Cell Biology: Overview of Organic Chemistry

AI-Generated Study Guide

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

I. Quiz

Instructions: Answer each question in 2-3 sentences.

1. **Define organic chemistry in modern terms and list two exceptions to this definition.** Organic chemistry is broadly defined as the study of carbon-containing compounds. However, there are exceptions such as pure carbon forms like graphite and diamond, as well as simple carbon compounds like carbon dioxide, which are not considered organic in a chemical context.
2. **Explain the specialness of carbon in terms of its valence and bonding versatility.** Carbon is special due to its tetravalence, meaning it consistently forms four covalent bonds. This allows it to create a vast array of stable molecules by forming single, double, or triple bonds with itself and other atoms, making it the most versatile element for molecular construction.
3. **What is a hydrocarbon, and why are they considered excellent fuel sources both inside and outside the body?** Hydrocarbons are organic compounds composed solely of hydrogen and carbon atoms. They are excellent fuel sources because the nonpolar covalent bonds between carbon and hydrogen store a significant amount of chemical energy, which can be released efficiently through combustion reactions, providing energy for various processes.
4. **Describe the concept of "valence" for an atom and how it differs from "valence electrons."** Valence refers to the number of additional electrons an atom needs to fill its outermost electron shell, or equivalently, the number of covalent bonds it must form to satisfy its bonding requirements. This differs from valence electrons, which are simply the number of electrons already present in the outermost shell.
5. **What are isomers, and what is the key difference between structural isomers and geometric isomers?** Isomers are chemical compounds that have the exact same chemical formula but different arrangements of their atoms, leading to distinct substances. Structural isomers differ in the arrangement of their carbon skeleton (e.g.,

branching), while geometric isomers involve a double bond that restricts rotation, leading to different spatial arrangements (cis/trans configurations) of atoms around that bond.

6. **Explain the concept of chirality and its significance for enantiomers in a biological context.** Chirality describes molecules that are non-superimposable mirror images of each other, similar to left and right hands. Enantiomers are chiral compounds, meaning they exist as "left-handed" (levo, L or S) and "right-handed" (dextro, D or R) versions. In biology, this is significant because biological receptors are often "handed," meaning only one enantiomer of a chemical signal or drug will fit and elicit a biological response.
7. **Identify the three components of a nucleotide, and explain the difference between a nucleotide and a nucleoside.** A nucleotide consists of a pentose sugar, a nitrogenous base, and at least one phosphate group. A nucleoside, on the other hand, is composed only of a pentose sugar and a nitrogenous base, lacking the phosphate group(s).
8. **Describe the primary function of ATP in cells, using the analogy of a "debit card."** ATP (adenosine triphosphate) serves as the primary temporary energy currency of the cell. Like a debit card with a balance, ATP stores energy in the bonds between its phosphate groups; when a phosphate is cleaved (ATP to ADP), energy is released to power cellular work, much like spending money from a debit card.
9. **What is phosphorylation and dephosphorylation, and how do cells utilize these processes to control protein function?** Phosphorylation is the process of adding a phosphate group to a molecule, typically a protein, while dephosphorylation is the removal of a phosphate group. Cells use these reversible processes as a switch to quickly change a protein's shape, thereby altering its activity (turning it "on" or "off") without the energetically expensive process of synthesizing or destroying the protein.
10. **Explain why hydrocarbons like those found in fats are considered to have a high energy density compared to carbohydrates and proteins.** Hydrocarbons, such as the fatty acid tails of fats, have a high energy density because they are composed of nonpolar carbon-hydrogen bonds, which store a large amount of chemical energy. This makes them efficient for energy storage, as the body can store more energy per gram as fat compared to carbohydrates or proteins, which have more polar bonds and are less energy-rich per unit mass.

II. Essay Questions

1. Discuss the historical and modern definitions of "organic" in chemistry, including specific examples of compounds that challenge the simpler definitions. How does the specialness of carbon's bonding contribute to the vast diversity of organic compounds?
2. Compare and contrast the three types of isomers discussed (structural, geometric, and enantiomers). Provide an example of each and explain how their distinct structures impact their chemical or biological properties, particularly in the context of biological recognition.
3. Select three functional groups discussed in the lecture (excluding methyl). For each, describe its chemical structure, categorize the type of organic compound it forms, and explain its significant role or importance in biological molecules or processes.

4. Elaborate on the significance of ATP as the "energy currency" of the cell. Trace the origin of the energy stored in ATP, explain the reversible reaction of ATP hydrolysis, and discuss how the cell regulates its ATP levels in response to energy demand.
5. Analyze the fundamental differences in bonding and properties between metals and non-metals, particularly focusing on the formation of molecules versus ionic compounds. Explain how the valence of key non-metal elements (Hydrogen, Oxygen, Nitrogen, Carbon) dictates their bonding behavior in organic molecules.

III. Glossary of Key Terms

- **Organic Chemistry:** The branch of chemistry primarily concerned with compounds containing carbon, especially carbon-hydrogen bonds.
- **Inorganic Chemistry:** The branch of chemistry dealing with compounds generally lacking carbon-hydrogen bonds, including minerals, metals, and simple carbon compounds like CO2.
- **Carbon-containing:** A broad description for compounds that include carbon atoms, but not all are necessarily "organic" in a chemical sense (e.g., graphite, diamond, CO2).
- **Tetravalence:** The property of an atom, like carbon, to form four covalent bonds. This versatility allows carbon to create diverse and complex molecular structures.
- **Hydrocarbon:** An organic compound composed exclusively of hydrogen and carbon atoms.
- **Alkane:** A type of hydrocarbon that contains only single covalent bonds between carbon atoms. Their names typically end in "-ane" (e.g., methane, ethane).
- **Alkene:** A type of hydrocarbon that contains at least one carbon-carbon double bond. Their names typically end in "-ene" (e.g., ethene, butene).
- **Alkyne:** A type of hydrocarbon that contains at least one carbon-carbon triple bond. Their names typically end in "-yne" (e.g., ethyne).
- **Valence:** The bonding capacity of an atom, specifically the number of additional electrons needed to complete its outermost electron shell. Also indicates the number of covalent bonds an atom typically forms.
- **Valence Electrons:** The electrons located in the outermost electron shell of an atom, which are involved in chemical bonding.
- **Electronegativity:** A measure of an atom's ability to attract shared electrons in a covalent bond. Differences in electronegativity determine bond polarity.
- **Nonpolar Covalent Bond:** A type of covalent bond where electrons are shared equally between two atoms due to similar electronegativity values (e.g., C-H bond).
- **Polar Covalent Bond:** A type of covalent bond where electrons are shared unequally between two atoms due to differing electronegativity values (e.g., O-H bond).
- **Isomers:** Molecules that have the same molecular formula but different arrangements of atoms, resulting in distinct chemical substances.
- **Structural Isomers (Constitutional Isomers):** Isomers that differ in the covalent arrangement of their atoms, such as branching patterns of the carbon skeleton.

- **Geometric Isomers (Cis-Trans Isomers):** Isomers that have the same covalent bonds but differ in the spatial arrangement of atoms around a rigid structure, typically a double bond, which prevents rotation.
- **Enantiomers (Optical Isomers):** Stereoisomers that are non-superimposable mirror images of each other, often arising from a chiral carbon atom bonded to four different groups.
- **Chiral Compound:** A molecule that is non-superimposable on its mirror image, possessing "handedness."
- **L and D Notation (Levo and Dextro):** A system for distinguishing between two enantiomers, referring to their "left-handed" (L) or "right-handed" (D) configuration based on specific chemical conventions.
- **S and R Notation (Sinistral and Recto):** A more systematic and unambiguous system for specifying the absolute configuration of chiral centers, where S (sinistral) indicates counter-clockwise priority and R (recto) indicates clockwise priority.
- **Functional Group:** A specific group of atoms within a molecule that is responsible for the characteristic chemical reactions of that molecule.
- **Hydroxyl Group (-OH):** A functional group consisting of an oxygen atom bonded to a hydrogen atom. Organic compounds containing hydroxyl groups are called **alcohols**.
- **Carbonyl Group (C=O):** A functional group consisting of a carbon atom double-bonded to an oxygen atom.
- **Ketone:** An organic compound containing a carbonyl group within the carbon skeleton (not at the end).
- **Aldehyde:** An organic compound containing a carbonyl group at the end of the carbon skeleton.
- **Carboxyl Group (-COOH):** A functional group consisting of a carbonyl group attached to a hydroxyl group. Compounds containing a carboxyl group are called **carboxylic acids** (or organic acids) and are typically acidic.
- **Amino Group (-NH2):** A functional group consisting of a nitrogen atom bonded to two hydrogen atoms. Compounds containing an amino group are called **amines**.
- **Sulfhydryl Group (-SH):** A functional group consisting of a sulfur atom bonded to a hydrogen atom. Compounds containing a sulfhydryl group are called **thiols**.
- **Phosphate Group (-PO4):** A functional group consisting of a phosphorus atom bonded to four oxygen atoms, typically charged. Organic compounds containing phosphate groups are called **organic phosphates**. Key roles include energy storage (ATP), structural components (phospholipids), and signaling (DNA/RNA).
- **Methyl Group (-CH3):** A functional group consisting of a carbon atom bonded to three hydrogen atoms. Compounds containing methyl groups are called **methylated compounds**.
- **ATP (Adenosine Triphosphate):** A nucleotide that serves as the primary energy currency of the cell, temporarily storing and transferring energy.
- **ADP (Adenosine Diphosphate):** A molecule similar to ATP but with two phosphate groups. It is formed when ATP releases energy by losing a phosphate.
- **AMP (Adenosine Monophosphate):** A molecule similar to ATP but with one phosphate group.

- **Nucleotide:** The monomer (building block) of nucleic acids (DNA and RNA), composed of a pentose sugar, a nitrogenous base, and one or more phosphate groups.
- **Nucleoside:** A molecule composed of a pentose sugar and a nitrogenous base, lacking the phosphate group(s) found in a nucleotide.
- **Inorganic Phosphate (Pi):** A phosphate group that is not attached to a carbon-containing molecule. It is released during ATP hydrolysis.
- **Phosphorylation:** The process of adding a phosphate group to a molecule, often to a protein, typically to activate or deactivate it.
- **Dephosphorylation:** The process of removing a phosphate group from a molecule, often to revert its activity.
- **Macromolecule:** A very large molecule, typically composed of many smaller repeating subunits. The four major classes in biology are carbohydrates, lipids, proteins, and nucleic acids.
- **Polymer:** A large molecule (macromolecule) composed of many repeating smaller units (monomers) linked together.
- **Monomer:** The basic repeating unit that makes up a polymer.
- **Entropy:** A thermodynamic property that represents the degree of randomness or disorder in a system. The second law of thermodynamics states that the entropy of the universe is always increasing.
- **Orbital:** A region of space around the nucleus of an atom where an electron is most likely to be found. Each orbital can hold a maximum of two electrons.
- **Subshell:** A group of orbitals within an electron shell that have the same energy level and shape (e.g., s, p, d, f subshells).
- **Electron Shell (Energy Level):** A principal level of electrons surrounding the nucleus of an atom, represented by periods (rows) on the periodic table.
- **Cation:** A positively charged ion, formed when an atom loses one or more electrons.
- **Anion:** A negatively charged ion, formed when an atom gains one or more electrons.
- **Ionic Bond:** A type of chemical bond formed by the electrostatic attraction between oppositely charged ions, typically between a metal and a non-metal.
- **Covalent Bond:** A type of chemical bond formed by the sharing of electron pairs between atoms, typically between two non-metals.
- **Salt:** An ionic compound formed by the combination of a cation and an anion (e.g., NaCl).
- **Formula Unit:** The empirical formula of an ionic compound, representing the simplest whole-number ratio of ions in the compound. It is the smallest electrically neutral unit of a salt.
- **Autoionization of Water:** The process by which water molecules spontaneously dissociate into hydrogen ions (H+ or protons) and hydroxide ions (OH-).
- **pH Scale:** A logarithmic scale used to specify the acidity or basicity of an aqueous solution. It is inversely related to the concentration of hydrogen ions.