Cell Biology: Biological Macromolecules

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

I. Quiz: Short Answer Questions

Answer each question in 2-3 sentences.

1. Explain the key difference between anabolism and catabolism within the broader context of metabolism. Provide an example of a reaction that exemplifies each process.
2. How do dehydration reactions and hydrolysis reactions relate to the building and breaking down of macromolecules? Illustrate with an example involving a specific type of macromolecule.
3. Why are lipids not considered polymers, unlike proteins, polysaccharides, and nucleic acids? How do their building blocks differ from those of true polymers?
4. Describe the two independent ways in which monosaccharides can be classified. Give an example for each classification method.
5. What is the functional difference between storage polysaccharides and structural polysaccharides? Provide an example of each and specify their primary monomer.
6. Explain why animal fats tend to be solid at room temperature while plant oils tend to be liquid. Relate your answer to the concepts of saturated and unsaturated fatty acids.
7. How does the amphipathic nature of phospholipids contribute to their critical role in biological membranes?
8. Besides their role in providing traits, identify and briefly describe three distinct functional categories of proteins.
9. Differentiate between a protein and a polypeptide. Under what circumstances are these terms interchangeable, and when are they distinct?
10. Briefly explain the concept of protein denaturation and renaturation. Provide an example where denaturation is permanent and an example where it is reversible.

II. Answer Key

1. Anabolism is the part of metabolism where larger molecules are built from smaller ones, requiring energy and involving dehydration reactions. Catabolism is the opposite, involving the breaking down of larger molecules into smaller ones, releasing energy and

involving hydrolysis reactions. For example, building a protein from amino acids is anabolism, while breaking down starch into glucose is catabolism.

2. Dehydration reactions remove a molecule of water to join smaller chunks (monomers) together, building a larger molecule (polymer). Hydrolysis reactions, conversely, add water to split a larger molecule into smaller chunks. For instance, building a polysaccharide from monosaccharides occurs via dehydration, while breaking it down happens through hydrolysis.
3. Lipids are not polymers because they are not built by stringing together repeating monomer subunits in a chain. Instead, they are typically constructed from different types of smaller molecules, such as a glycerol backbone combined with fatty acid tails, which are linked by ester linkages rather than a repeating monomeric unit.
4. Monosaccharides can be classified by the number of carbons in their skeleton (e.g., trioses like glyceraldehyde with three carbons, pentoses like ribose with five, or hexoses like glucose with six) and by the type of carbonyl group they possess (aldoses if the carbonyl is at the end of the carbon skeleton, or ketoses if it's elsewhere).
5. Storage polysaccharides are primarily used to store energy (fuel) for later use, acting as compact reserves. Examples include starch in plants and glycogen in animals, both made exclusively of glucose monomers. Structural polysaccharides provide support and strength, forming components of cellular or organismal structures, such as cellulose in plant cell walls, also made of glucose.
6. Animal fats are predominantly composed of saturated fatty acids, which have no double bonds in their hydrocarbon chains, allowing them to pack tightly together and remain solid at room temperature. Plant oils, on the other hand, contain a higher proportion of unsaturated fatty acids with double bonds, creating "bends" that prevent tight packing, thus making them liquid at room temperature.
7. Phospholipids are amphipathic, meaning they have both a hydrophilic (water-loving) polar head and hydrophobic (water-fearing) nonpolar tails. This dual nature causes them to spontaneously self-assemble into a bilayer in the presence of water, forming the fundamental structure of all cellular plasma membranes by arranging the hydrophobic tails away from water and the hydrophilic heads towards it.
8. Three functional categories of proteins include: **Enzymatic proteins**, which act as biological catalysts to speed up chemical reactions (e.g., sucrase breaking down sucrose). **Transport proteins**, which move substances within an organism (e.g., hemoglobin carrying oxygen in blood) or across cell membranes (e.g., transmembrane transport proteins). **Defensive proteins** (e.g., antibodies) that protect the body against foreign invaders.
9. A polypeptide refers to a single linear chain of amino acids linked by peptide bonds. A protein is a functional biological molecule, which can consist of either a single polypeptide (in which case the terms are interchangeable) or multiple polypeptides associating together (a multimer protein). For example, a simple enzyme might be a single polypeptide, but hemoglobin is a multimer protein composed of four polypeptides.
10. Protein denaturation is the process where a protein loses its specific three-dimensional shape (conformation) due to changes in environmental conditions like temperature or pH, leading to a loss of function. Renaturation is the reversal of this process if the

denaturing conditions are mild enough. Boiling an egg white is an example of permanent denaturation, while a slight, non-lethal change in temperature might cause temporary denaturation that is reversible upon restoring the original conditions.

III. Essay Questions

1. Discuss the significance of the "common ancestor" hypothesis in biology, citing evidence from the universal set of 20 biological amino acids and their role in protein structure and function.
2. Compare and contrast the structural characteristics and biological functions of carbohydrates and lipids. Include specific examples of each macromolecule type and explain how their unique structures enable their diverse roles.
3. Proteins are often described as the "workhorses" of the cell due to their incredible functional diversity. Elaborate on how the four levels of protein structure (primary, secondary, tertiary, and quaternary) contribute to this versatility, providing examples of how changes at one level can impact overall function.
4. Explain the central dogma of molecular biology as it relates to DNA, RNA, and protein synthesis, as described in the provided material. Detail the processes of transcription and translation, highlighting the roles of each nucleic acid and the cellular machinery involved.
5. Analyze the concept of biological specificity as illustrated by enzymes, receptors, and antibodies. How does the three-dimensional shape of proteins underlie their ability to interact selectively with other molecules, and what are the implications of this specificity for cellular function and organismal health?

IV. Glossary of Key Terms

- **Active Site:** The specific region on an enzyme where the substrate binds and catalysis occurs.
- **Aldose:** A monosaccharide (simple sugar) that contains an aldehyde group, typically at the end of its carbon skeleton in its linear form.
- **Alpha Helix:** A common type of secondary protein structure characterized by a spiral or corkscrew shape, stabilized by hydrogen bonds.
- **Amino Acid:** The monomer subunit of proteins, characterized by a central carbon atom bonded to an amino group, a carboxyl group, a hydrogen atom, and a variable "R-group" side chain.
- **Amphipathic:** A molecule having both hydrophilic (water-loving) and hydrophobic (water-fearing) properties. Phospholipids are an example.
- **Anabolism:** The metabolic processes that build complex molecules from simpler ones, typically requiring energy input.
- **Antibodies:** Proteins produced by the immune system that recognize and bind to specific antigens (foreign substances), marking them for destruction.

- **Antigen:** Any substance that elicits an immune response, typically recognized by antibodies.
- **Beta Pleated Sheet:** A common type of secondary protein structure characterized by a folded, accordion-like arrangement, stabilized by hydrogen bonds.
- **Carbohydrates:** A broad category of organic compounds including sugars, starch, and cellulose, typically characterized by the general formula CnH2nOn. Polysaccharides are the macromolecular carbohydrates.
- **Carboxyl Group:** A functional group consisting of a carbon atom double-bonded to an oxygen atom and single-bonded to a hydroxyl group (-COOH). Found in carboxylic acids and amino acids.
- **Catabolism:** The metabolic processes that break down complex molecules into simpler ones, typically releasing energy.
- **Catalyst:** A substance that speeds up the rate of a chemical reaction without being consumed in the process. Enzymes are biological catalysts.
- **Cellulose:** A major structural polysaccharide in plants, made of beta-glucose monomers linked in a way that forms strong fibers.
- **Chaperone Proteins:** Proteins that help newly synthesized polypeptides fold correctly into their functional three-dimensional shapes.
- **Chiral Carbon:** A carbon atom bonded to four different atoms or groups, leading to the possibility of enantiomers (mirror-image isomers).
- **Cholesterol:** A type of steroid lipid found in animal cell membranes and serving as a precursor for steroid hormones.
- **Complementarity:** In DNA, the specific pairing of nitrogenous bases (adenine with thymine, guanine with cytosine) between two strands, allowing for accurate replication and transcription.
- **Confirmation:** The specific three-dimensional shape of a protein, which is crucial for its biological function.
- **Contractile Proteins:** Proteins involved in muscle contraction and other forms of cellular movement (e.g., actin and myosin).
- **Dehydration Reaction:** A chemical reaction in which two molecules are joined together by the removal of a water molecule; used to build polymers from monomers.
- **Denaturation:** The process by which a protein loses its normal three-dimensional structure and, consequently, its biological activity, often due to extreme changes in temperature, pH, or chemical environment.
- **Deoxyribose:** The five-carbon sugar found in DNA nucleotides, lacking an oxygen atom at the 2' carbon compared to ribose.
- **Disaccharide:** A carbohydrate formed from two monosaccharides joined by a glycosidic linkage (e.g., sucrose).
- **Disulfide Bridge:** A strong covalent bond between the sulfur atoms of two cysteine amino acid residues, helping to stabilize protein tertiary and quaternary structures.
- **DNA (Deoxyribonucleic Acid):** A nucleic acid that serves as the genetic material in all known organisms, typically existing as a double helix of two polynucleotide strands.
- **Enzyme:** A protein (or in some cases, RNA) that acts as a biological catalyst, speeding up specific biochemical reactions.

- **Ester Linkage:** The covalent bond formed between a hydroxyl group and a carboxyl group, linking fatty acids to glycerol in fats and phospholipids.
- **Fat:** A type of lipid, also known as a triglyceride or triacylglycerol, composed of a glycerol molecule ester-linked to three fatty acids; primarily used for energy storage.
- **Fatty Acid:** A long hydrocarbon chain with a carboxyl group at one end, a component of many lipids. Can be saturated or unsaturated.
- **Fibrous Proteins:** Proteins that are long, insoluble strands, primarily serving structural roles (e.g., collagen, keratin).
- **Gene Expression:** The overall process by which information from a gene is used in the synthesis of a functional gene product, such as a protein.
- **Globular Proteins:** Proteins that are roughly spherical and soluble in water, performing various functions such as enzymes, hormones, and receptors.
- **Glycogen:** The main storage polysaccharide in animals, highly branched and composed of glucose monomers.
- **Glycosidic Linkage:** The covalent bond formed between two monosaccharides, linking them together to form disaccharides or polysaccharides.
- **Hemoglobin:** A globular, multimer protein in red blood cells that transports oxygen and carbon dioxide.
- **Hexose:** A monosaccharide containing six carbon atoms (e.g., glucose, galactose, fructose).
- **Hormonal Proteins:** Proteins that act as chemical messengers, regulating physiological processes (e.g., insulin).
- **Hydrocarbon:** An organic compound consisting entirely of hydrogen and carbon atoms. Generally nonpolar.
- **Hydrophilic:** "Water-loving"; describes substances that are attracted to or dissolve in water (typically polar or charged molecules).
- **Hydrophobic:** "Water-fearing"; describes substances that are repelled by water (typically nonpolar molecules).
- **Hydrophobic Interactions:** Weak attractive forces between nonpolar molecules or regions of molecules when surrounded by water, causing them to cluster together.
- **Hydrolysis Reaction:** A chemical reaction in which a molecule is split into smaller molecules by the addition of water; used to break down polymers into monomers.
- **Isomers:** Molecules that have the same chemical formula but different structural arrangements of atoms, leading to different properties.
- **Ketose:** A monosaccharide (simple sugar) that contains a ketone group, with the carbonyl group located somewhere other than the end of the carbon skeleton.
- **Kiten:** A structural polysaccharide found in the exoskeletons of insects and crustaceans, and in the cell walls of fungi.
- **Ligand:** A molecule that binds specifically to another, typically larger, molecule (like a protein receptor or enzyme).
- **Lipids:** A diverse group of nonpolar organic compounds including fats, phospholipids, and steroids, characterized by their insolubility in water.
- **Macromolecules:** Large organic molecules essential for life, including proteins, carbohydrates (polysaccharides), lipids, and nucleic acids.

- **Metabolism:** The sum of all chemical reactions that occur in an organism, encompassing both anabolism and catabolism.
- **Monosaccharide:** A simple sugar, the basic monomer unit of carbohydrates (e.g., glucose, fructose, galactose).
- **Multimer Protein:** A protein composed of two or more polypeptide chains associated together to form the functional protein.
- **Mutualistic Symbiosis:** A symbiotic relationship between two species where both organisms benefit.
- **Nitrogenous Base:** A nitrogen-containing organic molecule that is a component of nucleotides (e.g., adenine, guanine, cytosine, thymine, uracil).
- **Nonpolar:** Describes a covalent bond or molecule in which electrons are shared equally between atoms, resulting in no partial charges.
- **Nucleic Acids:** Polymers specialized for the storage, transmission, and expression of genetic information, including DNA and RNA.
- **Nucleotide:** The monomer subunit of nucleic acids, consisting of a pentose sugar, a phosphate group, and a nitrogenous base.
- **Oligosaccharide:** A carbohydrate composed of a relatively small number of monosaccharides (typically 3-10), more than a disaccharide but less than a polysaccharide.
- **Peptide Bond:** The covalent bond formed by a dehydration reaction between the carboxyl group of one amino acid and the amino group of another, linking them in a polypeptide chain.
- **Pentose:** A monosaccharide containing five carbon atoms (e.g., ribose, deoxyribose).
- **Phospholipid:** A type of lipid composed of a glycerol backbone, two fatty acid tails, and a phosphate group (often with another small polar molecule attached), which is amphipathic and forms cell membranes.
- **Polar:** Describes a covalent bond or molecule in which electrons are shared unequally between atoms, resulting in partial positive and negative charges.
- **Polypeptide:** A polymer of amino acids linked by peptide bonds; a single linear chain of amino acids.
- **Polysaccharide:** A complex carbohydrate polymer composed of many monosaccharide monomers joined by glycosidic linkages.
- **Primary Structure (Protein):** The unique linear sequence of amino acids in a polypeptide chain.
- **Protein:** A biologically functional molecule consisting of one or more polypeptides folded into a specific three-dimensional shape.
- **Quaternary Structure (Protein):** The overall three-dimensional arrangement of multiple polypeptide chains in a multimer protein.
- **Receptor Proteins:** Proteins, typically on cell surfaces or within cells, that bind to specific signal molecules (ligands) and transmit information into the cell.
- **Renaturation:** The process by which a denatured protein refolds back into its original, functional three-dimensional shape.
- **Replication:** The process by which DNA makes an exact copy of itself.
- **Ribose:** The five-carbon sugar found in RNA nucleotides.

- **Ribozymes:** RNA molecules that function as catalysts, similar to enzymes (which are typically proteins).
- **RNA (Ribonucleic Acid):** A nucleic acid that plays various roles in gene expression, including carrying genetic information from DNA (mRNA), transferring amino acids (tRNA), and forming ribosomes (rRNA).
- **Saturated Fatty Acid:** A fatty acid in which all carbon-carbon bonds in the hydrocarbon chain are single bonds, allowing it to be saturated with hydrogen atoms.
- **Secondary Structure (Protein):** Localized, repeating folding patterns within a polypeptide chain, primarily alpha helices and beta pleated sheets, stabilized by hydrogen bonds between backbone atoms.
- **Side Chain (R-group):** The variable part of an amino acid that determines its unique chemical properties and is responsible for the diversity of amino acids and protein shapes.
- **Starch:** A major storage polysaccharide in plants, composed of glucose monomers.
- **Steroid Hormones:** Lipid-based hormones derived from cholesterol that act as chemical signals.
- **Sterols:** A category of lipids characterized by a four-ring carbon skeleton (e.g., cholesterol).
- **Structural Polysaccharides:** Polysaccharides that provide structural support and strength to organisms (e.g., cellulose, chitin).
- **Structural Proteins:** Proteins that provide support and shape to cells and tissues (e.g., collagen, keratin).
- **Substrate:** The reactant molecule(s) upon which an enzyme acts.
- **Tertiary Structure (Protein):** The overall three-dimensional shape of a single polypeptide chain, resulting from interactions between the R-groups of the amino acids.
- **Transcription:** The process of synthesizing RNA from a DNA template.
- **Translation:** The process of synthesizing a polypeptide (protein) from an mRNA template.
- **Triglyceride:** See "Fat."
- **Triose:** A monosaccharide containing three carbon atoms (e.g., glyceraldehyde).
- **Unsaturated Fatty Acid:** A fatty acid that contains one or more double bonds in its hydrocarbon chain, resulting in kinks or bends that prevent tight packing.