials.

Some cells are specialized to be better equipped to exchange materials.

A cells' ability to exchange materials is dependent on its surface area to volume ratio. A larger surface area gives a better exchange of materials. The higher the surface area to volume ratio, the better the exchange of materials and energy.

Some cells are specialized to obtain nutrients/eliminate wastes. These cells have surfaces designed for exchange with the environment.

Cristae in inner mitochondrial membrane greatly increase surface area and can produce more ATP this way.

2.4 Plasma Membranes

The plasma membrane separates a cell from its surroundings and allows cells to maintain a separate and stable internal environment.

Membranes are selectively permeable - it allows some substances to cross it more easily than others.

The current model for the animal cell membrane consists of proteins, glycoproteins, and sterols that can flow in a phospholipid bilayer. This is called the fluid mosaic model.

Phospholipids constitute most of the membrane. Phospholipids are amphipathic - this means they have both hydrophilic and hydrophobic regions. They have a polar "head" and a nonpolar "tail".

Phospholipids form a bilayer - two layers with hydrophilic heads facing out and hydrophobic tails facing in.

Fatty acid tails can be unsaturated or saturated. Unsaturated fatty acid tails increase membrane fluidity.

Cholestrol in the bilyaer also increases membrane fluidity.

2.5 Membrane Permeability

The membrane's selective permeability is a result of its structure. Fatty acid tails in the middle keep out polar molecules.

Small, nonpolar molecules can move freely through the membrane.

Large polar molecules and charged molecules cannot pass through fatty acid tails. These molecules move across through channels and transport proteins.

Small, polar, uncharged molecules can pass in small amounts. Water can move through aquaporins.

Cell walls of plant cells are made of celluose (a polysaccharide) fibers embedded in carbohydrates and proteins. Cell walls provide a structural boundary and barrier for some substances.

2.6 Membrane Transport

2.7 Facilitated Diffusion

2.8 Tonicity and Osmoregulation

2.9 Mechanisms of Transport

2.10 Cell Compartmentalization

2.11 Origins of Cell Compartmentalization

3 Cellular Energetics

3.1 Enzyme Structure

3.2 Enzyme Catalysis

3.3 Environmental Impacts on Enzyme Function

3.4 Cellular Energy

3.5 Photosynthesis

3.6 Cellular Respiration

3.7 Fitness

4 Cell Communication and Cell Cycle

4.1 Cell Communication

4.2 Introduction to Cell Transduction

4.3 Signal Transduction

4.4 Changes in Signal Transduction Pathways

4.5 Feedback

4.6 Cell Cycle

4.7 Regulation of Cell Cycle

5 Heredity

5.1 Meiosis

5.2 Meiosis and Genetic Diversity

5.3 Mendelian Genetics

5.4 Non-Medelian Genetics

5.5 Environmental Effects on Phenotype

5.6 Chromosomal Inheritance

6 Gene Expression and Regulation

6.1 DNA and RNA Structure

6.2 Replication

6.3 Transcription and RNA Processing

6.4 Translation

6.5 Regulation of Gene Expression

6.6 Gene Expression and Cell Specialization

6.7 Mutations

6.8 Biotechnology

7 Natural Selection

7.1 Introduction to Natural Selection

7.2 Natural Selection

7.3 Artificial Selection

7.4 Population Genetics

7.5 Hardy-Weinburg Equilibrium

7.6 Evidence of Evolution

7.7 Common Ancestry

7.8 Continuing Evolution

7.9 Phylogeny

7.10 Speciation

7.11 Extinction

7.12 Variations in Populations

7.13 Origin of Life on Earth

8 Ecology

8.1 Responses to the Environment

8.2 Energy Flow Through Ecosystems

8.3 Population Ecology

8.4 Effect of Density of Populations

8.5 Community Ecology

8.6 Biodiversity

8.7 Disruptions to Ecosystems