Module 1D – Biochemistry

- Biochemistry is the chemistry of living organisms.
- In this module we will focus on the structure, function, and properties of the various organic molecules that make up living organisms.

Objective # 18

Distinguish between organic and inorganic molecules.

Objective 18

- Inorganic molecules:
  - Relatively small, simple molecules that usually lack C (a few have one C atom).
  - Examples: H₂O, CO₂, NH₃, O₂, H₂

- Organic molecules:
  - Larger, more complex molecules whose structure is based on a backbone of C atoms (always contain C as a major part of their structure).
  - Examples: C₆H₁₂O₆, C₂H₅COOH
  - Living organisms are composed of both inorganic and organic molecules.

Objective # 19

Identify the characteristics of carbon that allow it to play such an important role in the chemistry of life.

Objective 19

- Carbon has an atomic # of 6. How many valence electrons does it have?
- Carbon can form 4 strong covalent bonds with up to 4 other atoms.
- Carbon atoms can form strong covalent bonds with each other to produce unbranched chains, branched chains, and rings.
Objective 19

- Carbon rings can join with each other to form interlocking rings or chains of rings.
- Carbon can form single, double, or triple covalent bonds with other atoms.

Objective # 20

Explain what isomers are.

Objective 20

- Isomers are molecules that have the same molecular formula (same number and type of atoms) but which have different properties because the atoms are arranged differently.

Isomers of C₆H₁₂O₆

- Fructose
- Glucose
- Galactose

Objective # 21

Explain what a functional group is, and be able to identify the structure and characteristics of each of the following functional groups:

a) hydroxyl
b) carboxyl
c) amine
d) methyl
e) phosphate

Objective 21

- A functional group is a small group of atoms that is part of a larger molecule and gives it specific properties.
Objective # 22
Define the following terms and be able to give or recognize examples of each:

a) Monomer, dimer, polymer
b) Condensation reaction (or dehydration synthesis)
c) Hydrolysis reaction

Objective 22a

- Large organic molecules are called macromolecules.
- Macromolecules are formed by joining smaller organic molecules called subunits, or building blocks, or monomers.
- When 2 similar or identical monomers are joined we get a dimer.

Objective 22b

- Subunits are joined during a type of reaction called condensation or dehydration synthesis. An –OH is removed from one subunit, an –H is removed from the other, and H₂O is formed.
Objective 22c
The reverse reaction is called hydrolysis. It involves breaking a macromolecule into smaller subunits. A molecule of water is added for each subunit that is removed:

Objective # 23
- Describe the structure and functions of each of the following groups of organic compounds. Also be able to identify examples from each group:
  a) Carbohydrates
  b) Lipids
  c) Proteins
  d) Nucleotide-based compounds

Objective 23a
- Carbohydrates are made of monomers called simple sugars or monosaccharides.
- Monosaccharides are used for short term energy storage, and serve as structural components of larger organic molecules.
- They contain C, H, and O in an approximate ratio of 1:2:1.

Objective 23a
- Monosaccharides are classified according to the number of C atoms they contain:
  > 3 C = triose e.g. glyceraldehyde
  > 4 C = tetrose
  > 5 C = pentose e.g. ribose, deoxyribose
  > 6 C = hexose e.g. glucose, fructose, galactose
- Monosaccharides in living organisms generally have 3C, 5C, or 6C:
Objective 23a

- When monosaccharides with 5 or more C atoms are dissolved in water (as they always are in living systems) most of the molecules assume a ring shape.
- Glucose can form 2 types of rings, α-glucose and β-glucose:

Fructose and α-glucose can be joined by a condensation reaction to produce the disaccharide sucrose:

Many organisms transport sugar within their bodies in the form of disaccharides.
Two α-glucose molecules can be joined by a condensation reaction to produce the disaccharide maltose:

Galactose and α-glucose can be joined by a condensation reaction to produce the disaccharide lactose:

Objective 23a

- Polysaccharides consist of many monosaccharides joined by condensation to form long branched or unbranched chains.
- Some polysaccharides are used to store excess sugars, while others are used as structural materials.

Objective 23a

- Storage Polysaccharides:
  - α-glucose subunits can be joined by α-1,4 linkages to form long unbranched chains

Objective 23a

- Branches can be added to the chain using α-1,6 linkages:

Objective 23a

- Plants use α-glucose to make starches, including amylose (coiled and unbranched) and amylopectin (coiled and branched):
Objective 23a

- Animals use $\alpha$-glucose to make glycogen which is more extensively branched than amylopectin:

![Glycogen](image)

Objective 23a

- Structural Polysaccharides:
  - Cellulose is a long unbranched chain of $\beta$-glucose subunits. It is a major component of plant cell walls.

![Cellulose structure](image)

Objective 23a

- Chitin is similar to cellulose, but a nitrogen group is added to each glucose. It is found in the exoskeleton of arthropods and cell walls of fungi.

Objective 23b

- Lipids are structurally diverse molecules that are greasy and insoluble in H$_2$O.
- We will examine 4 types of lipids:
  - Fats and oils
  - Phospholipids
  - Terpenes
  - Steroids

Objective 23b

- Fats and oils are composed of 2 types of subunits: glycerol and fatty acids.
- Glycerol is an alcohol with 3 carbons, each bearing a hydroxyl group:

H H H
H - C - C - C - H
O O O
H H H

Objective 23b

- A fatty acid has a long hydrocarbon chain with a carboxyl group at one end.
- It may be saturated (no double bonds between the C atoms of the hydrocarbon chain), monounsaturated (one double bond), or polyunsaturated (more than one double bond).
- H can be added to unsaturated fatty acids using a process called hydrogenation.
Fatty Acids:

- Glycerol + 1 fatty acid = monoglyceride
- Glycerol + 2 fatty acids = diglyceride
- Glycerol + 3 fatty acids = triacylglycerol (also called a triglyceride or fat.)

Saturated fat

- Most animal fats contain saturated fatty acids and tend to be solid at room temperature.

- Most plant fats contain unsaturated fatty acids. They tend to be liquid at room temperature, and are called oils.

Objective 23b

Unsaturated fat

- Because fats and oils are such concentrated sources of energy, they are often used for long term energy storage.

- In animals, fats also act as insulators and cushions.
Objective 23b

- In phospholipids, two of the –OH groups on glycerol are joined to fatty acids. The third –OH joins to a phosphate group which joins, in turn, to another polar group of atoms.
- The phosphate and polar groups are hydrophilic (polar head) while the hydrocarbon chains of the 2 fatty acids are hydrophobic (nonpolar tails).

Objective 23b

- In water, phospholipids will spontaneously orient so that the nonpolar tails are shielded from contact with the polar H₂O molecules.
- Phospholipids are major components of cell membranes.

Objective 23b

- Terpenes are long-chain lipids that are components of many important biological pigments such as chlorophyll.
Objective 23b

- Steroids are lipids whose principle component is the steroid nucleus, a structure made of 4 interlocking rings of carbon atoms.

- Examples:
  - Cholesterol is a component of animal cell membranes.

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Objective 23b

- Testosterone and estrogen are steroids that function as sex hormones. Hormones are chemical messengers. After being secreted by endocrine glands, they are carried by the blood to specific target cells where they trigger a response, such as the production or activation of a protein:

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Objective 23c

- Proteins perform many essential functions in living organisms:

<table>
<thead>
<tr>
<th>Function</th>
<th>Class of Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalysis</td>
<td>enzymes</td>
</tr>
<tr>
<td>Defense</td>
<td>immunoglobulins, toxins</td>
</tr>
<tr>
<td>Cell recognition</td>
<td>antigens</td>
</tr>
<tr>
<td>Transport through the body</td>
<td>globins</td>
</tr>
<tr>
<td>Membrane transport</td>
<td>transporters</td>
</tr>
<tr>
<td>Structure/support</td>
<td>fibers</td>
</tr>
<tr>
<td>Motion</td>
<td>muscle</td>
</tr>
<tr>
<td>Osmotic regulation</td>
<td>albumin</td>
</tr>
<tr>
<td>Gene regulation</td>
<td>repressors, activators</td>
</tr>
<tr>
<td>Messengers</td>
<td>hormones</td>
</tr>
<tr>
<td>Storage</td>
<td>Ion binding</td>
</tr>
</tbody>
</table>
Objective 23c

- One of the most important groups of proteins are enzymes.
- Enzymes are proteins that function as catalysts – substances that facilitate or speed up specific chemical reactions without being altered themselves.

Objective 23c

- Proteins are composed of monomers called amino acids.
- An amino acid consists of a central carbon atom joined to 4 other groups:
  - H atom
  - Amino group (NH$_2$)
  - Carboxyl group (COOH)
  - R group (varies)

Three amino acids with the central carbon in red, the amino group in blue, and the R group shaded in white:

Objective 23c

- About 20 different amino acids occur naturally in proteins. They are identical except for the R group.
- Two amino acids can join by condensation to form a dipeptide plus H$_2$O.
- The bond between 2 amino acids is called a peptide bond.
Objective 23c

- A polypeptide consists of many amino acids joined by peptide bonds to form a long unbranched chain:

  ![Peptide bond](image)

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Objective 23c

- A protein consists of one or more polypeptides which are coiled and folded into a specific 3-D shape.
- The final overall shape of a protein determines its function.

Objective 23c

- Scientists generally recognize 4 levels of protein structure:
  1) Primary structure is the sequence of amino acids in the polypeptide chains that make up a protein
     - e.g. Ala-Gly-Val-Ser-Glu-Val-His-

![Primary Structure of a protein](image)

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Objective 23c

- Secondary structure is the regular, repeated pattern of coiling or folding that occurs in certain areas of the polypeptide chain.
  - the two most common patterns are the β-pleated sheet and the α-helix

![Secondary Structure](image)

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3) Tertiary structure – the final overall shape of a protein. Proteins can be classified into 2 basic shapes:
   - Globular – compact, round shape; these proteins are soluble in H₂O
   - Fibrous – thin, threadlike shape; these proteins are insoluble in H₂O

4) Quaternary structure – the way the different polypeptide chains of a protein fit together. Only present in proteins composed of more than one polypeptide chain.

- The way a polypeptide coils and folds is determined by a variety of chemical interactions. The stability of these interactions is affected by environmental conditions such as temperature and pH.
- In addition, cells have chaperone proteins, which help the polypeptides fold correctly.
If a protein’s environment is altered, the protein may change its shape or even unfold completely. This process is called denaturation.

When proteins are denatured, they are usually rendered biologically inactive.
Objective 23d

- Nucleotide-based compounds are composed of subunits called nucleotides.

- A nucleotide consists of 3 parts:
  - Pentose (5 C) sugar – ribose/deoxyribose
  - Nitrogenous base attached to 1' C
  - Phosphate group (-PO₄) attached to 5' C

Objective 23d

- There are 2 types of nitrogenous bases:
  - Purines have a double ring structure and include adenine (A) and guanine (G).
  - Pyrimidines have a single ring structure and include cytosine (C), thymine (T), and uracil (U).

Objective 23d

- We will examine 3 groups of nucleotide-based compounds:
  - Adenosine phosphates
  - Nucleotide coenzymes
  - Nucleic acids
Objective 23d

- Adenosine phosphates:
  - Ribose + Adenine = Adenosine
  - Adenosine + 1 phosphate = AMP (adenosine monophosphate)
  - Adenosine + 2 phosphates = ADP (adenosine diphosphate)
  - Adenosine + 3 phosphates = ATP (adenosine triphosphate)

Objective 23d

- cAMP plays an important role as a second messenger.
- ATP is called the “energy currency” of the cell. The energy stored in the bond that connects the third phosphate to the rest of the molecule supplies the energy needed for most cell activities.

Objective 23d

- Nucleotide coenzymes:
  - consist of 2 nucleotides joined by condensation
  - e.g. NAD⁺, FAD, NADP⁺
  - function as electron carriers. They transport e⁻ and H⁺ within the cell for use in chemical reactions.

Objective 23d

- Nucleic acids (RNA and DNA) are polynucleotides.
  - The nucleotides in RNA contain the sugar ribose and the bases A, G, C, U.
  - The nucleotides in DNA contain the sugar deoxyribose and the bases A, G, C, T.
Objective 23d

RNA:
- consists of a single, unbranched chain of RNA nucleotides.
- plays several important roles during the process of protein synthesis.

DNA:
- consists of 2 unbranched chains of DNA nucleotides twisted into a double helix.
- the 2 chains are held together by H bonds between the nitrogenous bases.
- A always pairs with T, and G with C.
- functions as the heredity information in all living organisms.
DNA vs. RNA