Chapter 5: What are the major types of organic molecules?

1. Discuss hydrolysis and condensation, and the connection between them.

2. Carbohydrates: what are they, and what are they used for? What terms are associated with them (including the monomers and the polymer bond name)? Give some examples of molecules in this group.

3. Lipids: what are they, and what are they used for? What terms are associated with them (including major classes and bond names)? Give some examples of molecules in this group.

4. Polypeptides: what are they, and what are they used for? What terms are associated with them (including the monomers and the polymer bond name)? Give some examples of molecules in this group.

5. Discuss how to tell which of these categories an amino acid falls into: hydrophobic or hydrophilic (and within the hydrophilic, polar or charged).

6. Discuss the four levels of protein structure.

7. Nucleic acids: what are they, and what are they used for? What terms are associated with them (including the monomers and the polymer bond name)? Give some examples of molecules in this group.

8. What are 5’ and 3’ ends? What does “antiparallel” mean in DNA?

9. What are ATP, cAMP, and NAD+? What are their roles in cells?
Chapter 5: What are the major types of organic molecules?

I. many biological molecules are polymers

   A. **polymers** are long chains or branching chains based on repeating subunits (**monomers**)
      1. example: proteins (the polymer) are made from amino acids (the monomers)
      2. example: nucleic acids (the polymer) are made from nucleotides (the monomers)
   
   B. very large polymers (hundreds of subunits or more) are called **macromolecules**
   
   C. polymers are degraded into monomers by **hydrolysis** (“break with water”)
      1. typically requires an enzyme to occur at a decent rate
      2. hydrogen from water is attached to one monomer, and a hydroxyl from water is attached to the other
   
   D. monomers are covalently linked to form polymers by **condensation**
      1. also typically requires an enzyme to occur at a decent rate
      2. typically the equivalent of a water molecule is removed (dehydration synthesis)

II. The four major classes of biologically important organic molecules are: **carbohydrates**, **lipids**, **proteins** or **polypeptides** (and related compounds), and **nucleic acids** (and related compounds)

III. **carbohydrates** include sugars, starches, and cellulose

   A. carbohydrates contain only the elements carbon, hydrogen, and oxygen
   
   B. the ratio works out so that carbohydrates are typically \((\text{CH}_2\text{O})_n\)
   
   C. carbohydrates are the main molecules in biological systems created for energy storage and consumed for energy production; some are also used as building materials
   
   D. grouped into monosaccharides, disaccharides, and polysaccharides
      
      1. **monosaccharides** are simple sugars (a single monomer)
         - have 3, 4, 5, 6, or 7 carbons
         - referred to as trioses, tetroses, pentoses, hexoses, and heptoses
         - examples of pentoses include ribose and deoxyribose (part of nucleic acids)
         - examples of hexoses include **glucose**, fructose, and galactose; glucose is most abundant
         - Examine the structural formulas for glucose, fructose, and galactose. Note that they are all isomers of each other (i.e. they have the chemical formula \(\text{C}_6\text{H}_{12}\text{O}_6\)). Glucose and galactose are structural isomers of fructose, while glucose and galactose are **diastereomers** (a type of stereoisomer).
            - pentose and hexose sugars actually form ring structures in solution
                - this often creates diastereomers
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- example: \( \alpha \)-glucose and \( \beta \)-glucose
- note how carbons are given numbers to indicate position

2. disaccharides consist of two monosaccharide units
- the two monomers are joined by a glycosidic linkage or glycosidic bond
- formed when the equivalent of a water molecule is removed from the two monosaccharides
- an oxygen atom is bound to a carbon from each monomer
- typically, the linkage is between carbon 1 of one and 4 of the other
- maltose, sucrose, and lactose are common disaccharides
  - maltose (malt sugar): has two glucose subunits
  - sucrose (table sugar): glucose + fructose
  - lactose (milk sugar): glucose + galactose

3. polysaccharides are macromolecules made of repeating monosaccharides units linked together by glycosidic bonds
- number of subunits varies, typically thousands
- can be branched or unbranched
- some are easily broken down and are good for energy storage (examples: starch, glycogen)
- some are harder to break down and are good as structural components (example: cellulose)
- starch is the main storage carbohydrate of plants
  - polymer made from \( \alpha \)-glucose units linked primarily between carbons 1 and 4
  - amylose = unbranched starch chain (only have \( \alpha \)1-4 linkages)
  - amylopectin = branched starch chain (branches by linkages between carbons 1 and 6)
  - plants store starches in organelles called amyloplasts, a type of plastid
- glycogen is the main storage carbohydrate of animals
  - similar to starch, but very highly branched and more water-soluble
  - is NOT stored in an organelle; mostly found in liver and muscle cells
- cellulose is the major structural component of most plant cell walls
  - polymer made from \( \beta \)-glucose units linked primarily between carbons 1 and 4 (similar to starch, but note that the \( \beta \)1-4 linkage makes a huge difference)
  - unlike starch, most organisms cannot digest cellulose
  - cellulose is a major constituent of cotton, wood, and paper
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- cellulose contains ~50% of the carbon in found in plants
- fibrous cellulose is the “fiber” in your diet
- some fungi, bacteria, and protozoa make enzymes that can break down cellulose
- animals that live on materials rich in cellulose, e.g. cattle, sheep and termites, contain microorganisms in their gut that are able to break down cellulose for use by the animal

4. carbohydrates can be modified from the basic \((\text{CH}_2\text{O})_n\) formula
   - many modified carbohydrates have important biological roles
   - example: chitin – structural component in fungal cell walls and arthropod exoskeletons
   - example: galactosamine in cartilage
   - example: glycoproteins and glycolipids in cellular membranes

IV. lipids are fats and fat-like substances
   A. lipids are a heterogeneous group of compounds defined by solubility, not structure
   B. oily or fatty compounds
   C. lipids are principally hydrophobic, and are relatively insoluble in water (some do have polar and nonpolar regions)
      1. lipids consist mainly of carbon and hydrogen
      2. some oxygen and/or phosphorus, mainly in the polar regions of lipids that have such regions
   D. roles of lipids include serving as membrane structural components, as signaling molecules, and as energy storage molecules
   E. major classes of lipids that you need to know are triacylglycerols (fats), phospholipids, and terpenes
   F. triacylglycerols contain glycerol joined to three fatty acids
      1. glycerol is a three carbon alcohol with 3 -OH groups
      2. a fatty acid is a long, unbranched hydrocarbon chain carboxyl group at one end
         - saturated fatty acids contain no carbon-carbon double bonds (usually solid at room temp)
         - unsaturated fatty acids contain one or more double bonds (usually liquid at room temp)
            - monounsaturated – one double bond
            - polyunsaturated – more than one double bond
         - about 30 different fatty acids are commonly found in triacylglycerols; most have an even number of carbons
      3. condensation results in an ester linkage between a fatty acid and the glycerol
         - one attached fatty acid = monoacylglycerol
         - two = diacylglycerol
         - three = triacylglycerol
4. triacylglycerols (also called triglycerides) are the most abundant lipids, and are important sources of energy

G. phospholipids consist of a diacylglycerol molecule, a phosphate group esterified to the third -OH group of glycerol, and an organic molecule (usually charged or polar) esterified to the phosphate

1. phospholipids are amphipathic; they have a nonpolar end (the two fatty acids) and a polar end (the phosphate and organic molecule)

2. this is often drawn with a polar “head” and two nonpolar “tails”

3. the nonpolar (or hydrophobic) portion of the molecule tends to stay away from water, and the polar (or hydrophilic) portion of the molecule tends to interact with water

4. because of this character phospholipids are important constituents of biological membranes

H. terpenes are long-chained lipids built from 5-carbon isoprene units

1. many pigments, such as chlorophyll, carotenoids, and retinal, are terpenes or modified terpenes (often called terpenoids)

2. other terpenes/terpenoids include natural rubber and “essential oils” such as plant fragrances and many spices

3. steroids are terpene derivatives that contain four rings of carbon atoms
   - side chains extend from the rings; length and structure of the side chains varies
   - one type of steroid, cholesterol, is an important component of cell membranes
   - other examples: many hormones such as testosterone, estrogens

V. proteins are macromolecules that are polymers formed from amino acids monomers

A. proteins have great structural diversity and perform many roles

B. roles include enzyme catalysis, defense, transport, structure/support, motion, regulation; protein structure determines protein function

C. proteins are polymers made of amino acid monomers linked together by peptide bonds

1. amino acids consist of a central or alpha carbon; bound to that carbon is a hydrogen atom, an amino group (-NH₂), a carboxyl group (-COOH), and a variable side group (R group)
   - the R group determines the identity and much of the chemical properties of the amino acid
   - there are 20 amino acids that commonly occur in proteins; pay attention to what makes an R group polar, nonpolar, or ionic (charged) and thus their hydrophobic or hydrophilic nature
   - most amino acids have enantiomers; when this is so, the amino acids found in proteins are nearly always of the L-configuration
   - plants and bacteria can usually make their own amino acids; many animals must obtain some amino acids from their diet (essential amino acids)
2. the **peptide bond** joins the carboxyl group of one amino acid to the amino group of another; is formed by a condensation reaction

3. two amino acids fastened together by a **peptide bond** is called a dipeptide, several amino acids fastened together by peptide bonds are called a **polypeptide**

D. the sequence of amino acids determine the structure (and thus the properties) of a protein

E. proteins have 4 levels of organization or structure

1. **primary structure** ($1^\circ$) of a protein is the sequence of amino acids in the peptide chain

2. **secondary structure** ($2^\circ$) of a protein results from hydrogen bonds involving the backbone, where the peptide chain is held in structures, either a coiled $\alpha$-helix or folded $\beta$-pleated sheet; proteins often have both types of secondary structure in different regions of the chain

3. **tertiary structure** ($3^\circ$) of a protein is the overall folded shape of a single polypeptide chain, determined by secondary structure combined with interactions between R groups (NOTE: book defines this in a confusing way, use my way)

4. **quaternary structure** ($4^\circ$) of a protein results from interactions between two or more separate polypeptide chains

   - the interactions are of the same type that produce $2^\circ$ and $3^\circ$ structure in a single polypeptide chain
   - when present, $4^\circ$ structure is the final three-dimensional structure of the protein (the **protein conformation**)
   - example: hemoglobin has 4 polypeptide chains
   - not all proteins have $4^\circ$ structure

5. ultimately the secondary, tertiary, and quaternary structures of a protein derive from its primary structure, but molecular chaperones may aid the folding process

6. protein conformation determines function

7. **denaturation** is unfolding of a protein, disrupting $2^\circ$, $3^\circ$, and $4^\circ$ structure

   - changes in temperature, pH, or exposure to various chemicals can cause denaturation
   - denatured proteins typically cannot perform their normal biological function
   - denaturation is generally irreversible

F. **enzymes** are biological substances that regulate the rates of the chemical reactions in living organisms; most enzymes are proteins (covered in some detail later in this course)

G. “related compounds” –amino acids; modified amino acids; polypeptides too short to be considered true proteins; and modified short polypeptides
VI. **nucleic acids** transmit hereditary information by determining what proteins a cell makes

A. two classes of nucleic acids found in cells: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA)
   1. DNA carries the genetic information cells use to make proteins
   2. RNA functions in protein synthesis according to mechanisms we will discuss later in the semester

B. nucleic acids are polymers made of nucleotide monomers
   1. a nucleotide consists of
      - a five-carbon sugar (ribose or deoxyribose)
      - one or more **phosphate groups**, and
      - a **nitrogenous base**, an organic ring compound that contains nitrogen
   2. **purines** are double-ring nitrogenous bases
   3. **pyrimidines** are single-ring nitrogenous bases

C. DNA typically contains the purines adenine (A) and guanine (G), and the pyrimidines cytosine (C) and thymine (T)

D. RNA typically contains the purines adenine (A) and guanine (G), and the pyrimidines cytosine (C) and uracil (U)

E. nucleotides are fastened together by **phosphodiester bonds**
   1. the phosphate group of one nucleotide is fastened to the sugar of the adjacent nucleotide
   2. the joining is yet another condensation reaction
   3. the way that the are joined creates a polynucleotide strand with 5’ and 3’ ends

F. the sequence of the 4 bases fastened to the sugar-phosphate backbone is genetic information

G. DNA is typically a double stranded molecule
   1. the two strands twist into a double helix
   2. hydrogen bonds between the nitrogenous bases of opposite strands hold the strands together
   3. the two strands are **antiparallel**

H. RNA is typically a single stranded nucleic acid molecule, having only a single polynucleotide chain

I. “related compounds” – nucleotides, modified nucleotides, dinucleotides

J. some single and double nucleotides with important biological functions:
   1. adenosine triphosphate (ATP) is an important energy carrying compound in metabolism
   2. cyclic adenosine monophosphate (cAMP) is a hormone intermediary compound
   3. nicotinamide adenine dinucleotide (NAD⁺) is an electron carrier which is oxidized or reduced in many metabolic reactions