UNIT 1: CHEMISTRY OF LIFE

Key Terms for this section:

- ☐ adhesion
- ☐ amino acid
- ☐ atom
- ☐ atomic mass
- ☐ atomic number
- ☐ carbohydrate
- ☐ cholesterol
- ☐ cohesion
- ☐ covalent bond
- ☐ DNA
- ☐ disaccharide
- ☐ electron
- ☐ fatty acid
- ☐ hydrogen bond
- ☐ hydrophilic
- ☐ hydrophobic
- ☐ ionic bond
- ☐ isotope
- ☐ monosaccharide
- ☐ neutron
- ☐ nonpolar covalent bond
- ☐ nucleic acid
- ☐ nucleotide
- ☐ peptide bond
- ☐ phospholipid
- ☐ polar covalent bond
- ☐ polysaccharide
- ☐ proton
- ☐ purine
- ☐ pyrimidine
- ☐ RNA
- ☐ radioactive isotope
- ☐ specific heat
- ☐ steroid
- ☐ surface tension
- ☐ triglyceride
- ☐ valence electrons
- ☐ van der Waals interaction

Unit 1: Chemistry of Life	Unit 1 Topics
	1.1 Structure of Water and Hydrogen Bonding
	1.2 Elements of Life
	1.3 Introduction to Biological Macromolecules
	1.4 Properties of Biological Macromolecules
	1.5 Structure and Function of Biological Macromolecules
	1.6 Nucleic Acids

Atomic Structure and Bonding

- The **atom** is composed of three subatomic particles. The nucleus of the atom contains positively charged **proton**s and neutral **neutrons**. The negatively charged **electrons** are located in orbitals around the nucleus.
- The **atomic number** is equal to the number of protons in the nucleus.
- The **atomic mass** is equal to the number of protons and the number of neutrons combined. Neutrons and protons have a mass that is several orders of magnitude heavier than an electron. Neutron and proton masses are both considered part of the atomic mass while the electron mass is not large enough to affect the atomic mass.
- The **atomic weight** is the weighted average of all of the isotopes of a particular element.
- Atoms of the same element can have a different number of neutrons which causes a different mass number. These atoms are called **isotopes**.
- **Radioactive isotopes** are actively decaying into more stable atoms. These isotopes can be used for radiometric dating of rocks and fossils and as medical markers during biological scans.

The electron configuration of atoms determines its chemical reactivity and bonding patterns.

- Electrons are located in **orbitals** that surround the atom's nucleus. There are a variety of orbital shapes and patterns. Each orbital can hold two electrons.
- The orbitals are organized into **energy levels**. There are different types of orbitals that are arranged differently in space. Each orbital can hold a maximum of two electrons. There is one s orbital holding a maximum of two electrons, there are 3 p orbitals holding a maximum of six electrons, five d orbitals holding a maximum of 10 electrons, and seven f orbitals holding a maximum of 14 electrons.
- The electrons in the outermost s and p orbitals are called the **valence electrons** and determine the chemical reactivity of an atom.
- The number of valence electrons determines how an atom will bond with another atom.
- The **octet rule** says that atoms try to complete valence energy levels through bonding.
- Two atoms can share one, two or three pairs of electrons in a **covalent bond**. The sharing of electrons develops the strongest chemical bond.
- When two atoms have fairly similar electronegativity values, they share the electrons equally in a **nonpolar covalent bond**.
- When the two atoms sharing the electrons have unequal electronegativity values, the electrons will spend more time at one atom and will be shared unequally in a **polar covalent bond**.
- One atom can give one, two, or three electrons to another atom. This electron transfer causes the electron donor to become a positively charged cation and the electron acceptor to become a negatively charged anion. The oppositely charged ions are attracted to each other and form an **ionic bond**. Ionic bonds are strong in dry environments, but weak in aqueous environments. The charged particles are very reactive and can be separated in aqueous environments.

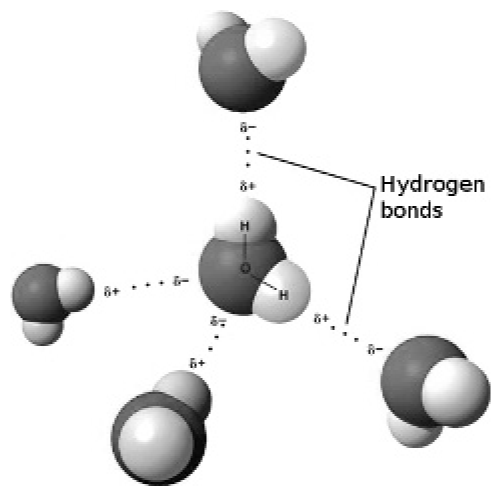
Many whole molecules can be attracted to one another in intermolecular attractions.

- A **hydrogen bond** is a temporary interaction between two molecules that both have polar covalent bonds. The more electronegative atom in a molecule will pull the shared pair of electrons toward it and have a partial negative charge while the less electronegative atom will have a slightly positive charge. These partial charges are weak and temporary due to the movement of electrons. The partial positive charge of one polar molecule will be attracted to the partial negative charge of another polar molecule. It is not a chemical bond at all, but an intermolecular attraction between two molecules.
- **Van der Waals interactions** occur between nonpolar covalent molecules. With the movement of electrons, it is possible that at any given moment the electrons might be clustered more around one of the atoms giving that atom a temporary negative charge and the other atom a temporary positive charge. The oppositely charged areas in two nonpolar molecules are attracted to one another. It is not a chemical bond at all, but an intermolecular attraction between two molecules.

Properties of Water

The properties of water impact living systems.

- **Polarity** is present. Water is a polar molecule, with a partial positive charge at one end and a partial negative charge at the other end.
- **Hydrogen bonding** is very abundant. Temporary bonds form between molecules that have these partial positive and partial negative charges. These are hydrogen bonds. Hydrogen bonds are transient (short lived); however they are very numerous in solution.



- **Adhesion** is the attraction of a water molecule to another substance.
- **Cohesion** is the attraction of one water molecule to another water molecule.
- Water has a very strong **surface tension**. It is very hard to break the surface of the water due to formation of hydrogen bonds.
- **Water has a high specific heat capacity.** Due to cohesion, water molecules resist increasing their motion and rapid changes in temperature. You can add much heat to water and not increase the temperature. Much energy goes to break hydrogen bonds. There isn't a significant temperature change.
- Water is the **universal solvent.** Water is a hydrophilic solvent and therefore dissolves most substances.
- A **solute** is the substance that is dissolved.
- A **solvent** is the substance that does the dissolving.
- A **solution** forms when the solute has dissolved within the solvent.
- **Heat of vaporization** is very unusual. It takes a lot of heat to evaporate water due to the frequent breaking and reforming of hydrogen bonds.

Organic Molecules

Carbon is the central atom in organic molecules.

- Since carbon has four **valence electrons**, it forms four covalent bonds. Since covalent bonds are very strong, carbon adds a great deal of strength to the backbone of organic molecules.
- Carbon forms many different bonding angles that allow for the formation of both ring structures and straight chains.
- Carbon can bond to carbon and other elements through single, double, and triple covalent bonds, which creates several different bond angles and patterns.
- Carbon never bonds ionically. It will always provide a strong covalent center to any molecule.

Organic molecules contain several reoccurring functional groups that help determine the overall properties of those molecules.

Functional Group	**Structure of Functional Group**	**Properties and Compounds that have the Functional Group**
Hydroxyl	--OH It is an oxygen bonded to a hydrogen.	• Compounds that have a hydroxyl group are called alcohols. • This group is polar due to the stronger electronegativity of the oxygen atom compared to hydrogen.
Carbonyl	--CO It is a carbon double bonded to an oxygen atom.	• Ketones have a carbonyl group on a middle carbon. • Aldehydes have a carbonyl group on one of the terminal carbons. • This group is weakly polar because the double bond disrupts the polarity.
Carboxyl	--COOH A carbon double bonded to an oxygen atom and bonded to a hydroxyl group is a carboxyl.	• The hydrogen ions tend to dissociate from this group giving these molecules acidic properties. • Compounds that have this carboxyl group are called organic acids or carboxylic acids. • This functional group is polar and reactive.
Amino	--NH_2 A nitrogen bonded to two hydrogen atoms makes an amino group.	• This group is very polar. • It absorbs H+ and acts as a base. • Compounds that have this group are called amines.
Methyl	--CH_3 A carbon bonded to three hydrogen atoms forms this group.	• This group is nonpolar because there is an equal sharing of electrons. • It is very abundant in hydrocarbons.
Phosphate	--PO_4 It forms from a phosphorous bonded to four oxygen atoms.	• This group is very polar. • This group is ionized, it is an anion. • It is found in nucleotides, ATP, and phospholipids.
Sulfhydryl	--SH It forms from a sulfur bonded to a hydrogen.	• Compounds that have this group are called thiols. • This group is involved in protein folding. It is found in some amino acids.

Macromolecules

Carbon is the central atom in all four organic macromolecules: carbohydrates, lipids, proteins, and nucleic acids.

Organic Macromolecules	Description of Structure	Functions and Examples
Carbohydrates	• They are made from monomer subunits called **monosaccharides**. • Monosaccharides have three to seven carbons and an empirical formula of $C_nH_{2n}O_n$. • Monosaccharides link together via **dehydration synthesis** to form a covalent bond called a **glycosidic linkage.** • A **disaccharide** has two monosaccharide subunits. • A **polysaccharide** has hundreds of monosaccharide subunits. • **Oligosaccharide**s have a few (4 to 20) monosaccharides.	• Glucose, fructose, and ribose are examples of monosaccharides. • Monosaccharides and disaccharides provide energy to cells. • Sucrose and lactose are common disaccharides. • Polysaccharides can be used for structural support or for storage of extra sugar. • Plants use starch as an energy storage polysaccharide and cellulose as a structural support polysaccharide. • Animals and fungi use chitin as a structural support polysaccharide. • Animals use glycogen as an energy storage polysaccharide. • Oligosaccharides are an important component in cell membranes.
Lipids	• They are nonpolar. • Lipids are hydrophobic. • They are made up primarily of carbon and hydrogen. • **Fatty acids** have a carboxyl group and long hydrocarbon chain. • **Saturated fatty acids** have single bonds between the carbons in the hydrocarbon chain. • **Unsaturated fatty acids have** multiple bonds between some carbons in the hydrocarbon chain. • **Triglycerides** have a glycerol attached to three fatty acids by dehydration synthesis. • **Saturated fats** have two or three saturated fatty acids and are solid at room temperature. • **Unsaturated fats** have two or three unsaturated fatty acids and are liquid at room temperature. • **Phospholipids** have a glycerol attached to two fatty acids and one phosphate group. • **Steroids** have four fused hydrocarbon rings.	• Triglycerides function to store energy. • Phospholipids are amphipathic and important components of the cell membrane. • Steroids are often hormones. Their lipid structure allows them to pass through the plasma membrane and bind to a receptor in the cell's interior. Estrogen and testosterone are examples of lipid hormones. • **Cholesterol** is a steroid that is important in the cell membrane.

Organic Macromolecules	Description of Structure	Functions and Examples
Proteins	• The monomer is an **amino acid.** • An amino acid has a central carbon, a carboxyl group, an amino group, and an R group. • There are 20 different amino acids and 20 different R groups. • Amino acids link together by dehydration synthesis. • A **peptide bond** is a covalent bond that forms between the carbon of the carboxyl group of one amino acid and the nitrogen of the amino group of the next amino acid. • Proteins have a very complicated three-dimensional shape. • **Chaperonins** organize the protein folding process. • The three-dimensional shape determines the protein's function. • The **primary structure** is the number and sequence of amino acids. It is due to the formation of peptide bonds. • The **secondary structure** includes **alpha helices** and **pleated sheets.** Alpha helices and pleated sheets occur because of hydrogen bonding between amino acids. • The **tertiary structure** is the three-dimensional shape of the protein that is reinforced by attractions and bonding between R groups. The types of bonding responsible for the three-dimensional structure of the protein include **disulfide bridges**, hydrogen bonding, and van der Waals interactions. • The **quaternary structure** results when two or more protein chains come together to form one large functional protein.	• Proteins have many possible functions—transport, enzymes, structural support, recognition sequences, hormones, and neurotransmitters. • The function is connected to the three-dimensional shape of the protein. • When the shape of the protein is disrupted, it is **denatured**. • Proteins can be denatured by changes in pH, temperature, and salt concentrations. • Denatured proteins are nonfunctional. • Examples of proteins include collagen, rubisco, ATP synthase, cytochrome, catalase, hemoglobin, and insulin.

Organic Macromolecules	Description of Structure	Functions and Examples
Nucleic Acids	• They are made up of monomer subunits called **nucleotides.** • Nucleotides have a phosphate group, a five-carbon sugar, and a **nitrogenous base**. • There are two possible sugars, **ribose** and **deoxyribos**e. • There are five possible nitrogenous bases: **adenine**, **thymine**, **cytosine**, **guanine**, and **uracil**. • Thymine, cytosine, and uracil have a single six-member carbon-nitrogen ring and are called **pyrimidines**. • Guanine and adenine have a six-member carbon and nitrogen ring fused to a five-member carbon-nitrogen ring and are called **purines.** • Nucleotides link together by a **phosphodiester linkage.** The phosphate group of the nucleotide is attached to the sugar of the next nucleotide making the sugar-phosphate backbone.	• DNA and RNA are examples. • RNA is a single strand of nucleotides. • RNA has ribose as the sugar. • RNA uses adenine, uracil, guanine, and cytosine as the nitrogenous bases. • DNA is a double strand of nucleotides. • DNA has deoxyribose as the sugar. • DNA uses adenine, thymine, guanine, and cytosine as the nitrogenous bases. • DNA is the genetic material. • RNA forms as an intermediate between DNA and proteins. It can also transfer amino acids, can be part of spliceosomes or part of ribosomes.

☑ Can you:

- ☐ **describe** the structure of an atom?
- ☐ **compare** and **contrast** covalent bonding with ionic bonding?
- ☐ **explain** the processes of hydrogen bonding and van der Waals interactions?
- ☐ **describe** the properties of water?
- ☐ **explain** how cohesion, adhesion and surface tension occur?
- ☐ **describe** the biological significance of water?
- ☐ **compare and contrast** different functional groups present in organic molecules?
- ☐ **explain** the structure and function of a variety of carbohydrates, lipids, proteins, and nucleic acids?
- ☐ **explain** the four levels of structure found in a protein?
- ☐ **explain** the structure of DNA?
- ☐ **explain** the structure of RNA?