OUTLINE:

- The Nature of Atoms
- Compounds and Chemical Bonds
- The Role of Water in Life
- Major Molecules of Life
The Nature of Atoms

- Everything that takes up space and has mass is called matter.

- All matter is made of atoms, each containing a nucleus with protons and neutrons surrounded by a cloud of electrons.
  - Atoms are units of matter that cannot be broken down into simpler substances by ordinary chemical means.
Figure 2.1 Atoms can be represented in different ways.

(a) A three-dimensional representation of an atom of helium, showing protons and neutrons in the nucleus and electrons occupying a region around the nucleus.

(b) A two-dimensional representation of an atom of helium.

(c) A two-dimensional representation of an atom of oxygen.
TABLE 2.1 Review of Subatomic Particles

<table>
<thead>
<tr>
<th>Particle</th>
<th>Location</th>
<th>Charge</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>Nucleus</td>
<td>1 positive unit</td>
<td>1 atomic mass unit</td>
</tr>
<tr>
<td>Neutron</td>
<td>Nucleus</td>
<td>None</td>
<td>1 atomic mass unit</td>
</tr>
<tr>
<td>Electron</td>
<td>Outside the nucleus</td>
<td>1 negative unit</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
The Nature of Atoms

- **Element**
  - A form of matter that cannot be broken down into simpler substances
  - Made of many atoms that are all the same
The Nature of Atoms

- Each element has an atomic number and atomic mass
  - Atomic number
    - The number of protons in the nucleus
  - Atomic mass
    - The number of protons plus the number of neutrons (note that electrons have an insignificant mass)
Figure 2.2 The Periodic Table (After Dmitri Mendeleev 1869).
The Nature of Atoms

- Elements with the same number of protons but different numbers of neutrons are called isotopes.

- Example of Carbon atom
  - All carbon atoms have six protons in the nucleus.
  - Common isotopes of carbon include $^{12}\text{C}$ (with six neutrons), $^{13}\text{C}$ (with seven neutrons), and $^{14}\text{C}$ (with eight neutrons).
The Nature of Atoms

- Radiation is energy moving through space, such as radio waves, light, and heat.
- Some elements have isotopes that can be stable (do not change over time) or unstable (emits radiation to regain a stable state).
- A radioisotope is an unstable isotope.
- Radiation can be very harmful, causing the death of cells, or very beneficial, as evidenced by its use in science, including medicine.
Figure 2.3 Sunburn, perhaps the most common burn from radiation.
Example of Carbon atom isotopes

- Carbon has two stable, naturally occurring isotopes: $^{12}\text{C}$ (98.93% of the carbon on Earth) and $^{13}\text{C}$ (1.07%) and a total of 15 known isotopes.

- $^{14}\text{C}$ is a radioisotope in trace amounts (0.0000000001%, that is one part per trillion!) used in radiocarbon dating to determine the age of carbonaceous materials up to 40,000 years old.
Example important isotopes used in medicine

- Radioactive iodine Iodine-131 ($^{131}\text{I}$), also called radioiodine for thyroid imagery.

- Radiation used to kill cancer cells. Example of prostate cancer cells killed with radioactive seeds (pellets of iodine-125 or palladium-103) implanted in the gland.
Figure 2.4 Use of radioactive iodine.

(a) An image of a normal thyroid gland
(b) An image of an enlarged thyroid gland
Figure 2.5 Prostate cancer can be treated by implanting radioactive seeds.
Compounds and Chemical Bonds

- Two or more elements may combine to form a compound
- A compound’s characteristics are usually different from those of its elements
- The atoms in a compound are held together by chemical bonds
Figure 2.7 The characteristics of compounds.

(a) The element sodium is a solid metal.

(b) Elemental sodium reacts explosively with water.

(c) The element chlorine is a yellow gas.

(d) When the elements sodium and chlorine join, they form table salt, a compound quite different from its elements.
Compounds and Chemical Bonds

- **Molecule**
  - A chemical structure held together by covalent bonds
  - The chemical structure shows the number of each element forming the molecule

- **Ion**
  - An atom or group of atoms with a positive or negative electrical charge
Figure 2.8 Atoms of hydrogen, carbon, and oxygen.

- **Hydrogen atom** (atomic number = 1)
- **Carbon atom** (atomic number = 6)
- **Oxygen atom** (atomic number = 8)

The shell closest to the nucleus can hold up to 2 electrons.

The next shell out can hold up to 8 electrons (the shell shown here has 6). Atoms with more than 10 electrons have additional shells.
Figure 2.9 **Covalent bonds form when atoms share electrons.**

(a) The molecule methane (CH₄) is formed by the sharing of electrons between one carbon atom and four hydrogen atoms. Because in each case one pair of electrons is shared, the bonds formed are single covalent bonds.

(b) The oxygen atoms in a molecule of carbon dioxide (CO₂) form double covalent bonds with the carbon atom. In double bonds, two pairs of electrons are shared.

(c) The nitrogen atoms in nitrogen gas (N₂) form a triple covalent bond, in which three pairs of electrons are shared.
Figure 2.10 An ionic bond involves the transfer of electrons between atoms.

An atom of sodium transfers the electron in its outer shell to an atom of chlorine.

Having given up an electron, sodium becomes a positively charged ion.

Having received an electron, chlorine becomes a negatively charged ion.

Sodium atom + Chlorine atom → Sodium chloride (NaCl)

The oppositely charged sodium and chloride ions are attracted to one another, forming sodium chloride.
The Role of Water in Life

- When the electrons of a covalent bond are shared unequally, the bond is called polar
  - The resulting molecules are called polar molecules
  - Water is a polar molecule
    - Its unique properties such as its high heat capacity, its high heat of vaporization, and its superior ability as a dissolving agent can be traced to its polarity
(a) Water is formed when an oxygen atom covalently bonds (shares electrons) with two hydrogen atoms. Because of the unequal sharing of electrons, oxygen carries a slight negative charge, and the hydrogen atoms carry a slight positive charge.
(b) The hydrogen atoms from one water molecule are attracted to the oxygen atoms of other water molecules. This relatively weak attraction (shown by dotted lines) is called a hydrogen bond.
Water and Chemistry

The structure of the water molecule gives water several unique properties that make it ideal for living organisms. This tutorial examines these structure-property relationships and discusses the importance of water's unusual characteristics.

Press "PLAY" to begin Animation.
The Role of Water in Life

- Acids and bases react differently to water
  - Acids release hydrogen ions (H\(^+\)) when placed in water
  - Bases produce hydroxide ions (OH\(^-\)) when added to water

- pH
  - The negative logarithm of the concentration of the H\(^+\) ion in solution
  - The lower the pH on the pH scale, the greater the acidity
  - The higher the pH, the more basic a solution
Figure 2.13 The pH scale.
The Role of Water in Life

- Buffers
  - Prevent dramatic changes in pH
  - Remove excess H\(^+\) from solutions when concentrations of H\(^+\) increase
  - Add H\(^+\) when concentrations of H\(^+\) decrease
    - Many body fluids have the buffering capacity to maintain a stable internal environment
Major Molecules of Life

- Biological macromolecules
  - The giant molecules of life
  - They are long chains called polymers made of repeating units called monomers.

poly = many

mono = one
When polymers are built up, water is removed, and the reaction is called dehydration synthesis.

De-hydration: removes hydro: water

Conversely, when the same molecules are broken apart, water is added and the reaction is called hydrolysis.

Hydro: water, lysis: to cut
Figure 2.15 *Formation and breaking apart of polymers.*

(a) Polymers are formed by dehydration synthesis, in which a water molecule is removed and two monomers are joined.

(b) Polymers are broken down by hydrolysis, in which the addition of a water molecule disrupts the bonds between two monomers.
Monomers and Polymers

Macromolecules that consist of many small repeating subunits linked in a chain are called polymers. The small molecular subunits that form the building blocks of polymers are called monomers. This tutorial examines the role of dehydration and hydrolysis reactions in the assembly and breakdown of biological polymers such as proteins, carbohydrates, and nucleic acids.

Press "PLAY" to begin Animation.
Major Molecules of Life

- Carbohydrates
  - Polymers, made of monosaccharides (monomers added together)
  - Composed only of C, H, and O
- Glucose and fructose are examples of monosaccharides
  - Simple (mono) sugars
- Sucrose and lactose are examples of disaccharides
  - Double (di) sugars
Figure 2.16 Monosaccharides are simple sugars.

The straight-chain formula of glucose

A ring structure of glucose in which carbon atoms within the ring are designated with the letter C

A ring structure of glucose in which the C for carbon atoms within the ring is omitted
Figure 2.17 Disaccharides are built from two monosaccharides.
Polysaccharides

Chains of monosaccharides that store energy or provide structure

The storage polysaccharide in animals is glycogen, which humans store mainly in the cells of liver and muscles

The storage polysaccharide in plants is starch
**Figure 2.18 Polysaccharides.**

(a) Glycogen is the storage polysaccharide in animals. Granules of glycogen are stored in cells of the liver.

(b) Cellulose is a structural polysaccharide found in the cell walls of plants.

Micrograph of cellulose fibrils in plant cell wall.
Major Molecules of Life

- Cellulose
  - An indigestible (to humans) polysaccharide made of repeating units of glucose
  - Humans lack the enzyme necessary to digest cellulose
  - However it is an important form of dietary fiber in the human diet
Major Molecules of Life

- **Lipids**
  - Water-insoluble molecules made of C, H, and O
  - Store long-term energy
  - Protect vital organs
  - Form cell membranes

- **Fats and oils are examples of triglycerides**
  - Polymers made of one molecule of glycerol and three fatty acids
  - The fatty acids bond to glycerol through dehydration synthesis
Figure 2.19 *Triglycerides.*

(a) A fatty acid bonds to glycerol through dehydration synthesis.

(b) This triglyceride contains one unsaturated fatty acid (note the presence of a double bond between the carbon atoms) and two saturated fatty acids (note the absence of any double bonds between the carbon atoms).
Lipid Structure and Function

Lipids are a diverse group of molecules with two important features. First, lipids contain large regions composed almost entirely of hydrogen and carbon. Second, these regions are nonpolar and make lipids hydrophobic and insoluble in water. Lipids serve a wide variety of functions. Some are energy-storage molecules, some form waterproof coverings on plants and animals, some make up the bulk of all the membranes of a cell, and still others are hormones.

Press "PLAY" to begin Animation.
Major Molecules of Life

- Phospholipid molecules have
  - A glycerol head that is polar and hydrophilic (hydro: Greek for water, philia: to love) mix with watery environments inside and outside the cell
  - A fatty acid tail that is nonpolar and hydrophobic (hydro: water, phobos: fear) that points inward and helps hold the membrane together
(a) A phospholipid consists of a variable group designated by the letter R, a phosphate, a glycerol, and two fatty acids. Because the variable group is often polar and the fatty acids nonpolar, phospholipids have a polar hydrophilic (“water-loving”) head and a nonpolar hydrophobic (“water-fearing”) tail.

(b) Within the phospholipid bilayer of the plasma membrane, the hydrophobic tails point inward and help hold the membrane together. The outward-pointing hydrophilic heads mix with the watery environments inside and outside the cell.
Steroids

- A type of lipid that consists of four carbon rings attached to molecules that vary from one steroid to the next

- Estrogen and testosterone are examples of steroids and found in males and females respectively, as is cholesterol, which is a risk factor for heart disease when found in high levels in the blood
Figure 2.21 The steroid cholesterol.
Major Molecules of Life

- **Proteins**
  - **Amino acids**
    - The building blocks of proteins
    - Consist of a central carbon atom bound to a hydrogen (H) atom, an amino group (NH$_2$), and a carboxyl group (COOH) in addition to a unique side chain (R).
Figure 2.22 Structure of an amino acid.
Amino acids that form proteins are linked by bonds called peptide bonds, which are formed through—*again*—dehydration synthesis.

Chains of only a few amino acids are called peptides.

Chains of 10 or more amino acids are called polypeptides.
Figure 2.23 Formation of a peptide bond between two amino acids through dehydration synthesis.

Amino acid glycine + Amino acid alanine $\rightarrow$ Dipeptide glycylalanine + $\text{H}_2\text{O}$
Major Molecules of Life

- Proteins
  - Polypeptide chains of at least 50 amino acids that provide structure, transport, and movement for the body
  - Proteins have four distinct levels of structure that affect their function in the body
    - Primary
    - Secondary
    - Tertiary
    - Quaternary
Figure 2.24 *Levels of protein structure.*

**Primary structure**: is the specific sequence of amino acids. Each amino acid is depicted here as a bead within the polypeptide chain.

**Secondary structure**: such as the helix shown here, results from the bending and coiling of the chain of amino acids. Hydrogen bonding between portions of different amino acids is responsible for secondary structure.

**Tertiary structure**: is the three-dimensional shape of proteins. Interactions between R groups (the side chains of amino acids) determine tertiary structure.

**Quaternary structure**: Some proteins have two or more polypeptide chains, each chain forming a subunit. Quaternary structure results from the attractive forces between two or more subunits.
Protein Structure

Proteins come in many shapes, and biologists recognize four levels of organization in protein structure. A single molecule of hemoglobin, the oxygen-carrying protein in red blood cells, illustrates all four structural levels, from primary to quaternary structure.
Press "PLAY" to begin Animation.
Major Molecules of Life

- Changes in the chemical environment of a protein can cause it to lose its structure, resulting in a loss of function.
- This is called denaturation.
- Temperature and/or pH changes are the major cause of denaturation.
Major Molecules of Life

- Enzymes are almost always proteins
  - They speed up chemical reactions without being consumed
  - Without enzymes, chemical reactions within our cells would occur far too slowly to sustain life
  - However an enzyme can’t make a reaction that can’t occur happen.
- Are very specific in their activity
  - Specificity is due to the unique shape of each enzyme’s active site
Major Molecules of Life

- Enzymes bind to substrates at the active site, forming an enzyme-substrate complex
  - Sometimes cofactors, often called coenzymes, bind at the active site to facilitate the reaction
- The substrate is converted to one or more products
Figure 2.25 The working cycle of an enzyme.

Step 1: The cycle begins when the active site of the enzyme is unoccupied and the substrate is present.

Step 2: The substrate binds to the active site of the enzyme, forming an enzyme-substrate complex.

Step 3: The substrate is converted to products that are released from the active site, and the cycle can begin again.

(a) A decomposition reaction involving an enzyme

(b) A synthesis reaction involving an enzyme
Major Molecules of Life

- Nucleic acids
  - DeoxyriboNucleic Acid DNA and Ribonucleic Acid (RNA) are the two types of nucleic acids.
  - Both are polymers of smaller units called nucleotides.
  - Genes are segments of polymers called deoxyribonucleic acid (DNA).
  - A nucleotide is made up of a five-carbon sugar bonded to one of five nitrogen-containing bases and a phosphate group.
Figure 2.26 Structure of a nucleotide.
Major Molecules of Life

- RNA and DNA have structural differences related to the sugar, bases, and number of strands
TABLE 2.4 Review of the Structural Differences between RNA and DNA

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>RNA</th>
<th>DNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>Ribose</td>
<td>Deoxyribose</td>
</tr>
<tr>
<td>Bases</td>
<td>Adenine, guanine, cytosine, uracil</td>
<td>Adenine, guanine, cytosine, thymine</td>
</tr>
<tr>
<td>Number of strands</td>
<td>One</td>
<td>Two; twisted to form double helix</td>
</tr>
</tbody>
</table>
Figure 2.27 *RNA is a single-stranded nucleic acid.*
Figure 2.28 DNA structure.
Major Molecules of Life

- A special nucleotide is adenosine triphosphate (ATP)
  - A molecule capable of storing energy in its phosphate-to-phosphate bonds
- All energy from the breakdown of molecules, such as glucose, must be channeled through ATP before the body can use it
- ATP is often described as the energy currency of cells
Figure 2.29 Structure and function of adenosine triphosphate (ATP).
Nucleic Acids

Nucleic acids such as DNA and RNA are polymers of nucleotides. DNA serves as the primary storage of genetic information in nearly all organisms. In this tutorial, you will learn about the structure of nucleotides and how these monomers are joined together to form nucleic acids such as DNA.

Press "PLAY" to begin Animation.
You Should Now Be Able To:

- Explain and describe the nature and structure of atoms
- Understand the importance of isotopes
- Understand the importance of compounds and chemical bonds
- Know the structure and function of water molecule and the role of water in life
- List the major molecules of life
- Understand dehydration and hydrolysis chemical reactions for building up/breaking down polymers.