CHAPTER 2

The Chemistry of Life

Learning Outcomes

In this chapter students will:

2.1 Describe the basic structure of atoms and how they participate in reactions essential to life. (Modules 2.1–2.3)
2.2 Illustrate different types of chemical bonds that can form between atoms. (Module 2.4)
2.3 Explain the unique chemical properties of water molecules and how these properties are essential to life. (Modules 2.5, 2.6)
2.4 Describe the significance of carbon in forming the basis of the four classes of biological macromolecules. (Module 2.7)
2.5 Differentiate between hydrolysis and dehydration synthesis reactions as processes of metabolism. (Module 2.8)
2.6 Describe in specific terms the forms and functions of the four classes of biological macromolecules. (Modules 2.7, 2.9–2.13)

Module Outlines

2.1 All life is made of molecules, which are made of atoms.

- **CORE IDEA:** All matter consists of atoms, which are often bonded together into molecules. Individual elements combine to form compounds. Reactants are transformed into products through chemical reactions.

A. Matter, Atoms, and Molecules
  1. Every object is composed of matter.
    a. **Matter** is anything that occupies space and has mass (substance).
    b. Three phases of matter are gas, liquid, or solid.
  2. All matter consists of atoms.
    a. **Atoms** are the smallest units that retain all the properties of their type of matter.
    b. Atoms are usually bonded to each other as **molecules**.
B. Elements and Compounds
  1. All matter is composed of individual elements.
    a. **Elements** are substances that cannot be broken down into other substances by chemical reactions.
      i. Examples of elements include hydrogen, carbon, uranium, and gold.
    b. **Compounds** are substances with two or more elements in a fixed ratio.
  2. Chemical Reactions
    a. During a **chemical reaction**, atoms remain whole but they are swapped as molecules are broken down or built up.
      i. Atoms are never created or destroyed in a chemical reaction.
    b. **Reactants** (starting material) → **products** (ending matter)
      i. Example: cellular respiration

2.2 All matter consists of chemical elements.

- **CORE IDEA:** All matter is composed of elements. Of the 92 natural elements, only 25 are used in living cells. Of these, 4 make up the bulk of the cell, 7 are required in small amounts, and 14 are required only in tiny amounts.

A. All living organisms are composed of matter, and all matter is composed of elements.
  1. **Elements** are substances that cannot be broken down into other substances by chemical reactions.
    a. There are 92 naturally occurring elements.
    b. Several elements are created artificially in labs.
  2. Periodic table of the elements
    a. **Periodic table of the elements** lists all of the chemical elements, ordered by atomic number.
    b. **Atomic number**—number of **protons**
    c. **Symbol**—One- or two-letter designation for element
    d. **Atomic weight**—number of protons plus **neutrons**
  3. Elements essential to life
    a. Four of the 92 naturally occurring elements make up the majority of matter in organisms.
      i. Oxygen, carbon, hydrogen, and nitrogen
    b. Another seven account for much of the remaining mass.
      i. Calcium, phosphorus, potassium, sulfur, sodium, chlorine, and magnesium
    c. Fourteen **trace elements** are present in tiny amounts but cells cannot survive without them.
      i. Boron, chromium, cobalt, copper, fluorine, iodine, iron, manganese, molybdenum, selenium, silicon, tin, vanadium, and zinc

2.3 Atoms are composed of subatomic particles.

- **CORE IDEA:** All atoms are composed of protons, neutrons, and electrons. The number of protons determines the element, the number of neutrons determines the isotope, and the number of electrons determines the ion state and chemical reactivity.

A. All matter is composed of atoms. Atoms are composed of subatomic particles.
  1. **Neutrons**—equal in mass to protons, located in **nucleus**, 0 charge
  2. **Protons**—equal in mass to neutrons, located in nucleus, positive charge
    a. The number of protons determines the chemical element.
  3. **Electrons**—very little mass, located in electron shells in electron cloud, negative charge

B. Atom of nitrogen
  1. Locations of subatomic particles
    a. Neutrons and protons in nucleus
      i. Equal number of protons and electrons means no net charge on atom.
    b. Electrons: two in inner shell, five in outer shell
      i. Electrons in outer shell determine chemical properties of element.

C. Nitrogen-15 isotope (or N-15 or ^{15}N)
  1. **Isotopes** of the same element vary in the number of neutrons.
  2. 8 protons + 7 neutrons = 15

D. Nitrogen ion
  1. N^{3-} has ten electrons. It has three more electrons than the neutral atom.
  2. **Ions** vary in the number of electrons in the electron cloud.

3. Adding electrons increases the negative charge.
4. Each missing electron increases the positive charge.

2.4 Atoms are held together by chemical bonds.

- **CORE IDEA:** Chemical bonds can be ionic (via electron transfer) or covalent (via electron sharing). Covalent bonds can be nonpolar (equal sharing) or polar (unequal sharing). Hydrogen bonds are important in the structure of water.

A. During chemical reactions, atoms form **chemical bonds** by gaining, releasing, or sharing electrons with other atoms.

B. Chemical bonds

1. **Ionic bonds** involve the transfer of one or more electrons from one atom to another.
   - **a.** Atom receiving electron(s) becomes negatively charged = an ion.
   - **b.** Atom donating electron(s) becomes positively charged = an ion.
   - **c.** Ions are an atom or group of atoms that has acquired a charge by the gain or loss of electrons.
   - **d.** Ionic bonds are held together by the attraction of opposite charges.
2. **Covalent bonds** involve the sharing of one or more electrons between atoms.
   - **a.** A covalent bond consists of a pair of shared electrons (one from each atom).
   - **b.** Covalent bonds hold molecules together.
   - **c.** A **single bond** is a single pair of shared electrons.
     - **i.** Indicated by a solid line
   - **d.** A **double bond** has two pairs of shared electrons.
     - **i.** Indicated by a pair of lines
     - **ii.** Hydrogen gas H_2: H=H.
   - **e.** A triple bond is three pairs of shared electrons.
     - **i.** Relatively rare
3. Polar versus nonpolar bonds
   - **a.** All covalent bonds share pairs of electrons.
   - **b.** Equal sharing results in a **nonpolar bond**.
   - **c.** Unequal sharing results in a **polar bond**.
     - **i.** A polar bond creates a slightly positive end and slightly negative end.
     - **ii.** Unequal sharing in a polar bond does *not* create ions.
4. Hydrogen bonds
   - **a.** A molecule of water has two polar covalent bonds.
   - **b.** Electrons are more attracted to oxygen nucleus than hydrogen nuclei.
   - **c.** Oxygen atoms carry a slight negative charge while hydrogen nuclei are slightly positive.
   - **d.** **Hydrogen bonds** form between slightly negative oxygen nucleus and a slightly positive hydrogen nucleus in a separate water molecule.
     - **i.** Hydrogen bond networks are responsible for properties of water.
     - **ii.** Hydrogen bonds occur also in other molecules.

2.5 The structure of water gives it unique properties.

- **CORE IDEA:** The polar nature of water molecules allows them to form networks of hydrogen bonds. This special ability endows water with many life-supporting properties.

A. All life depends on water.

1. Life first appeared in water and evolved there for billions of years before moving onto land.
2. Nearly all cells are, by weight, mostly water.
3. Water has special properties that are a result of its unique chemical structure.

B. Hydrogen bonding in water
  1. One pair of electrons is shared unequally between the oxygen (O) and hydrogen (H) in water.
  2. Unequal sharing creates a polar (unequally charged) molecule.
    a. Slightly negative charge on oxygen
    b. Slightly positive charge on hydrogens
  3. Hydrogen bonds form between water molecules in extensive networks.

C. Ice floating
  1. Unlike nearly every other liquid, when water molecules freeze, they move apart.
  2. Water expands as it freezes.
  3. Ice is less dense than water and it floats.
  4. Floating ice is biologically relevant. A thin layer of ice insulates the water below in winter.

D. Water as a solvent
  1. **Solvents** are a dissolving agent.
  2. A **solution** is the solvent plus the material being dissolved.
  3. Water is an effective solvent due to its polar nature.

E. Temperature regulation
  1. Liquid water readily absorbs and releases heat.
  2. Water resists temperature changes more than most substances.
  3. Water moderates temperature changes.
    a. On a global scale, oceans help moderate Earth's surface temperature.
    b. On a personal scale, sweating helps moderate our temperature by cooling our skin.

F. Cohesion and Adhesion
  1. **Cohesion** is the tendency of water molecules to stick to each other due to hydrogen bonding.
    a. It creates surface tension, a film-like surface on which items can be suspended.
  2. **Adhesion** is the clinging of one substance to another.
    a. Adhesion causes water droplets to stick to surfaces.

2.6 pH is a measure of the acidity of a solution.

- **CORE IDEA:** The concentration of H^+ ions in an aqueous solution determines the pH, from acidic (0 to 7) to basic (7 to 14). Buffers can help reduce changes in pH. pH changes in the environment can affect the health of ecosystems.

A. Most of the chemical reactions of life occur in water.
  1. An **aqueous solution** is one that contains a substance dissolved in water.
  2. Within the aqueous solution, a small percentage of the water molecules break apart into hydrogen ions (H^+) and hydroxide ions (OH^-).
  3. Additionally, substances dissolved in water may also add H^+ ions to the solution.
  4. The concentration of H^+ ions determines its pH.
  5. The **pH scale** runs from 0 (most acidic) to 14 (most basic) with 7 as neutral.
    a. Each number in the pH scale represents a tenfold change in H^+ ion concentration.

B. pH scale
  1. Acids
    a. An **acid** is a chemical that, when dissolved in water, releases H^+ ions.
    b. Acids have a pH between 0 and 7.

2. Bases
   a. A **base** is a chemical that, when dissolved in water, removes H^+ ions from a solution.
   b. Bases have a pH between 7 and 14.

C. Buffers
1. **Buffers** are chemicals that minimize changes in pH by accepting H^+ ions when in excess or by donating H^+ ions when they are in short supply.
2. Buffers in human blood keep it at a nearly neutral pH despite changes in H^+ concentration.

D. Acid precipitation
1. Acid precipitation is caused by chemicals that react with water in the air to form strong acids.
2. Burning fossil fuels can create acid precipitation.
3. This damages lakes, streams, forests, and soils.
4. The U.S. Clean Air Act has been effective in reducing acid precipitation.

E. Ocean acidification
1. As CO_2 levels rise in the atmosphere, about 25% of the excess CO_2 is absorbed by the oceans.
2. As CO_2 dissolves in water, it lowers the pH of the oceans.
3. This damages coral reefs and other ecosystems by limiting the ability of organisms to build their exoskeletons or shells.

2.7 All life on Earth is based on carbon.

- **CORE IDEA:** All organisms have an abundance of organic compounds, consisting of carbon skeletons that may have functional groups attached. There are four classes of large organic compounds that are particularly important to life: carbohydrates, lipids, proteins, and nucleic acids.

A. All organisms on Earth are “carbon-based life-forms.”
1. **Organic compounds** contain carbon bonded to other elements.
2. Carbon is able to form large, highly branched, diverse chains that can serve as the basic skeleton for a wide variety of chemical compounds.

B. Carbon skeletons
1. Each carbon atom forms four bonds to other atoms.
2. Carbon skeletons vary in length and branching pattern, and some fuse to form rings.

C. Functional groups
1. **Functional groups** are sets of atoms attached to the carbon skeleton.
2. Functional groups participate in chemical reactions with other compounds.
3. Functional groups often determine the overall properties of an organic compound.
4. Some biologically important functional groups include hydroxyl group, amino group, and phosphate group.

D. Biologically important organic compounds
1. **Carbohydrates—cellulose**, **glucose**
2. **Lipids—coconut oil**, **cholesterol**
3. **Proteins—hexokinase**, **keratin**
4. **Nucleic acids—DNA**, **RNA**

2.8 Most biological macromolecules are polymers.

- **CORE IDEA:** Macromolecules (large molecules) are often polymers made by joining together monomers via dehydration synthesis reactions. Polymers can be broken down into the monomers that make them up via hydrolysis reactions.

A. Macromolecules
1. **Macromolecules** are large molecules that can have complex structures.
2. All macromolecules are built up and broken down by similar chemical reactions.

B. Hydrolysis reactions
1. **Polymers** are large molecules made by joining smaller molecules called **monomers**.
2. Polymers can be broken down into monomers via **hydrolysis reactions**.
3. Hydrolysis reactions are the opposite of a **dehydration synthesis reaction**.
4. During hydrolysis, a water molecule provides the atoms needed to separate a monomer from the rest of the chain.

C. Dehydration synthesis reactions
1. Monomers are linked together by a **dehydration synthesis reaction**.
2. A new chemical bond is created as a molecule of water is removed.
3. Dehydration synthesis is the opposite of a hydrolysis reaction.

D. Metabolism
1. **Metabolism** is the sum of all the chemical reactions taking place in your body.
2. These reactions include breaking down or building up polymers.
3. Your digestive system breaks down meat (protein) into amino acids.
4. Your cells use these amino acids to build up new proteins.

2.9 Carbohydrates are composed of monosaccharides.

- **CORE IDEA:** Carbohydrates consist of one or more monosaccharides joined together. Simple sugars (monosaccharides) include glucose and fructose; disaccharides include sucrose; and polysaccharides include starch and cellulose.

A. Carbohydrates
1. All **carbohydrates** are molecules constructed from one or more **monosaccharides** (simple sugars).
2. Carbohydrates are a common source of dietary energy for animals and a structural component of plants.

B. Monosaccharides
1. Monosaccharides are the building blocks of carbohydrates.
2. **Glucose** and **fructose** are **isomers** and have the same numbers and kinds of atoms but differ in arrangement of atoms.

C. Disaccharides
1. A **disaccharide** is a double sugar formed by joining two monosaccharides.
2. **Sucrose** is composed of a glucose joined to a fructose.
3. Other common disaccharides include **lactose** and **maltose**.
4. Many sugars have names ending in "-ose."

D. Polysaccharides
1. **Polysaccharides** are complex carbohydrates made by joining many monosaccharides into a long chain.
2. **Starch** is a storage molecule for plants.
3. **Cellulose** is a structural component of plants.
4. **Glycogen** is stored by animals in muscle and liver cells.
5. Chitin forms the outer skeleton of arthropods and many fungi.

2.10 Lipids are a diverse group of hydrophobic molecules.

- **CORE IDEA:** Lipids are a diverse group of hydrophobic organic compounds. Lipids include phospholipids, cholesterol, triglycerides, and steroid hormones.

A. Lipids
1. They are a very diverse group of organic compounds.

2. All **lipids** are **hydrophobic**, meaning they do not mix with water.

B. Phospholipids

1. Every living cell is surrounded by a membrane.
2. These membranes are **phospholipid bilayers**.
   a. They are composed of two layers of **phospholipids**.
3. A phospholipid contains a phosphate group in its hydrophilic head and two long hydrophobic tails.

C. Cholesterol

1. It is found in animal cell membranes.
   a. It helps maintain fluidity.
2. Animal cells use **cholesterol** to synthesize several important lipid hormones.
3. Cholesterol is found in animal-derived foods.
4. Types of cholesterol
   a. LDL—low-density lipoprotein ("bad cholesterol")—levels can be increased through poor diet
   b. HDL—high-density lipoprotein ("good cholesterol")—levels can be increased through exercise

D. Triglycerides

1. A **triglyceride** is a typical dietary fat.
2. A triglyceride consists of one molecule of glycerol joined to three **fatty acid** molecules.
3. The carbon/hydrogen chains in the fatty acid tails store a lot of energy.
   a. Fatty foods, therefore, have a lot of calories.
4. Excess calories in the body are stored by adding triglycerides to adipose tissue.

E. Steroid hormones

1. **Steroids** contain four fused chemical rings.
2. Cholesterol is one familiar steroid.
3. Cholesterol is used to produce hormones such as the sex hormones, estrogen, and testosterone.
4. **Anabolic steroids** are synthetic variants of testosterone used to increase body mass, but with potentially dangerous side effects.
   a. Mark McGuire has admitted to using these performance-enhancing drugs.

2.11 Your diet contains several different kinds of fats.

- **CORE IDEA:** Lipids include dietary fats: saturated fats and unsaturated fats (including trans fats and omega-3 fats). Unsaturated fats tend to be healthier than saturated fats, but trans unsaturated fats are particularly unhealthy.

A. Dietary lipids

1. Most of the lipids you consume in your diet are triglycerides.
2. Each triglyceride molecule contains three long, fatty acid chains connected to one glycerol.

B. Saturated fats

1. **Saturated fats** have the maximum number of hydrogens along the fatty acid tail.
   a. All are single chemical bonds.
   b. As a result, the fatty acid tails are straight.
2. Saturated fats tend to be solid at room temperature.
3. They are found in highest quantities (but not exclusively) in animal products.
4. They generally are less healthy.

C. Unsaturated fats

1. Unsaturated fats have one or more double bonds in the fatty acid tail.

a. There are fewer than the maximum number of hydrogens.

b. As a result, the fatty acid tails are bent.

2. Unsaturated fats tend to be liquid at room temperature.

3. They are found in highest quantities (but not exclusively) in vegetable and fish oils.

4. They generally are healthier.

5. Types of unsaturated fats

a. Trans fat

i. Hydrogenation is a manufacturing process that renders unsaturated fat solid.

ii. Hydrogenation produces **trans fats**.

iii. Trans fats are very unhealthy and must be listed explicitly on food labels.

b. Healthy fats

i. Omega-3 fatty acids are known to reduce the risk of heart disease.

ii. Fish, chicken, eggs, peanuts, and beans are high in omega-3 fatty acids.

2.12 Proteins perform many of life's functions.

- **CORE IDEA:** Proteins are a diverse set of molecules made from amino acids joined by peptide bonds. Proteins perform most of the tasks required of life. Each kind of protein has a unique shape that determines its functions.

A. Proteins

1. Each kind of **protein** has a unique structure and shape that allows it to perform a specific function.

B. Protein structure

1. All proteins are made by joining **amino acid** monomers together.

a. Peptide bonds are formed through **dehydration synthesis**.

2. Amino acids

a. Every amino acid contains a central carbon atom, an amino group, and a carboxylic acid group.

b. Each of the 20 kinds of amino acids contains a different side group that gives it unique chemical properties.

3. The specific order of amino acids determines the overall structure of that protein.

a. A **polypeptide** is a long chain of amino acids.

b. Every polypeptide twists and folds into a unique, three-dimensional shape.

c. Some proteins contain multiple polypeptide chains joined to form a large complex.

i. Hemoglobin is made of four polypeptide chains.

C. Functions of proteins

1. If something is getting done in your body, chances are there is a protein doing it.

2. Note that each protein has a unique shape that enables it to perform its unique function.

3. Examples include transport, defense, structure, enzymes, and movement.

D. Protein form and function

1. The precise amino acid sequence of a protein determines its overall shape and its function.

2. Changes in the amino acid sequence may alter the protein's ability to perform its normal task.

3. Changing one amino acid in one of the 146 amino acids making up one of the polypeptides in hemoglobin causes the protein to misfold.

a. Sickle-cell disease results from a mutation.

2.13 Enzymes speed chemical reactions.

- **CORE IDEA:** Enzymes are proteins that speed chemical reactions by lowering activation energy. A substrate binds to the active site of an enzyme and is converted to one or more products. Inhibitors are molecules that prevent enzymes from working.

A. Enzymes
  1. **Enzymes** are proteins that speed up a chemical reaction without being changed themselves.
  2. All living cells contain a huge variety of different enzymes, each promoting its own specific reaction.

B. Enzymes and their substrates
  1. Each enzyme recognizes one specific target molecule, its **substrate**.
  2. The substrate bonds to the **active site** of the enzyme.
    a. The active site has a shape that is complementary to the substrate.
  3. The enzyme lactase splits lactose into glucose and galactose.
  4. The enzyme is unchanged by the reactions and can work again and again.

C. Activation energy
  1. The **activation energy** is the amount of energy required for a chemical reaction to proceed.
  2. An enzyme reduces the activation energy, allowing the reaction to proceed faster.

D. Inhibitors
  1. **Inhibitors** bind to an enzyme and disrupt its function to lower the reaction rate.
    a. **Competitive inhibitors** bind to the active site.
      i. Competitive inhibitors in the active site prevent the substrate from binding.
    b. **Noncompetitive inhibitors** bind somewhere other than the active site.
      i. Noncompetitive inhibitors change the shape of the enzyme such that the substrate cannot bind to the active site.

E. Function follows form.
  1. Enzyme function depends on shape.
  2. Changing an enzyme's shape will change its function.
  3. Lactose intolerance is caused by a mutation that alters the shape of the enzyme.
    a. The enzyme no longer breaks apart lactose.

Key Terms

2.1 All life is made of molecules, which are made of atoms.

Atom	Compound	Molecule
Chemical reaction	Element	Product
Chemistry	Matter	Reactant

2.2 All matter consists of chemical elements.

Atomic number	Element	Symbol
Atomic weight	Periodic table of the elements	Trace element

2.3 Atoms are composed of subatomic particles.

Electron	Neutron	Subatomic particle
Ion	Nucleus	
Isotope	Proton	

2.4 Atoms are held together by chemical bonds.

Chemical bond	Hydrogen bond	Polar bond
Covalent bond	Ionic bond	Single bond
Double bond	Nonpolar bond	

2.5 The structure of water gives it unique properties.

Adhesion	Solution
Cohesion	Solvent

2.6 pH is a measure of the acidity of a solution.

Acid	Base	pH scale
Aqueous solution	Buffer	

2.7 All life on Earth is based on carbon.

Carbohydrate	Functional group	Nucleic acid
Cellulose	Glucose	Organic compound
Cholesterol	Hexokinase	Protein
Coconut oil	Keratin	RNA
DNA	Lipid	

2.8 Most biological macromolecules are polymers.

Dehydration synthesis reaction	Macromolecule	Polymer
	Metabolism	
Hydrolysis reaction	Monomer	

2.9 Carbohydrates are composed of monosaccharides.

Carbohydrate	Glucose	Monosaccharaide
Cellulose	Glycogen	Polysaccharide
Disaccharide	Isomer	Starch
Fructose	Lactose	

2.10 Lipids are a diverse group of hydrophobic molecules.

Anabolic steroid	Hydrophobic	Phospholipid bilayer
Cholesterol	Lipid	Steroid
Fatty acid	Phospholipid	triglyceride

2.11 Your diet contains several different kinds of fats.

Hydrogenation	Saturated fat	Unsaturated fat
Omega-3 fatty acid	Trans fat	

2.12 Proteins perform many of life's functions.

Amino acid	Polypeptide
Peptide bond	Protein

2.13 Enzymes speed chemical reactions.

Activation energy	Enzyme	Substrate
Active site	Inhibitor	
Competitive inhibitor	Noncompetitive inhibitor	

Student Misconceptions and Teaching Tips

- Students should recognize that they have some knowledge that can be applied to this course. They may feel that every concept in this chemistry review is foreign. Encourage them by pointing out common molecules that they are familiar with or common substances that are chemicals discussed in this chapter.

- Chemical structures will be intimidating to many students. Be explicit in what you will be requiring for the exam to reduce their anxiety.

2.1 All life is made of molecules, which are made of atoms.

- ○ The concept of mass is problematic. Students are familiar with weight and assume weight and mass mean the same thing. Weight differs depending on gravity. Point out that a person who weighs 150 pounds on Earth weighs 56.7 pounds on Mars but 354.6 pounds on Jupiter. The person's mass remains the same.
- ○ Oxygen gas (O_2) is a molecule but not a compound. H_2O is both a molecule and a compound.
- ○ The numbers in chemical formulas are very important. Point out the difference in the numeral "6" in $6CO_2$ versus the "6" in $C_6H_{12}O_6$.

2.2 All matter consists of chemical elements.

- ○ The periodic chart on page 18 may inspire fear in science-phobic students. Encourage them to view it merely as a tool. Be explicit in exactly what is expected material on an exam. Students will want to know if they should memorize the table or not.

2.3 Atoms are composed of subatomic particles.

- ○ The subatomic particle chart on page 20 is a great way to introduce tables as a way to organize large amounts of information. Nonscience majors may seem overwhelmed by the volume of material in a science course. Tables are a great way to organize material to make comparison and contrast easier.
- ○ Interesting topics to explore in isotopes are the following:
    - ▪ The use of isotopes in treating cancer. Radioactive iodine (131-I) can be used to selectively destroy thyroid cancer.
    - ▪ Radiation therapy for cancer works by damaging DNA in rapidly growing cells. That is bad for cancer but also has side effects for the human patient's other healthy, rapidly growing cells.
    - ▪ Radioactive chemicals are used by scientists in experiments. Many images of autoradiograms are available on the Web that could be used to highlight the use of radiation in science.
    - ▪ Carbon-14 dating can be used to learn the age of prehistoric artifacts. The exact methodology is not as important as the concept of the use of radiation as a tool.
- ○ Charges on ions often cause confusion. Adding electrons makes the ions more negative but losing electrons makes them more positive. Use practice problems in class or for homework to help students with this issue.
- ○ An organizing concept for a comparison of an element, isotope, and ion would be to ask three questions:
    - ▪ What happens if you change the number of protons in an element?
    - ▪ What happens if you change the number of neutrons in an element?
    - ▪ What happens if you change the number of electrons in an element?

2.4 Atoms are held together by chemical bonds.

- ○ The figure at the top right of page 22 is an excellent device for comparing and contrasting ionic and covalent bonds.
- ○ Emphasize the idea of a polar bond creating poles in a molecule.

- Nonpolar covalent bonds have an equal distribution of ions and no poles.
- The concept of slightly positive and negative ends in polar covalent bonds should be distinguished from ions that are positive and negative due to a loss or gain of electrons.
- Hydrogen bonds are the weakest bonds and yet they hold our most important molecule, DNA, together. The analogy of hydrogen bonds being like Velcro is useful. Individual Velcro bonds are weak but together they are very strong. A quick Web search for "Velcro wall" will reveal images of a Velcro suit that will hold the weight of a person to a Velcro wall.

2.5 The structure of water gives it unique properties.

- The concept of slightly positive and negative ends in polar covalent bonds should be distinguished from ions that are positive and negative due to a loss or gain of electrons.
- Hydrogen bonds form *between* water molecules as a result of polar covalent bonding *within* a water molecule.
- Describe a scenario of winter approaching and water beginning to freeze. What is the result if (1) ice sinks as it freezes, (2) the pond freezes from the bottom up versus ice floating, (3) the pond freezes from the top down?
- *Solution* and *solvent* sound very similar. If the term *solute* is included, it is even more confusing. Use a common example of adding sugar to water to name the parts.

2.6 pH is a measure of the acidity of a solution.

- Students often have problems reconciling an increase in acidity with a decrease in the pH value. Likewise, an increase in alkalinity is a decrease in H^+ concentration.

2.7 All life on Earth is based on carbon.

- The chemical structures may alarm students worried about what will be required on the exam. Be explicit in your instructions as to what you will expect them to know.
- Bring in diagrams of various molecular formulas and point out different carbon skeletons and/or functional groups in various biological molecules with which students may be familiar.

2.8 Most biological macromolecules are polymers.

- Emphasize that the answer to every single question regarding, How do I break any macromolecule apart? is hydrolysis. Likewise, the answer to every single question regarding, How do I put monomers together? is dehydration synthesis.
- Students come in with knowledge of the meaning of words. Highlight their knowledge to add to their confidence.
  - Ask students what it means to be dehydrated. It means I've lost or am losing water. So dehydration is a loss of water between two molecules. What does synthesis mean? To make something. Dehydration synthesis is to put two molecules together by pulling water from two molecules together.
  - What does *hydro* mean? Some may know it refers to water. *Lysis* may come up several times this semester. *Lysis* means to break apart. Hydrolysis is breaking two molecules apart by inserting a molecule of water at the bond.
  - What does *mono* mean (e.g., monorail, monogamy)? It means "one" or "single." A monomer is a single unit like a bead in a necklace.
  - What does *poly* mean (e.g., polygamy, polygon)? It means "many." The polymer is many monomers joined together like the whole necklace of beads.

- When most people hear the word *metabolism*, they think of weight loss. They think it applies only to the breakdown of food. Metabolism is all the reactions going on inside your cells, including those building up and breaking down polymers.

2.9 Carbohydrates are composed of monosaccharides.

- Isomers, ions, and isotopes all sound similar yet are very different. Make sure to point this out and compare/contrast the terms.
- The easiest way to demonstrate isomers is using your hands. The left hand and the right hand have all the same parts but a slightly different arrangement. Is the left hand structurally the same as the right hand? No. This will be important in biology. Reach out to shake hands with a student. If I reach out to shake your hand, it feels strange if you give me your left hand. When biological molecules interact, their structure will be very important.
- In common language, *sugar* means "table sugar" or "sucrose." Students may confuse the biological/chemical concept of sugar with the common language word *sugar*.
- The table from Module 2.8 can be filled in with information on carbohydrates to emphasize the concepts of monomer and polymer, and how they are joined/broken down.

2.10 Lipids are a diverse group of hydrophobic molecules.

- Common language can help to understand science terms.
  - What does *hydro* mean? This was covered in Module 2.8. It means "water."
  - What is a phobia? A fear. Hydrophobic molecules are "water-fearing."
  - What does the *phil* in *Philadelphia* mean? The City of Brotherly Love. Or the *phil* in *necrophilia?* It means "affinity" or "friendship" (or "unnatural attraction"). Hydrophilic means "water-loving."
- Cholesterol gets a bad reputation from the popular press. Point out that it is natural, normal, and healthy to have moderate amounts of cholesterol in your diet.
- The table from Module 2.8 can be filled in with information on lipids to emphasize the concepts of monomer and polymer and how they are joined/broken down. Some people do not consider lipids to follow the traditional monomer/polymer concept. Others will use triglycerides as the polymer example for lipids.

2.11 Your diet contains several different kinds of fats.

- The identity of fatty acid tails can differ in a single triglyceride. The types of triglycerides in a single food item can vary. We say that butter is "high" in saturated fats but it also contains unsaturated fat.
- What does *saturated* mean? It means "soaked" or "covered." Saturated fats are covered in hydrogens, which means all single bonds.
- The idea that saturated fatty acid tails are straight and so pack tightly together results in fats that are solid at room temperature. Think "lard" or "butter."
- Trans fats were a huge news item several years ago. Food packaging is required to list trans fat content and most manufacturers are phasing it out. The idea of creating a trans fat was to take cheap vegetable-origin fat (mostly unsaturated) and make it act and taste like expensive animal-origin fat (mostly saturated).

2.12 Proteins perform many of life's functions.

- The table from Module 2.8 can be filled in with information on proteins to emphasize the concepts of monomer and polymer and how they are joined/broken down.

- Images of different side groups could be included in a lecture to highlight their differences in size, shape, chemistry, and so on.
- Hemoglobin is the most common example of the fourth (or quaternary) level of structure of proteins. The problem is that students will confuse fourth level with four polypeptide subunits and think a protein has to have four subunits to have the fourth level of structure.
- Students will be very interested in sickle-cell disease. Make sure to do some background reading so you are ready for possible questions. Ask students what facts they know. Use any incorrect information as a teachable moment to provide correct information. Sickle-cell disease can be used as an example several times in the course to point out various levels of structure and function in biology.

2.13 Enzymes speed chemical reactions.

- We tend to associate together the words *higher* and *faster* in common language. Enzymes lower the activation energy to make the reaction faster. The visual image of lowering a hurdle to make it easier/faster to jump is excellent.
- Lactase and lactose intolerance are mentioned in this topic. Students may be or know someone who is lactose intolerant. A person who does not make enough or any lactase will be lactose intolerant. Highlight the spelling difference between *lactase* and *lactose*. A person who is lactose intolerant eats dairy products and is unable to digest them. The lactose then arrives in the large intestine where a feeding frenzy for bacteria ensues. This causes the side effects of bloating, gas, and diarrhea. Taking a pill containing lactase before consuming dairy products can aid some lactose-intolerant people.

Class Activities

2.1 All life is made of molecules, which are made of atoms.

- Student groups are given a list of chemical formulas. At least some should be familiar compounds and some should be single elements. Ask if the formula indicates a molecule, compound, both, or neither.

2.2 All matter consists of chemical elements.

- Encourage the use of math skills in a biology class. If a person weighs 150 pounds, how many pounds of calcium does he or she contain? The answer is 2.25 pounds of calcium in a 150-pound person. Different elements could be assigned to various student groups to calculate and present to the class or to do as homework.
- Students could be assigned to look for dietary sources of the different elements essential to life.

2.3 Atoms are composed of subatomic particles.

- Ion charges are difficult to grasp. Make a simple graphic of chlorine. The balanced atom has 17 protons and 17 electrons. Stack 17 blocks of one color representing protons and 17 blocks of another color representing electrons next to each other. These could be actual physical items, note cards taped to the board, or squares on a slide. The chlorine ion (Cl^-) has gained one electron. Add one block in the color representing an electron to the electron stack. The same can be done for sodium. The balanced atom has 11 protons and 11 electrons. The ion (Na^+) has lost an electron, so remove one electron from the electron stack.

- Radiation therapy in cancer has side effects on the patient's healthy, rapidly growing cells. Ask the class what the side effects of radiation therapy are. Point out how each is a side effect of damaging healthy, rapidly growing cells.

2.4 Atoms are held together by chemical bonds.

- Give descriptions of bonds and have students answer what type of bond is being described.

2.5 The structure of water gives it unique properties.

- Bring a glass of water and some sugar to class. Ask the students to name the component (solvent, solution). The term *solute* may be used to describe the sugar, although it is not used in the text.
- Surface tension can be visualized by dropping water on a penny with a pipet or eyedropper. If you have a video projection device, the demonstration is more effective in a lecture classroom. Soap can be added to alter the surface tension, and the demonstration is repeated. The penny will hold fewer drops of water with the soap added.

2.6 pH is a measure of the acidity of a solution.

- There are many demonstrations of pH available by doing a simple Internet search for "pH demo."
  - Bring various household items to the lecture. Use pH paper to measure the pH and order them by the results.
  - Red cabbage juice will change color when mixed with solutions of different pH. Directions are available on many websites.
- A simple model of a buffer can be made with one or two students as actors. One student will be the "buffer." The buffer can accept or donate H^+ ions (represented as notecards). The other student is the acidic or basic solution being added. Start off with equal numbers of H^+ and OH^- notecards taped to the board. In the first phase, the acidic solution adds H^+ to the solution. Ask the class if the pH has changed. The answer is yes, with more H^+ relative to OH^- after the acid adds H^+. The same can be done with a basic solution, taking H^+ off the board. Now the pH increases with less H^+ relative to OH^-. In the second phase, a buffer participates by adding H^+ from its reserve when the base takes H^+ out of solution. Ask the class if the pH has changed. The answer is no; the buffer counteracts the action of the base.
- Either the professor or students can bring in or post to a website recent articles dealing with acid precipitation or ocean acidification. Points could be given for posting an article or making thoughtful comments on a posted article. Distinguish between articles on the process versus actual new news.

2.7 All life on Earth is based on carbon.

- Assign student groups to sort a list of items into their class of biologically important organic compounds (most prominent ingredient). Examples of carbohydrates might include table sugar, brown paper bags, potatoes, and wood. Examples of lipids could include lard, egg yolk, olive oil, body fat, and cholesterol. Examples of proteins could be as diverse as hair, steak, and egg white. Examples of nucleic acids should be limited to RNA and DNA.

2.8 Most biological macromolecules are polymers.

- Tables can help to organize information so it does not seem overwhelming. The table can be filled in as topics in the rest of the chapter are completed.

Class of biological molecule	What is the monomer?	What is the polymer?	How are monomers joined?	How are polymers broken down?	Common examples
Carbohydrates					
Protein					
Lipids					
Nucleic Acids					

2.9–2.12 Summary Activity

- From the Instructor Exchange in MasteringBiology: *What Ingredients Make Up Your Snack Food?* Posted on May 31, 2011, by Instructor Exchange, written by Michelle Zurawski, Moraine Valley Community College.

2.9 Carbohydrates are composed of monosaccharides.

- Assign students as preclass homework to bring in examples of foods or other items that are composed of carbohydrates. Ask for volunteers to give their lists.

2.10 Lipids are a diverse group of hydrophobic molecules.

- Assign students as preclass homework to bring in examples of foods or other items that are composed of lipids. Ask for volunteers to give their lists.

2.11 Your diet contains several different kinds of fats.

- Assign students as preclass homework to bring in a list (or bring one yourself) of the types of fats found in various foods.

2.12 Proteins perform many of life's functions.

- Assign students as preclass homework to bring in examples of foods or other items that are composed of proteins or proteins with different functions in the body. Ask for volunteers to give their lists.
- Assign students to do limited readings on sickle-cell disease to prepare for a discussion of structure and function in proteins.

2.13 Enzymes speed chemical reactions.

- A demonstration of inhibition in enzyme reactions
  - Check out the seating in the lecture room. A seat can be an active site. If you have seats that fold down or up, you have the perfect arrangement. Otherwise, bring a roll of tape or trash bag. Bring some colored paper to act as a substrate molecule.
  - Ask for volunteers to help. You'll need a few people to be "substrate." A substrate sits in a chair and tears his or her piece of paper in half. A substrate can only tear the paper in half sitting in the seat. Allow several people to sit down, tear their papers, and get up. This is the normal rate of enzyme reaction.
  - Now add another set of volunteers called "competitive inhibitors." They line up with a substrate to sit in a chair. If a competitive inhibitor sits in the chair, it slows reaction rate down. The more competitive inhibitors (actors) there are to sit in the seat, the slower the reaction rate will be.

- A third set of volunteers are the “noncompetitive inhibitors.” They do not line up with a substrate to sit in the seat. Every time a substrate leaves the seat open, the noncompetitive inhibitor closes the seat or puts a trash bag over the seat or puts a piece of tape over the seat for a short length of time. This prevents the substrate from sitting down. The noncompetitive inhibitors do not bind to the active site.
- This scenario could be modified in many ways to test the effect of the addition of more substrates on the reaction rate, the addition of more enzymes (more chairs), and so on.