2

MOLECULES OF LIFE

Chapter Outline

Learning Objectives

2.1 Discuss the history and harmful health effects of *trans* fats.
2.2 Describe the atom and its components.
2.3 Define a chemical bond and, using examples, illustrate the different types of chemical bonds.
2.4 Explain the composition and properties of water.
2.5 Define pH and explain its importance in the maintenance of biological functions.
2.6 Define organic molecules and demonstrate their importance in the structure and function of biological systems.
2.7 Summarize the types of carbohydrates with examples.
2.8 Describe the structures and functions of the various types of lipids.
2.9 Describe the structure of a protein and explain its importance to protein function.
2.10 Describe the features and functions of various types of nucleic acids.

Key Terms

acid	ATP	carbohydrate
amino acid	base	cellulose
atomic number	buffer	charge

chemical bond
cohesion
compound
concentration
covalent bond
denature
DNA
electron
element
evaporation
fat
fatty acid
free radical
hydrogen bond
hydrophilic
ion
hydrophobic
ionic bond
isotopes
lipid
lipid bilayer
mass number
metabolism
monomers
nucleic acid
nucleotide
nucleus
neutron
organic
peptide bond
pH
phospholipid
polarity
polymers
prion
protein
proton
radioisotope
radioactive decay
reaction
RNA
salt
saturated fatty acid
shell model
solute
solution
solvent
steroid
temperature
tracer
triglyceride
unsaturated fatty acid
wax

Lecture Outline

2.1 Fear of Frying

A. The human body requires about one tablespoon of fat a day for survival. Many individuals routinely consume more fat than this, leading to an increase in several conditions, including heart disease.

B. Hydrogenation, for example, makes fats worse for human consumption, but it is created and marketed at an inexpensive price.

C. Organisms all require the same molecules as building blocks, but a small difference in how those molecules are assembled radically changes their functions.

2.2 Start with Atoms

A. Life's unique properties start with the properties of atoms.
   1. Atoms are the smallest building block of all substances.
   2. Atoms are composed of positively charged protons, negatively charged electrons, and neutral neutrons.
   3. Protons and neutrons are located in a central nucleus, while electrons orbit the nucleus.
   4. Atoms differ in their number of subatomic particles (protons, neutrons, and electrons).

B. Isotopes are elements with different numbers of neutrons in their nucleus.
   1. Mass number is a measure of the protons and neutrons in a nucleus.
   2. Some isotopes are radioactive, or radioisotopes, which means they are unstable, and they degenerate.
   3. Radioactive decay occurs when a nucleus sheds a neutron, proton, or both. This process is not affected by heat, and happens at a predictable and constant rate for different radioisotopes.

a. For example, ^{14}C decays into ^{14}N. Because of the constancy of this transformation, it is often used to date rocks.

4. Radioisotopes are also injected into organisms and used as tracers. ^{14}C can be injected into an organism and it will act like ^{12}C, except it can be detected because of its radioactivity. These molecules are called tracers.

C. Why Electrons Matter
1. Electrons are small but confer important properties to their atoms.
2. Electrons sit in special and predictable orbits, orbitals, around the nucleus of an atom.
3. A shell model is used to describe how the electrons exist in the orbital.
    a. The first shell holds two low-energy electrons.
    b. The more electrons an atom has, the more it fills the outer shells.
    c. If the outer shell of an electron is full, the molecule tends to be stable and nonreactive.
    d. If an atom has vacancies in its outer shell, it will react with other molecules to balance that outer shell.

D. Ions
1. Electrons and protons both have charges that equally balance each other out.
2. Changing the number of electrons in an atom changes its overall charge and creates an ion.

2.3 From Atoms to Molecules

A. Atoms can interact with other atoms and form unions called bonds.
1. A molecule is a union of two or more atoms of the same element.
2. A compound is a union of two or more different elements.
3. There are several different types of bonds that are described based on how the interaction occurs between participants in the bond.

B. Ionic bonds.
1. Ionic bonds are formed by the mutual attraction of two differently charged ions.
2. Ionic bonds form because of differences in charge.

C. Covalent bonds.
1. Covalent bonds form when two atoms share pairs of electrons in their outer shells.
2. Atoms can share up to three pairs of electrons.
3. Some covalent bonds can create polarity, or an uneven pull on the shared electrons.
    a. Nonpolar bonds represent equal electron sharing between atoms.
    b. In a polar bond, one atom exerts a stronger pull on the shared electrons, creating partial charges on the atoms. The best example is H_2O.
4. The oxygen exerts a stronger attraction on the shared electron. Because the negatively charged electrons are pulled closer to the oxygen, it confers a partially negative charge on that oxygen.
5. Because the shared electrons are pulled away from the hydrogen, the proton of the hydrogen now creates a partial positive charge.
6. Overall, one water molecule has no charge. There is a negative pole at the oxygen and positive poles at the hydrogen.

D. Hydrogen bonds.
1. The partial charges created by a polar covalent molecule can create interactions with other polar covalent molecules.
2. Hydrogen bonds are created by mutual attraction of two opposite partial charges.
3. Hydrogen bonds are much weaker than ionic or covalent bonds.

2.4 Hydrogen Bonds and Water

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   Hydrogen bonds are much weaker than ionic or covalent bonds.

B. Life emerged in water; living things are composed of mostly water; all metabolic reactions are carried out in water; water is important for life.

C. Water's special properties are based on the nature of its structure.
   1. Water is a polar covalent molecule as described in the previous section.
   2. This polarity causes attraction and hydrogen bonding, and leads to the characteristics of water.

D. Properties of water.
   1. Water is an excellent solvent.
      a. Solvents are substances that dissolve substances and then distribute the solute.
      b. Salts and sugars are two examples of solutes that dissolve easily in water.
   2. A salt is a solution that dissolves in water and releases ions other than H^+ and OH^-.
   3. Water creates special interactions with other compounds.
      a. Molecules that easily dissolve in water are called hydrophilic.
      b. Molecules that do not dissolve in water are considered hydrophobic.
   4. Water has temperature stability.
      a. Temperature is a measure of the energy of molecular motion.
      b. Hydrogen bonding restricts motion in water molecules, reducing the effect of adding energy to water. This allows water to absorb more energy than other substances before changing temperature.
   5. Water has cohesion.
      a. Because of the hydrogen bonds between water molecules, they resist being separated from each other.

2.5 Acids and Bases

A. Water can be separated into hydrogen (H^+) ions and hydroxide (OH^-) ions.

B. pH is a measure of the number of H^+ ions in a solution.
   1. If H^+ and OH^- are balanced, the solution is neutral, or pH 7. Pure water is neutral.
   2. If there are more H^+ ions, then the pH decreases or becomes acidic.
   3. If there are more OH^- ions, then the pH increases or becomes basic.
   4. Acids release H^+ into solutions.
   5. Bases accept H^+ ions.
   6. Acid and base interactions are controlled by organisms using buffers.
      a. A buffer is usually a weak acid or base and a salt that stabilizes a solution.

2.6 Organic Molecules

A. Living organisms are composed mainly of hydrogen, oxygen, and carbon.

B. Molecules that contain carbon and hydrogen are considered organic.

C. Carbon is a versatile molecule because it can bond with four other atoms.

D. From structure to function.
   1. Organic molecules are built differently but have similarities because of common origins.

2. Carbohydrates, proteins, lipids, and nucleic acids are composed of small organic subcomponents, or monomers (simple sugars, amino acids, fatty acids, and nucleotides, respectively).
3. Reactions create polymers from many monomers or break down polymers into the monomers that make them up.

2.7 Carbohydrates

A. Carbohydrates consist of carbon, hydrogen, and oxygen in a 1:2:1 ratio.
B. The monomer of carbohydrates is a five- or six-carbon simple sugar.
C. Most carbohydrates are water soluble, which allows for easy transport.
D. Cells use glucose (six carbons) as an energy source or for structure.
E. Carbohydrates exist in several variations.
   1. Monosaccharides contain one simple sugar.
   2. Disaccharides consist of two sugars, such as glucose and fructose combined to make sucrose.
   3. Oligosaccharides consist of a few (three or more) simple sugars and are generally attached to lipids or proteins for functions.
   4. Polysaccharides, or complex carbohydrates, contain many simple sugars linked together. The most common polysaccharides contain only glucose linked together in different arrangements.
      a. Cellulose is a plant carbohydrate where glucose is laid down side by side.
      b. Starch, also a plant carbohydrate, is on a long chain of glucose that wraps around like a spiral staircase.
      c. Glycogen is an animal polysaccharide where glucose forms branching patterns.

2.8 Lipids

A. Lipids are fatty, waxy, or oily substances in nature.
B. One common monomer of lipids is a fatty acid, a long hydrocarbon chain.
   1. Fats are lipids with one, two, or three fatty acids that are attached to an alcohol called glycerol.
      a. Most neutral fats have three fatty acid tails and are called triglycerides.
      b. Fatty acid tails that have only single bonds are considered saturated fats. Most saturated fats are solid at room temperature.
      c. Fatty acids with one or more double bonds are called unsaturated fats and are usually oils at room temperature.
   2. Phospholipids consist of two fatty acid tails attached to a phosphate head.
      a. The tails are hydrophobic, while the heads are hydrophilic.
      b. Phospholipids are the majority component of the cell membrane and form into a double-layer barrier.
         1. The phosphate heads face the inside and outside of the cell, while the hydrophobic tails sandwich in between the two layers of phosphate.
         2. The hydrophobic tails create a hydrophobic barrier that surrounds the cell.
   3. Waxes are complex lipid structures consisting of fatty acids bound to alcohol or carbon chains.
      a. The molecules pack so tightly that they form firm, water-repellent layers.
      b. Plants secrete a layer of wax to protect their exposed surfaces.
      c. Humans secrete waxes to lubricate their skin and hair.
      d. Bees store waxes in order to create honeycombs.

4. Steroids are lipids with carbon rings instead of fatty acid chains.
    a. Cholesterol is the most common steroid.
    b. Steroid hormones are a derivative of steroids.

2.9 Proteins

A. Proteins are compounds composed of one or more chains of amino acids.
B. An amino acid is a compound with an amine group, a carboxyl group, and an R group. The R group is a side chain.
C. Proteins are very diverse and complete many functions: structure, nutrition, enzymes, transport, communication, and immunity.
D. Thousands of different proteins are assembled from 22 different amino acids.
E. Protein synthesis involves the formation of peptide bonds, which create a union of carboxyl and amine groups. Long protein chains are sometimes referred to as polypeptide chains.
F. Proteins have a complex three-dimensional shape.
    1. The individual polypeptide sequence, the sequence of amino acids, is called the primary structure.
    2. As the polypeptide is formed, the primary structure starts to fold back onto itself into either a helical or pleated, sheet-like shape. This is the secondary structure of the protein.
    3. The complete three-dimensional shape of one amino acid chain is its tertiary shape.
    4. Finally, sometimes multiple chains associate with each other to create a complex protein. If two or more amino acid chains form a three-dimensional shape, it is said to have a quaternary structure.
G. The importance of protein structure.
    1. A protein only functions properly if it is in its correct three-dimensional shape, also called its conformation.
    2. A protein's conformation is held together by hydrogen bonds, which can be disrupted by changes in heat or pH.
        a. If a protein changes into a nonfunctional shape, it becomes denatured.
        b. Sometimes harmful protein variants form, called prions. Prions accumulate in brain tissue and cause serious damage to individuals carrying the prion variant.

2.10 Nucleic Acids

A. Nucleotides are small organic molecules that can act as energy carriers, coenzymes, chemical messengers, and as the subunits of DNA and RNA.
B. Nucleotides are composed of a phosphate group, a five-carbon sugar, and a nitrogen base.
    1. ATP has three phosphate groups; the outermost phosphate group allows for a great deal of energy transfer and plays a major role in metabolism.
    2. Nucleic acids are chains of nucleotides where the sugars of one nucleotide bond to the phosphates of another nucleotide.
    3. DNA, deoxyribonucleic acid, has a ribose sugar and only four different nitrogen bases. DNA consists of two nucleotide strands that run next to each other and form a double helix.
        a. DNA functions to store genetic information that carries out functions in the cell and can be reproduced for cellular and organismal reproduction.

Suggestions for Presenting the Material

- It is easy to assume that the information in this chapter is common knowledge. Indeed, students will have a variety of experience in biochemistry. Students with more experience can help the others during this time. Have students bring their text to class. Prepare a worksheet that breaks the chapter into several small but meaningful questions. Break class into smaller groups and assign each group one question. Give them 10–15 minutes to answer their questions, and then have them teach the class based on their answers. There will still be the ability to control what information the other students get by acting as a filter between the group and the class. However, this assigns an active role for the students in the learning process.
- If using class time is not an option, give the students a worksheet with the questions in advance, and have them answer the questions before attending class.
- Be careful when introducing chemical terminology that does not appear in this text. Without an adequate resource, it may confuse some of the students. If adding terminology that is not in the text is preferred, consider creating an online wiki for students or a vocabulary list that they are responsible for learning, so students at least have the correct spelling of words to be able to search for their meanings.
- Use lots of examples to explain the concepts in this chapter.
- Draw chemical equations on the board.
- Bring in ball-and-stick models and construct compounds with your students.
- Spend time stressing that the importance of water is based on its polar structure and its ability to hydrogen bond. Do in-class demonstrations using water to demonstrate its temperature stability compared to other substances.

Classroom and Laboratory Enrichment

- Have students create a notebook with drawings of each organic molecule with functions and comparisons.
- Complete a series of tests of temperature stability, cohesion, and solubility with water and other various liquids.
- Use a pH meter to test a series of common solutions.
- Test water versus other aqueous solutions for a variety of different variables: boiling point, freezing point, cohesion, evaporation, solvent ability. Sort the results into categories that describe how close the solution would be related to water.
- Try to dissolve different substances in water. Determine which substances dissolved easiest and why.
- Determine the amount of macromolecules in some common foods. Try to examine the food pyramid based on its similarities to the important macromolecules.

Impacts, Issues: Classroom Discussion Ideas

- Should the U.S. ban hydrogenated fats?
- Should a ban on hydrogenated fats take place at the level of restaurants or food production companies?
- How would this type of ban be enforced?
- How would this be similar/dissimilar to banning smoking?
- Some food companies claim to have zero *trans* fats in their products despite having up to one-half a gram of trans fats. How should that activity be regulated?

Additional Ideas for Classroom Discussion

- What are the differences between elements, atoms, and molecules?
- What is a radioisotope, and what are its benefits in research science?
- What is an ion, and why is it considered important biologically?
- How would you be able to identify an ion?
- What are the different types of chemical bonds? What are their strengths? Why are they important to biological systems?
- Why does hydrogen bonding make water such an important molecule?
- What are all of the important properties of water, and why are they important?
- Why is water considered the universal solvent?
- How is saying that an acid is strong or weak different than just measuring the absolute pH value?
- What makes a molecule organic? How would you identify an organic molecule?
- What are the four basic classes of organic molecules? How do they differ structurally? Functionally?
- What is the difference between a monomer and a polymer?
- Why is three-dimensional shape, or conformation, so critical to the functioning of protein molecules?
- What properties of lipids make them so incompatible with water?
- What is an energy carrier molecule?
- Why is the digestive system able to withstand a variety of pH changes, while other internal tissues are not?
- What is the difference between a hydrophobic and a hydrophilic substance?
- What makes a substance hydrophobic or hydrophilic?
- Why do ionic substances tend to dissolve so easily in water?

Suggested Articles

“Die-Off Fueled by Acidifying Oceans: Mass Extinction May Trace Partly to Changes in Water's pH.” Witze, A. *Science News,* 2011.
“Oldest Complex Organic Molecules Isolated.” *UPI NewsTrack,* 2006.
“Cholesterol: The Good, the Bad, and the Ugly.” D’Arrigo, T. *Diabetes Forecast*, 1999.

Videos, Animations, and Websites

Videos

National Science Foundation
Chemistry Now-Chemistry of Water.
http://www.nsf.gov/news/special_reports/chemistrynow/chem_water.jsp

Canadian Museum of Nature
How salt dissolves in water.
https://www.youtube.com/watch?v=xdedxfhcpWo

Bozeman Science—Carbohydrates
A video overview of carbohydrates.
https://www.youtube.com/watch?v=_zm_DyD6FJ0

Bozeman Science—The Lipids
A video overview of lipids.
https://www.youtube.com/watch?v=VGHD9e3yRIU

Bozeman Science—Proteins
A video overview of proteins.
http://www.bozemanscience.com/proteins/

Websites

American Museum of Natural History Water H_2O = Life Exhibit
An exhibit on the properties and importance of water.
http://www.amnh.org/exhibitions/water/

Modern Physics—University of Virginia
An overview of the history of atomic theory.
http://galileo.phys.virginia.edu/classes/252/atoms.html

USGS Water Basics
Information on many aspects of water.
http://ga.water.usgs.gov/edu/mwater.html

Centers for Disease Control: Nutrition—Carbohydrates
An overview of carbohydrates and how they are incorporated into a healthy diet.
http://www.cdc.gov/nutrition/everyone/basics/carbs.html

Centers for Disease Control: Nutrition—Proteins
An overview of proteins and how they are incorporated into a healthy diet.
http://www.cdc.gov/nutrition/everyone/basics/protein.html

How Would You Vote? Classroom Discussion Ideas

- Monitor the online voting. Should hydrogenated fats be banned from all food?
    - This should inspire debate; try to focus the discussion by comparing this measure to recent smoking laws.
    - Ask students how this type of law would be enforced.
    - Compare the situation of government regulation to similar attempts in Europe.

Term Paper Topics, Library Activities, and Special Projects

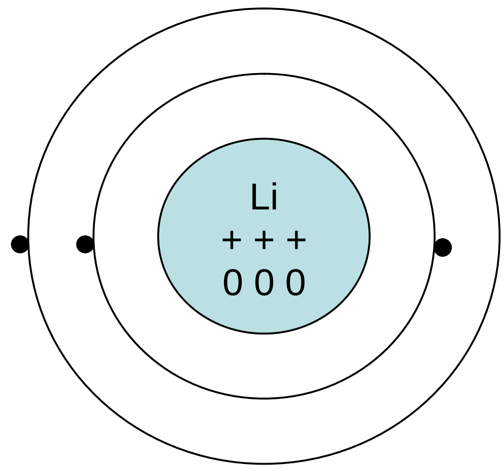
- What is a free radical, how does it form, and why is it important for cells to defend against them?
- Cellulose, starch, and glycogen are very similar, yet very different. Describe the process by which each of these molecules is formed. Why does the subtle difference in how the simple sugar monomers are bonded in starch and cellulose affect how the two molecules are used?
- What is a prion disease? Why are they hard to detect and treat?
- Describe the importance of water to biological organisms.
- Describe the roles that ions play in biological systems.
- Describe why termites are able to digest cellulose.
- Cholesterol gets a bad name because too much can cause problems for humans. Describe what the human body uses cholesterol for, and describe what happens if someone has too much or too little cholesterol in their system.

Answers to Self-Quiz Questions

1. d. Free radicals are dangerous because they emit energy.
2. hydrogen
3. a. ionic
4. c. H^+
5. c. hydrophobic
6. a. acid; base
7. e. a and c
8. c. double bonds
9. e. lipids
10. b. amino acids; nucleotides
11. d. all of the above
12. c. hydrophilic, b. atomic number, d. hydrogen bonds, a. positive charge, f. temperature, e. negative charge, g. solution
13. a. amino acids
14. c. wax, e. starch, f. triglyceride, d. DNA, a. polypeptide, b. ATP
15. f. protein, a. phospholipid, b. fat, c. nucleic acid, d. cellulose, e. nucleotide, h. wax, g. sucrose

Possible Responses to Critical Thinking Questions

1. Alchemists were trying to convert lead, atomic number 82, into gold, atomic number 79. This was never successful because it would involve rearranging the nuclei of the lead particles with a specific reduction in protons. This would be impossible because of the amount of energy required for this conversion. Perhaps a modern day particle accelerator could help complete the reaction.



2. 0 = neutron, + = proton, ● = electron
3. Polonium decays into mercury after shedding its alpha particle.
4. a. amino acid; b. glucose; c. polypeptide; d. fatty acid