INSTRUCTOR: Prof. Watkins (email: bwaterst@rusd.k12.ca.us)

COURSE DESCRIPTION: Advanced Placement (AP*) Biology is an intense, two-semester sequence designed to be the equivalent of a college introductory biology course typically taken by biology majors during their freshman year. Because of the volume and depth of material we'll cover, it is absolutely essential that you budget your time wisely to make sure that you keep up with the assigned readings!

COURSE OBJECTIVES: After successfully completing this course, the student (i.e., you) will have acquired a fundamental background in biology and an understanding of the major biological principles that are necessary for your professional and personal life. The major objectives include (1) to develop or enhance an appreciation for the biological realm, (2) to familiarize you with the use, value, and limitations of the scientific method, (3) to understand science as a process rather than an accumulation of facts, (4) to use and understand the vocabulary of modern biology in relevant applications, and (5) to apply biological knowledge and critical thinking to environmental and social concerns.


SUMMER ASSIGNMENT: In order to succeed in this class and, ultimately, to earn a passing grade (i.e., a “3” or better) on the AP Biology exam from the College Board, it is imperative that you “hit the ground running” next fall with a solid foundation in biochemistry. Therefore, the following summer assignment is required:

1. Obtain a copy of the AP* Biology textbook from the AHS library and a copy of the most recent edition of CliffsNotes AP* Biology from Amazon.com, Barnes & Noble, etc.
2. Read Chapters 3-5 in the textbook and complete the attached Student Study Guide questions. Do not answer questions that require you to construct a concept map. Please write your answers directly on the pages provided! These are due by Friday, August 24, 2018.
3. Read the Cliffs AP* Biology chapter on chemistry (Chapter 2).

Your first exam is scheduled for the second week of the school year and will cover the chapters on biochemistry and metabolism. If you have any questions, please contact me via email at the address given above.

Have an outstanding summer, and I’ll look forward to seeing you in the fall!

Biologically,

Prof. Watkins
Chapter 3

Water and the Fitness of the Environment

Key Concepts

3.1 The polarity of water molecules results in hydrogen bonding

3.2 Four emergent properties of water contribute to Earth’s fitness for life

3.3 Dissociation of water molecules leads to acidic and basic conditions that affect living organisms

Framework

Water makes up 70% to 95% of the cell content of living organisms and covers 75% of the Earth’s surface. Its unique properties make the external environment fit for living organisms and the internal environments of organisms fit for the chemical and physical processes of life.

Hydrogen bonding between polar water molecules creates a cohesive liquid with a high specific heat and high heat of vaporization, both of which help to regulate environmental temperature. Ice floats and protects oceans and lakes from freezing. The polarity of water makes it a versatile solvent. An organism’s pH may be regulated by buffers. Acid precipitation poses a serious environmental threat.

Chapter Review

3.1 The polarity of water molecules results in hydrogen bonding

A water molecule consists of two hydrogen atoms each covalently bonded to a more electronegative oxygen atom. This polar molecule has a shape like a wide V with a slight positive charge on each hydrogen atom (δ+) and a slight negative charge (δ−) associated with the oxygen. Hydrogen bonds, electrical attractions between the hydrogen atom of one water molecule and the oxygen atom of a nearby water molecule, create a higher level of structural organization and lead to the emergent properties of water.

3.2 Four emergent properties of water contribute to Earth’s fitness for life

Cohesion Liquid water is unusually cohesive due to the constant forming and reforming of hydrogen bonds that hold the molecules together. This cohesion creates a more structurally organized liquid and helps water to be pulled upward in plants. The adhesion of water molecules to the walls of plant vessels also contributes to water transport. Hydrogen bonding between water molecules produces a high surface tension at the interface between water and air.

Interactive Question 3.1

Draw the four water molecules that can hydrogen-bond to this water molecule. Show the bonds and the slight negative and positive charges that account for the formation of these hydrogen bonds.

Moderation of Temperature

In a body of matter, heat is a measure of the total quantity of kinetic energy, the energy associated with the movement of atoms and molecules. Temperature measures the average kinetic energy of the molecules in a substance.
Temperature is measured using a **Celsius scale**. Water at sea level freezes at 0°C and boils at 100°C. A **calorie (cal)** is the amount of heat energy it takes to raise 1 g of water 1°C. A **kilocalorie (kcal)** is 1,000 calories, the amount of heat required to raise 1 kg of water 1°C. A **joule (J)** equals 0.239 cal; a calorie is 4.184 J.

**Specific heat** is the amount of heat absorbed or lost when 1 g of a substance changes its temperature by 1°C. Water's specific heat of 1 cal/g°C is unusually high compared with that of other common substances; water must absorb or release a relatively large quantity of heat in order for its temperature to change. Heat must be absorbed to break hydrogen bonds before water molecules can move faster and the temperature can rise, and conversely, heat is released when hydrogen bonds form as the temperature of water drops. The ability of large bodies of water to stabilize air temperature is due to the high specific heat of water. The high proportion of water in the environment and within organisms keeps temperature fluctuations within limits that permit life.

The transformation from a liquid to a gas is called vaporization or evaporation and happens when molecules with sufficient kinetic energy overcome their attraction to other molecules and escape into the air as gas. The **heat of vaporization** is the quantity of heat that must be absorbed for 1 g of a liquid to be converted to a gas. Water has a high heat of vaporization (580 cal/g at 25°C) because a large amount of heat is needed to break the hydrogen bonds holding water molecules together. This property of water helps moderate the climate on Earth as solar heat is dissipated from tropical seas during evaporation and heat is released when moist tropical air condenses to form rain.

As a substance vaporizes, the liquid left behind loses the kinetic energy of the escaping molecules and cools down. **Evaporative cooling** helps to protect terrestrial organisms from overheating and contributes to the stability of temperatures in lakes and ponds.

**Insulation of Water Bodies by Floating Ice** As water cools below 4°C, it expands. By 0°C, each water molecule becomes hydrogen-bonded to four other molecules, creating a crystalline lattice that spaces the molecules apart. Ice is less dense than liquid water, and therefore, it floats. The floating ice insulates the liquid water below.

**The Solvent of Life** A **solution** is a liquid homogeneous mixture of two or more substances; the dissolving agent is called the **solvent** and the substance that is dissolved is the **solute**. Water is the solvent in an **aqueous solution**. The positive and negative regions of water molecules are attracted to oppositely charged ions or partially charged regions of polar molecules. Thus, solute molecules become surrounded by water molecules (a **hydration shell**) and dissolve into solution.

---

**INTERACTIVE QUESTION 3.2**

The following concept map is one way to show how the breaking and forming of hydrogen bonds is related to temperature moderation. Fill in the blanks and compare your choice of concepts to those given in the answer section. Or, better still, create your own map to help you understand how water stabilizes temperature.

---

Ionic and polar substances are **hydrophilic**; they have an affinity for water due to electrical attractions and hydrogen bonding. Large hydrophilic substances may not dissolve but become suspended in an aqueous solution, forming a mixture called a **colloid**. Nonionic and nonpolar molecules are **hydrophobic**; they will not easily mix with or dissolve in water.
INTERACTIVE QUESTION 3.3

Indicate whether the following are hydrophilic or hydrophobic. Do these substances contain ionic, polar covalent bonds, or nonpolar covalent bonds?

a. olive oil  c. salt
b. sugar d. candle wax

Most of the chemical reactions of life take place in water. A mole (mol) is the amount of a substance that has a mass in grams numerically equivalent to its molecular mass (sum of the mass of all atoms in the molecule) in daltons. A mole of any substance has exactly the same number of molecules—6.02 × 10²³, called Avogadro’s number. The molarity of a solution (abbreviated M) refers to the number of moles of a solute dissolved in 1 liter of solution.

INTERACTIVE QUESTION 3.4

a. How many grams of lactic acid (C₃H₆O₃) are in a 0.5 M solution of lactic acid? (¹²C, ¹H, ¹⁶O)

b. How many grams of salt (NaCl) must be dissolved in water to make 2 liters of a 2 M salt solution? (²³Na, ³⁴Cl)

3.3 Dissociation of water molecules leads to acidic and basic conditions that affect living organisms

A water molecule can dissociate into a hydrogen ion, H⁺ (which binds to another water molecule to form a hydronium ion, H₃O⁺) and a hydroxide ion, OH⁻. Although reversible and statistically rare, this dissociation into the highly reactive hydrogen and hydroxide ions has important biological consequences. In pure water at 25°C, the concentrations of H⁺ and OH⁻ ions are the same; both are equal to 10⁻⁷ M.

Effects of Changes in pH When acids or bases dissolve in water, the H⁺ and OH⁻ balance shifts. An acid adds H⁺ to a solution, whereas a base reduces H⁺ in a solution by accepting hydrogen ions or by adding hydroxide ions (which then combine with H⁺ and thus remove hydrogen ions). A strong acid or strong base may dissociate completely when mixed with water. A weak acid or base reversibly dissociates, releasing or binding H⁺.

In an aqueous solution, the product of the [H⁺] and [OH⁻] is constant at 10⁻¹⁴. Brackets, [ ], indicate molar concentration. If the [H⁺] is higher, then the [OH⁻] is lower, due to the tendency of excess hydrogen ions to combine with the hydroxide ions in solution and form water. Likewise, an increase in [OH⁻] causes an equivalent decrease in [H⁺]. If [OH⁻] is equal to 10⁻¹⁰ M, then [H⁺] will equal 10⁻⁴ M.

The logarithmic pH scale compresses the range of hydrogen and hydroxide ion concentrations, which can vary in different solutions by many orders of magnitude. The pH of a solution is defined as the negative log (base 10) of the [H⁺]: pH = −log [H⁺]. For a neutral aqueous solution, [H⁺] is 10⁻⁷ M, and the pH equals 7. As the [H⁺] increases in an acidic solution, the pH value decreases. The difference between each unit of the pH scale represents a tenfold difference in the concentration of [H⁺] and [OH⁻].

INTERACTIVE QUESTION 3.5

Complete the following table to review your understanding of pH.

<table>
<thead>
<tr>
<th>[H⁺]</th>
<th>[OH⁻]</th>
<th>pH</th>
<th>Acidic, Basic, or Neutral?</th>
</tr>
</thead>
<tbody>
<tr>
<td>10⁻¹¹</td>
<td></td>
<td>3</td>
<td>acidic</td>
</tr>
<tr>
<td>10⁻⁸</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10⁻⁷</td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Most cells have an internal pH close to 7. Buffers within the cell maintain a constant pH by accepting excess H⁺ ions or donating H⁺ ions when H⁺ concentration decreases. Weak acid-base pairs that reversibly bind hydrogen ions are typical of most buffering systems.

INTERACTIVE QUESTION 3.6

The carbonic acid/bicarbonate system is an important biological buffer. Label the molecules and ions in this equation and indicate which is the H⁺ donor and which is the acceptor.

\[
\text{H₂CO₃} \rightleftharpoons \text{HCO}_₃^- + \text{H}^+
\]

In which direction will this reaction proceed

a. when the pH of a solution begins to fall?

b. when the pH rises above normal level?
The Threat of Acid Precipitation  Acid precipitation, rain, snow, or fog with a pH lower than normal (pH 5.6), is due to the reaction of water in the atmosphere with the sulfur oxides and nitrogen oxides released by the combustion of fossil fuels. Aquatic life is damaged by acid precipitation, and lowering the pH of the soil solution affects the solubility of minerals needed by plants.

Word Roots

kilo- = a thousand (kilocalorie: a thousand calories)
hydro- = water; -philos = loving; -phobos = fearing (hydrophilic: having an affinity for water; hydrophobic: having an aversion to water)

Structure Your Knowledge

1. Fill in the table below that summarizes the properties of water that contribute to the fitness of the environment for life.

2. To become proficient in the use of the concepts relating to pH, develop a concept map to organize your understanding of the following terms: pH, [H⁺], [OH⁻], acidic, basic, neutral, buffer, 1–14, acid-base pair. Remember to label connecting lines and add additional concepts as you need them. A suggested concept map is given in the answer section, but remember that your concept map should represent your own understanding. The value of this exercise is in organizing these concepts for yourself.

<table>
<thead>
<tr>
<th>Property</th>
<th>Explanation of Property</th>
<th>Example of Benefit to Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Hydrogen bonds hold molecules together and adhere them to hydrophilic surface.</td>
<td>b.</td>
</tr>
<tr>
<td>High specific heat</td>
<td>c.</td>
<td>Temperature changes in environment and organisms are moderated.</td>
</tr>
<tr>
<td>d.</td>
<td>Hydrogen bonds must be broken for water to evaporate.</td>
<td>e.</td>
</tr>
<tr>
<td>f.</td>
<td>Water molecules with high kinetic energy evaporate; remaining molecules are cooler.</td>
<td>g.</td>
</tr>
<tr>
<td>Ice floats</td>
<td>h.</td>
<td>i.</td>
</tr>
<tr>
<td>j.</td>
<td>k.</td>
<td>Most chemical reactions in life involve solutes dissolved in water.</td>
</tr>
</tbody>
</table>

Test Your Knowledge

MULTIPLE CHOICE: Choose the one best answer.

1. Each water molecule is capable of forming
   a. one hydrogen bond.
   b. three hydrogen bonds.
   c. four hydrogen bonds.
   d. two covalent bonds and two hydrogen bonds.
   e. two covalent bonds and four hydrogen bonds.

2. The polarity of water molecules
   a. promotes the formation of hydrogen bonds.
   b. helps water to dissolve nonpolar solutes.
   c. lowers the heat of vaporization and leads to evaporative cooling.
   d. creates a crystalline structure in liquid water.
   e. does all of the above.

3. What accounts for the movement of water up the vessels of a tall tree?
   a. cohesion
   b. hydrogen bonding
   c. adhesion
   d. hydrophilic vessel walls
   e. all of the above

4. Climates tend to be moderate near large bodies of water because
   a. a large amount of solar heat is absorbed during the gradual rise in temperature of the water.
   b. water releases heat to the environment as it cools.
   c. the high specific heat of water helps to moderate air temperatures.
   d. a great deal of heat is absorbed and released by the breaking and forming of hydrogen bonds.
   e. all of the above.
5. Temperature is a measure of
   a. specific heat.
   b. average kinetic energy of molecules.
   c. total kinetic energy of molecules.
   d. Celsius degrees.
   e. joules.

6. Evaporative cooling is a result of
   a. a low heat of vaporization.
   b. a high specific heat.
   c. absorption of heat as hydrogen bonds break.
   d. a reduction in the average kinetic energy of a
      liquid after energetic water molecules enter the
      gaseous state.
   e. release of heat caused by the breaking of hydro-
      gen bonds when water molecules escape.

7. Ice floats because
   a. air is trapped in the crystalline lattice.
   b. the formation of hydrogen bonds releases heat;
      warmer objects float.
   c. it has a smaller surface area than liquid water.
   d. it insulates bodies of water so they do not freeze
      from the bottom up.
   e. hydrogen bonding spaces the molecules farther
      apart, creating a less dense structure.

8. The molarity of a solution is equal to
   a. Avogadro’s number of molecules in 1 liter of
      solvent.
   b. the number of moles of a solute in 1 liter of
      solution.
   c. the molecular mass of a solute in 1 liter of
      solution.
   d. the number of solute particles in 1 liter of solvent.
   e. 342 g if the solute is sucrose.

9. Some archaea are able to live in lakes with pH val-
   ues of 11. How does pH 11 compare with the pH 7
   typical of your body cells?
   a. It is four times more acidic than pH 7.
   b. It is four times more basic than pH 7.
   c. It is a thousand times more acidic than pH 7.
   d. It is a thousand times more basic than pH 7.
   e. It is ten thousand times more basic than pH 7.

10. A buffer
    a. changes pH by a magnitude of 10.
    b. releases excess OH⁻.
    c. releases excess H⁺.
    d. is often a weak acid-base pair.
    e. always maintains a neutral pH.

11. Which of the following is least soluble in water?
    a. polar molecules
    b. nonpolar molecules
    c. ionic compounds
    d. hydrophilic molecules
    e. anions

12. Which would be the best method for reducing acid
    precipitation?
    a. Raise the height of smokestacks so that exhaust
       enters the upper atmosphere.
    b. Add buffers and bases to bodies of water whose
       pH has dropped.
    c. Use coal-burning generators rather than nuclear
       power to produce electricity.
    d. Tighten emission control standards for factories
       and automobiles.
    e. Reduce the concentration of heavy metals in in-
       dustrial exhaust.

13. What bonds must be broken for water to vaporize?
    a. polar covalent bonds
    b. nonpolar covalent bonds
    c. hydrogen bonds
    d. ionic bonds
    e. polar covalent and hydrogen bonds

14. How would you make a 0.1 M solution of glucose
    (C₆H₁₂O₆)? The mass numbers for these elements
    are approximately: C = 12, O = 16, H = 1.
    a. Mix 6 g C, 12 g H, and 6 g O in 1 liter of water.
    b. Mix 72 g C, 12 g H, and 96 g O in 1 liter of water.
    c. Mix 18 g of glucose with enough water to yield
       1 liter of solution.
    d. Mix 29 g of glucose with enough water to yield
       1 liter of solution.
    e. Mix 180 g of glucose with enough water to yield
       1 liter of solution.

15. How many molecules of glucose would be in the
    1 liter solution made in question 14?
    a. 0.1
    b. 6
    c. 60
    d. 6 × 10²³
    e. 6 × 10²²
16. Why is water such an excellent solvent?
   a. As a polar molecule, it can surround and dissolve ionic and polar molecules.
   b. It forms ionic bonds with ions, hydrogen bonds with polar molecules, and hydrophobic interactions with nonpolar molecules.
   c. It forms hydrogen bonds with itself.
   d. It has a high specific heat and a high heat of vaporization.
   e. It is wet and has a great deal of surface tension.

17. Which of the following when mixed with water would form a colloid?
   a. a large hydrophobic protein
   b. a large hydrophilic protein
   c. sugar
   d. cotton
   e. NaCl

18. Adding a base to a solution would
   a. raise the pH.
   b. lower the pH.
   c. decrease [H⁺].
   d. do both a and c.
   e. do both b and c.

19. A hydration shell is most likely to form around
   a. an ion.
   b. a fat.
   c. a sugar.
   d. both a and c.
   e. both b and c.

20. The following are the pH values for each item: cola—2; orange juice—3; beer—4; coffee—5; human blood—7.4. Which of these liquids has the highest molar concentration of OH⁻?
   a. cola
   b. orange juice
   c. beer
   d. coffee
   e. human blood

21. Comparing the [H⁺] of orange juice and coffee, the [H⁺] of
   a. orange juice is 10 times higher.
   b. orange juice is 100 times higher.
   c. orange juice is 1,000 times higher.
   d. coffee is two times higher.
   e. coffee is 100 times higher.

22. The ability of water molecules to form hydrogen bonds accounts for water’s
   a. high specific heat.
   b. evaporative cooling.
   c. high heat of vaporization.
   d. cohesiveness and surface tension.
   e. All of the above result from water’s hydrogen-bonding capacity.
Chapter 4
Carbon and the Molecular Diversity of Life

Key Concepts

4.1 Organic chemistry is the study of carbon compounds

4.2 Carbon atoms can form diverse molecules by bonding to four other atoms

4.3 Functional groups are the parts of molecules involved in chemical reactions

Framework

<table>
<thead>
<tr>
<th>CARBON</th>
</tr>
</thead>
<tbody>
<tr>
<td>diversity of life</td>
</tr>
<tr>
<td>makes possible</td>
</tr>
<tr>
<td>structural and functional diversity</td>
</tr>
<tr>
<td>complex organic molecules</td>
</tr>
<tr>
<td>straight or branching chains and rings</td>
</tr>
<tr>
<td>may exist as isomers</td>
</tr>
<tr>
<td>can build</td>
</tr>
<tr>
<td>can bind with</td>
</tr>
<tr>
<td>four covalent bonds</td>
</tr>
<tr>
<td>provide</td>
</tr>
<tr>
<td>can be</td>
</tr>
<tr>
<td>confer</td>
</tr>
<tr>
<td>specific properties</td>
</tr>
</tbody>
</table>

Chapter Review

4.1 Organic chemistry is the study of carbon compounds

Organic chemistry is the study of carbon-containing molecules. Early organic chemists could not synthesize the complex molecules found in living organisms and, therefore, attributed the existence of life and the formation of these molecules to a life force independent of physical and chemical laws, a belief known as vitalism. Mechanism, the philosophy underlying modern organic chemistry, holds that physical and chemical laws and explanations are sufficient to account for all natural phenomena, even the origin of life.

4.2 Carbon atoms can form diverse molecules by bonding to four other atoms

Formation of Bonds with Carbon Carbon has six electrons. To complete its valence shell, carbon forms four covalent bonds with other atoms. This tetraivalence is at the center of carbon's ability to form large and complex molecules with characteristic three-dimensional shapes and properties. When carbon forms four single covalent bonds, its hybrid orbitals create a tetrahedral shape. When two carbons are joined by a double bond, the other carbon bonds are in the same plane, forming a flat molecule.

Molecular Diversity Arising from Carbon Skeleton Variation Carbon atoms readily bond with each other, producing chains or rings of carbon atoms. These molecular backbones can vary in length, branching, placement of double bonds, and location of atoms of other elements. The simplest organic molecules are hydrocarbons, consisting of only carbon and hydrogen. The nonpolar C—H bonds in hydrocarbon chains account for their hydrophobic properties.

Isomers are compounds with the same molecular formula but different structural arrangements and, thus, different properties. Structural isomers differ in the covalent arrangement of atoms and often in the location of double bonds. Geometric isomers have the same sequence of covalently bonded atoms but differ in spatial arrangement due to the inflexibility of double bonds. A cis isomer has non-hydrogen atoms attached to double-bonded carbons on the same side of the double bond; a trans isomer has these atoms on opposite sides of the double bond. Enantiomers are left- and right-handed versions of each other and can
differ greatly in their biological activity. An asymmetric carbon is one that is covalently bonded to four different kinds of atoms or groups of atoms. Due to the tetrahedral shape of the asymmetric carbon, the four groups can be attached in spatial arrangements that are not superimposable on each other.

**INTERACTIVE QUESTION 4.1**

Identify the structural isomers, geometric isomers, and enantiomers from the following compounds. Which of the geometric isomers is the *cis* isomer?

<table>
<thead>
<tr>
<th>COOH</th>
<th>H H</th>
</tr>
</thead>
<tbody>
<tr>
<td>H C__ C__ H</td>
<td>H C__ C__ OH</td>
</tr>
<tr>
<td>OH</td>
<td>H H</td>
</tr>
<tr>
<td>L-lactic acid</td>
<td>ethanol</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COOH</th>
<th>H C__ C__ OH</th>
</tr>
</thead>
<tbody>
<tr>
<td>H _ C_ CH_</td>
<td>H O_ C_ C_ H</td>
</tr>
<tr>
<td>OH</td>
<td>O</td>
</tr>
<tr>
<td>D-lactic acid</td>
<td>fumaric acid</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>H H</th>
<th>H C__ C__ OH</th>
</tr>
</thead>
<tbody>
<tr>
<td>H C__ O_ C_ H</td>
<td>H C__ C_ OH</td>
</tr>
<tr>
<td>H H</td>
<td>O</td>
</tr>
<tr>
<td>dimethyl ether</td>
<td>maleic acid</td>
</tr>
</tbody>
</table>

**Carbonyl groups** consist of a carbon double-bonded to an oxygen (\(-\text{CO}\)). If the carbonyl group is at the end of the carbon skeleton, the compound is called an *aldehyde*. Otherwise, the compound is called a *ketone*.

A **carboxyl group** consists of a carbon double-bonded to an oxygen and also attached to a hydroxyl group (\(-\text{COOH}\)). Compounds with a carboxyl group are called **carboxylic acids** or organic acids because they tend to dissociate to release H\(^+\), becoming \(-\text{COO}^-\).

An **amino group** consists of a nitrogen atom bonded to two hydrogens (\(-\text{NH}_2\)) and to the carbon skeleton. Compounds with an amino group, called **amines**, can act as bases. The nitrogen, with its pair of unshared electrons, can attract a hydrogen ion, becoming \(-\text{NH}_3^+\).

The **sulphydryl group** consists of a sulfur atom bonded to a hydrogen (\(-\text{SH}\)). Thiol is a compound containing sulphydryl groups.

A **phosphate group** is bonded to the carbon skeleton by an oxygen attached to \(\text{PO}_4^{3-}\), a phosphorus atom that is bonded to three other oxygen atoms (\(-\text{PO}_3^{2-}\)). It is an ionized form of a phosphoric acid group (\(-\text{PO}_3\text{H}_2\)). Compounds containing phosphate groups are called **organic phosphates**. The group is an anion due to the dissociation of hydrogen ions.

**ATP: An Important Source of Energy for Cellular Processes**

**Adenosinetriphosphate (ATP)** is the cell’s primary energy-transferring molecule. The splitting off of the third phosphate group releases energy as ATP is converted to ADP.

**The chemical elements of life: a review**

Carbon, oxygen, hydrogen, nitrogen, and smaller quantities of sulfur and phosphorus, all capable of forming strong covalent bonds, are combined into the complex organic molecules of living matter. The versatility of carbon in forming four covalent bonds, linking readily with itself to produce chains and rings, and binding with other elements and functional groups makes possible the incredible diversity of organic molecules.

**Word Roots**

- **hydro-** = water (hydrocarbon: an organic molecule consisting only of carbon and hydrogen)
- **iso-** = equal (isomer: one of several organic compounds with the same molecular formula but different structures and, therefore, different properties)
- **enanti-** = opposite (enantiomer: molecules that are mirror images of each other)
carb- = coal (carboxyl group: a functional group present in organic acids, consisting of a carbon atom double-bonded to an oxygen atom and a hydroxyl group)

sulf- = sulfur (sulphydryl group: a functional group that consists of a sulfur atom bonded to an atom of hydrogen)

thio- = sulfur (thiol: organic compounds containing sulphydryl groups)

**Structure Your Knowledge**

1. Construct a concept map that illustrates your understanding of the characteristics and significance of the three types of isomers. A suggested map is in the answer section. Comparing and discussing your map with that of a study partner would be most helpful.

2. Fill in the following table on the functional groups.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Molecular Formula</th>
<th>Names and Characteristics of Organic Compounds Containing Functional Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>—OH</td>
<td>Aldehyde or ketone; polar group</td>
</tr>
<tr>
<td>Carboxyl</td>
<td>—COOH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>—NH₂</td>
<td>Thiols; cross-links stabilize protein structure</td>
</tr>
<tr>
<td>Phosphate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Test Your Knowledge**

MULTIPLE CHOICE: Choose the one best answer.

1. The tetravalence of carbon most directly results from
   a. its tetrahedral shape.
   b. its very slight electronegativity.
   c. its four electrons in the valence shell that can form four covalent bonds.
   d. its ability to form single, double, and triple bonds.
   e. its ability to form chains and rings of carbon atoms.

2. Hydrocarbons are not soluble in water because
   a. they are hydrophilic.
   b. the C—H bond is nonpolar.
   c. they do not ionize.
   d. they store energy in the many C—H bonds along the carbon backbone.
   e. they are lighter than water.

3. Which of the following is not true of an asymmetric carbon atom?
   a. It is attached to four different atoms or groups.
   b. It results in right- and left-handed versions of a molecule.
   c. It can be a part of enantiomers.
   d. Its configuration is in the shape of a tetrahedron.
   e. It can be a part of geometric isomers.

4. A reductionist approach to considering the structure and function of organic molecules would be based on
   a. mechanism.
   b. holism.
   c. determinism.
   d. vitalism.
   e. evolution.

5. The functional group that can cause an organic molecule to act as a base is
   a. —COOH.
   c. —SH.
   e. —OPO₃²⁻.
   b. —OH.
   d. —NH₂.

6. The functional group that confers acidic properties to organic molecules is
   a. —COOH.
   c. —SH.
   e. —C = O.
   b. —OH.
   d. —NH₂.

7. Which is not true about structural isomers?
   a. They have different chemical properties.
   b. They have the same molecular formula.
   c. Their atoms and bonds are arranged in different sequences.
   d. They are a result of restricted movement around a carbon double bond.
   e. Their possible numbers increase as carbon skeletons increase in size.

8. The fats stored in your body consist mostly of
   a. amino acids.
   b. alcohols.
   c. carboxylic acids.
   d. hydrocarbons.
   e. organic phosphates.
9. How many asymmetric carbons are there in the sugar ribose?

a. 1   c. 3   e. 5
b. 2   d. 4

MATCHING: Match the formulas (a–f) to the terms at the right. Choices may be used more than once; more than one right choice may be available.

1. structural isomers
2. geometric isomers
3. can have enantiomers
4. carboxylic acid
5. can make cross-link in protein
6. hydrophilic
7. hydrocarbon
8. amino acid
9. organic phosphate
10. aldehyde
11. amine
12. ketone
Chapter 5
The Structure and Function of Macromolecules

Key Concepts

5.1 Most macromolecules are polymers, built from monomers
5.2 Carbohydrates serve as fuel and building material
5.3 Lipids are a diverse group of hydrophobic molecules
5.4 Proteins have many structures, resulting in a wide range of functions
5.5 Nucleic acids store and transmit hereditary information

Chapter Review

Smaller organic molecules are joined together to form carbohydrates, lipids, proteins, and nucleic acids. These molecules, many of which are giant macromolecules, represent another level in the hierarchy of biological organization, and their functions derive from their complex and unique architectures.

5.1 Most macromolecules are polymers, built from monomers

Polymers are chainlike molecules formed from the linking together of many similar or identical small molecules, called monomers.

Synthesis and Breakdown of Polymers Monomers are joined by condensation reactions (or dehydration reactions), in which one monomer provides a hydroxyl group (−OH) and the other contributes a hydrogen (−H) to release a water molecule. With an input of energy and the help of enzymes, a covalent bond between the monomers is formed.

Hydrolysis is the breaking of bonds between monomers through the addition of water molecules. A hydroxyl group is joined to one monomer while a hydrogen is bonded with the other. Enzymes also control hydrolysis.

Framework

The central ideas of this chapter are that molecular function relates to molecular structure and that the diversity of molecular structure is the basis for the diversity of life. Combining a small number of monomers or subunits into unique sequences and three-dimensional structures creates a huge variety of macromolecules. The table below briefly summarizes the major characteristics of the four classes of macromolecules.

<table>
<thead>
<tr>
<th>Class</th>
<th>Monomers</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td>Monosaccharides</td>
<td>Energy, raw materials, energy storage, structural compounds</td>
</tr>
<tr>
<td>Proteins</td>
<td>Amino acids</td>
<td>Enzymes, transport, movement, receptors, defense, structure</td>
</tr>
<tr>
<td>Nucleic acids</td>
<td>Nucleotides</td>
<td>Heredity, code for amino acid sequence</td>
</tr>
<tr>
<td>Lipids</td>
<td>Glycerol and fatty acids → fats; phospholipids; steroids (do not form polymers)</td>
<td>Energy storage, membranes, hormones</td>
</tr>
</tbody>
</table>

25
Diversity of Polymers  Macromolecules are constructed from about 40 to 50 common monomers and a few rarer molecules. The seemingly endless variety of polymers arises from the essentially infinite number of possibilities in the sequencing and arrangement of these basic building blocks.

5.2 Carbohydrates serve as fuel and building material

Carbohydrates include sugars and their polymers.

Sugars  Monosaccharides have the general formula of (CH₂O)ₙ. The number of these units forming a sugar varies from three to seven, with hexoses (C₆H₁₂O₆), trioses, and pentoses found most commonly. Sugar molecules may be enantiomers due to the spatial arrangement of parts around asymmetric carbons.

Glucose is broken down to yield energy in cellular respiration. Monosaccharides serve also as the raw materials for synthesis of other organic molecules and as monomers that are synthesized into disaccharides or polysaccharides.

### INTERACTIVE QUESTION 5.1

Fill in the blanks to review the structure of monosaccharides.

You can recognize a monosaccharide by its multiple (a) _______ groups and its one (b) _______ group, whose location determines whether the sugar is an (c) _______ or a (d) _______. In aqueous solutions, most monosaccharides form (e) _______.

Sucrose, or table sugar, is a disaccharide consisting of a glucose and a fructose molecule. A glycosidic linkage is a covalent bond formed by a dehydration reaction between two monosaccharides.

Polysaccharides  Polysaccharides are storage or structural macromolecules made from a few hundred to a few thousand monosaccharides. Starch, a storage molecule in plants, is a polymer made of glucose molecules joined by 1–4 linkages that give starch a helical shape. Most animals have enzymes to hydrolyze plant starch into glucose. Animals produce glycogen, a highly branched polymer of glucose, as their energy storage form.

Cellulose, the major component of plant cell walls, is the most abundant organic compound on Earth. It differs from starch by the configuration of the ring form of glucose and the resulting geometry of the glycosidic bonds. In a plant cell wall, hydrogen bonds between hydroxyl groups hold parallel cellulose molecules together to form strong microfibrils.

Enzymes that digest the α linkages of starch are unable to hydrolyze the β linkages of cellulose. Only a few organisms (some bacteria, microorganisms, and fungi) have enzymes that can digest cellulose.

Chitin is a structural polysaccharide formed from glucose monomers with a nitrogen-containing group and found in the exoskeleton of arthropods and the cell walls of many fungi.

### INTERACTIVE QUESTION 5.2

Circle the atoms of these two glucose molecules that will be removed by a dehydration reaction. Then draw the resulting maltose molecule with its 1–4 glycosidic linkage (between the number 1 carbon of the first glucose and the number 4 carbon of the second).
5.3 Lipids are a diverse group of hydrophobic molecules

Fats, phospholipids, and steroids are a diverse assemblage of macromolecules that are classed together as lipids based on their hydrophobic behavior. Lipids do not form polymers.

**Fats**  
Fats are composed of fatty acids attached to the three-carbon alcohol, glycerol. A fatty acid consists of a long hydrocarbon chain with a carboxyl group at one end. The nonpolar hydrocarbons make a fat hydrophobic.

A triacylglycerol, or fat, consists of three fatty acid molecules, each linked to glycerol by an ester linkage, a bond that forms between a hydroxyl and a carboxyl group. Triglyceride is another name for fats.

Fatty acids with double bonds in their carbon skeletons are called unsaturated fatty acids. The cis double bonds create a kink in the hydrocarbon chain and prevent fat molecules that contain unsaturated fatty acids from packing closely together and becoming solidified at room temperature. Saturated fatty acids have no double bonds in their carbon skeletons. Most animal fats are saturated and solid at room temperature. The fats of plants and fish are generally unsaturated and are called oils. Diets rich in saturated fats and in "trans fats" made in the process of hydrogenating vegetable oils have been linked to cardiovascular disease.

Fats are excellent energy storage molecules, containing twice the energy reserves of carbohydrates such as starch. Adipose tissue, made of fat storage cells, also cushions organs and insulates the body.

**Phospholipids**  
Phospholipids consist of a glycerol linked to two fatty acids and a negatively charged phosphate group, to which other small molecules may be attached. The phosphate head of this molecule is hydrophilic and water soluble, whereas the two fatty acid chains are hydrophobic.

The unique structure of phospholipids makes them ideal constituents of cell membranes. Arranged in a bilayer, the hydrophilic heads face toward the aqueous solutions inside and outside the cell, and the hydrophobic tails mingle in the center of the membrane.

**Steroids**  
Steroids are a class of lipids distinguished by four connected carbon rings with various functional groups attached. Cholesterol is an important steroid that is a common component of animal cell membranes and a precursor for other steroids, including many hormones.
5.4 Proteins have many structures, resulting in a wide range of functions

Proteins are central to almost every function of life. As catalysts, protein enzymes selectively speed up the chemical reactions of a cell.

**Polypeptides** A polypeptide is a polymer of amino acids. A protein consists of one or more polypeptide chains folded into a specific three-dimensional shape or conformation.

**Amino acids** are composed of an asymmetric carbon (called the α carbon) bonded to a hydrogen, a carboxyl group, an amino group, and a variable side chain called the R group. At the pH in a cell, the amino and carboxyl groups are usually ionized. The R group confers the unique physical and chemical properties of each amino acid. Side chains may be either nonpolar and hydrophobic, or polar or charged (acidic or basic) and thus hydrophilic.

A **peptide bond** links the amino group of one amino acid with the carboxyl group of another. A polypeptide chain has a free amino group at one end and a free carboxyl group at the other. Polypeptides vary in length from a few to a thousand or more amino acids.

In the late 1940s and early ’50s, Sanger determined the primary structure of insulin through the laborious process of hydrolyzing the protein into small peptide chains, determining their amino acid sequences, and then overlapping the sequences of small fragments created with different agents to reconstruct the whole polypeptide. Most of these steps are now automated.

### INTERACTIVE QUESTION 5.5

Fill in this concept map to help you organize your understanding of lipids

- **LIPIDS** include molecules with hydrophobic and insoluble in water
- **a.** composed of 3-C alcohol
- **b.** long hydrocarbon chain with carboxyl group
- **c.** is a 3-C alcohol
- **d.** store energy in C-H bonds
- **e.** oils: kinks keep liquid at room temperature
- **f.** solid at room temperature
- **g.** forms a hydrophobic tail
- **h.** may function as bilayer forms
- **i.** forms a charged, hydrophilic head
- **j.** 4 carbon rings

### INTERACTIVE QUESTION 5.6

**a.** Draw the amino acids alanine (R group—CH₃) and serine (R group—CH₂OH) and then show how a dehydration reaction will form a peptide bond between them.

**b.** Which of these amino acids has a polar R group? ______ a nonpolar R group? ______

**c.** What does this molecule segment represent? Note the N-C-C-N-C-C sequence.

```
<table>
<thead>
<tr>
<th>H</th>
<th>H</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-C-C-N-C-C-N-C-C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>
```

**Protein Conformation and Function** Proteins have unique three-dimensional shapes created by the twisting
or folding of one or more polypeptide chains. Protein conformation is dependent upon the interactions among the amino acids making up the polypeptide chain and usually arises spontaneously as soon as the protein is synthesized in the cell. The unique conformation of a protein, which results from its sequence of amino acids, enables it to recognize and bind to other molecules.

**Primary structure** is the unique, genetically coded sequence of amino acids within a protein.

**Secondary structure** involves the coiling or folding of the polypeptide backbone, stabilized by hydrogen bonds between the electronegative oxygen of one peptide bond and the weakly positive hydrogen attached to the nitrogen of another peptide bond. An α helix is a coil produced by hydrogen bonding between every fourth amino acid. A β pleated sheet is also held by repeated hydrogen bonds along the polypeptide backbone. This secondary structure forms when regions of the polypeptide chain lie parallel to each other.

Interactions between the various side chains (R groups) of the constituent amino acids produce a protein's **tertiary structure**. **Hydrophobic interactions** between nonpolar side groups clumped in the center of the molecule due to their repulsion by water, van der Waals interactions among those nonpolar side chains, hydrogen bonds between polar side chains, and ionic bonds between negatively and positively charged side chains produce the stable and unique shape of the protein. Strong covalent bonds, called **disulfide bridges**, may occur between the sulfhydryl side groups of cysteine monomers that have been brought close together by the folding of the polypeptide.

**Quaternary structure** occurs in proteins that are composed of more than one polypeptide chain. The individual polypeptide subunits are held together in a precise structural arrangement.

Even a slight deviation from the sequence of amino acids can severely affect a protein's function by altering the protein's conformation. A substitution of only one of the 146 amino acids in the primary structure of hemoglobin causes sickle-cell disease.

The interactions that create and maintain secondary and tertiary structure can be disrupted by changes in pH, salt concentration, temperature, or other aspects of the environment, and the protein may **denature**, losing its native conformation and thus its function.

The amino acid sequences of more than 100,000 proteins have been determined. Using the technique of **X-ray crystallography**, coupled with computer modeling and graphics, biochemists have established the three-dimensional shape of thousands of these molecules. Researchers have developed methods for following a protein through its intermediate states on the way to its final form and have discovered **chaperonins**, chaperone proteins that assist other proteins during the folding process, perhaps by providing a sheltered environment.

---

**Interactive Question 5.7**

In the following diagram of a portion of a polypeptide, label the types of interactions that are shown. What level of structure are these interactions producing?

---

**Interactive Question 5.8**

a. Why would a change in pH cause a protein to denature?

b. Why would transfer to a nonpolar organic solvent (such as ether) cause denaturation?

c. A denatured protein may re-form to its functional shape when returned to its normal environment. What does that indicate about a protein's conformation?

---

**Interactive Question 5.9**

Now that you have gained more experience with concept maps, create your own map to help you organize the key concepts you have learned about proteins. Try to include the concepts of structure and function and look for cross-links on your map. One version of a protein concept map is included in the answer section, but remember that the real value is in the thinking process you must go through to create your own map.
5.5 Nucleic acids store and transmit hereditary information

Genes are the units of inheritance that determine the primary structure of proteins. Nucleic acids are polymers that carry and transmit this code.

The Roles of Nucleic Acids DNA, deoxyribonucleic acid, is the genetic material that is inherited from one generation to the next and is reproduced in each cell of an organism. The instructions coded in DNA are transcribed to RNA, ribonucleic acid, which directs the synthesis of proteins, the ultimate enactors of the genetic program. In a eukaryotic cell, DNA resides in the nucleus and messenger RNA carries the instructions for protein synthesis to ribosomes located in the cytoplasm.

---

**INTERACTIVE QUESTION 5.10**

Show the flow of genetic information in a cell.

\[ \text{DNA} \rightarrow \text{RNA} \rightarrow \text{Protein} \]

---

The Structure of Nucleic Acids Nucleic acids, also called polynucleotides, are polymers of nucleotides—monomers that consist of a pentose (five-carbon sugar) covalently bonded to a phosphate group and a nitrogenous base. A monomer without the phosphate group is called a nucleoside. There are two families of nitrogenous bases. Pyrimidines, including cytosine (C), thymine (T), and uracil (U), are characterized by six-membered rings of carbon and nitrogen atoms. Purines, adenine (A) and guanine (G), add a five-membered ring to the pyrimidine ring. Thymine is only in DNA; uracil is only in RNA. In DNA, the pentose is deoxyribose; in RNA it is ribose.

Nucleotides are linked together into a polynucleotide by phosphodiester linkages, which join the phosphate of one nucleotide with the sugar of the next. The polymer has two distinct ends: a 5' end with a phosphate attached to a 5' carbon and a 3' end with a hydroxyl group on a 3' carbon. The nitrogenous bases extend from this backbone of repeating sugar-phosphate units. The unique sequence of bases in a gene codes for the specific amino acid sequence of a protein.

---

**INTERACTIVE QUESTION 5.11**

\[ \begin{align*}
\text{O} & \text{P} & \text{O} & \text{CH}_2 & \text{O} \\
& & & & \\
& & & \text{H} & \text{H} \\
& & & \text{H} & \text{H} \\
\end{align*} \]

a. Label the three parts of this nucleotide. Indicate with an arrow where the phosphate group of the next nucleotide would attach to build a polynucleotide. Number the carbons of the pentose sugar.

b. Is this a purine or a pyrimidine?

c. Is this a DNA or RNA nucleotide?

---

The DNA Double Helix DNA molecules consist of two chains of polynucleotides spiraling around an imaginary axis in a double helix. The two chains run in opposite 5' to 3' directions, an arrangement called antiparallel. In 1953 Watson and Crick first proposed this double-helix arrangement, which consists of two sugar-phosphate backbones on the outside of the helix with their nitrogenous bases pairing and hydrogen-bonding together in the inside. Adenine pairs only with thymine; guanine always pairs with cytosine. Thus, the sequences of nitrogenous bases on the two strands of DNA are complementary. Because of this specific base-pairing property, DNA can replicate itself and precisely copy the genes of inheritance.

**DNA and Proteins as Tape Measures of Evolution**

Genes form the hereditary link between generations. Closely related members of the same species share many common DNA sequences and proteins. More closely related species have a larger proportion of their DNA and proteins in common. This "molecular genealogy" provides evidence of evolutionary relationships.

---

**INTERACTIVE QUESTION 5.12**

Take the time to create a concept map that summarizes what you have just reviewed about nucleic acids. Compare your map with that of a study partner or explain it to a friend. One version of a map on nucleic acids is included in the answer section. Refer to Figures 5.26 and 5.27 in your textbook to help you visualize polynucleotides and the double helix of DNA.
The Theme of Emergent Properties in the Chemistry of Life: A Review

At each stage in the hierarchy of levels from atoms through macromolecules, we have seen that novel properties arise with increasing structural organization.

Word Roots

con- = together (condensation reaction: a reaction in which two molecules become covalently bonded to each other through the loss of a small molecule, usually water)

di- = two (disaccharide: two monosaccharides joined together)
glyco- = sweet (glycogen: a polysaccharide sugar used to store energy in animals)
hydro- = water; -lyse = break (hydrolysis: breaking chemical bonds by adding water)
macro- = large (macromolecule: a large molecule)
meros- = part (polymer: a chain made from smaller organic molecules)
mono- = single; -sacchar = sugar (monosaccharide: simplest type of sugar)
poly- = many (polysaccharide: many monosaccharides joined together)
tri- = three (triacylglycerol: three fatty acids linked to one glycerol molecule)

Structure Your Knowledge

1. Describe the four structural levels in the conformation of a protein.
2. Identify the type of monomer or group shown by the formulas shown on the right. Then match the chemical formulae with their description. Answers may be used more than once.
   
   1. molecules that would combine to form a fat
   2. molecule that would be attached to other monomers by a peptide bond
   3. molecules or groups that would combine to form a nucleotide
   4. molecules that are carbohydrates
   5. molecule that is a purine
   6. monomer of a protein
   7. groups that would be joined by phosphodiester bonds
   8. most nonpolar (hydrophobic) molecule

a. 

b. 

c. 

d. 

e. 

f. 

g. 
Test Your Knowledge

MATCHING: Match the molecule with its type of molecule.

_____ 1. glycogen   A. carbohydrate  
_____ 2. cholesterol  B. lipid  
_____ 3. RNA   C. protein  
_____ 4. collagen   D. nucleic acid  
_____ 5. hemoglobin  
_____ 6. a gene  
_____ 7. triacylglycerol  
_____ 8. enzyme  
_____ 9. cellulose  
_____ 10. chitin

MULTIPLE CHOICE: Choose the one best answer.

1. Polymerization is a process that
   a. creates bonds between amino acids in the formation of a peptide chain.
   b. involves the removal of a water molecule.
   c. links the sugar of one nucleotide with the phosphate of the next.
   d. requires a condensation or dehydration reaction.
   e. may involve all of the above.

2. Which of the following is not true of a pentose?
   a. It can be found in nucleic acids.
   b. It can occur in a ring structure.
   c. It has the formula \( C_5H_{12}O_5 \).
   d. It has one carbonyl and four hydroxyl groups.
   e. It may be an aldose or a ketose.

3. Disaccharides can differ from each other in all of the following ways except
   a. in the number of their monosaccharides.
   b. as enantiomers.
   c. in the monomers involved.
   d. in the location of their glycosidic linkage.
   e. in their structural formulas.

4. Which of the following is not true of cellulose?
   a. It is the most abundant organic compound on Earth.
   b. It differs from starch because of the configuration of glucose and the geometry of the glycosidic linkage.
   c. It may be hydrogen-bonded to neighboring cellulose molecules to form microfibrils.
   d. Few organisms have enzymes that hydrolyze its glycosidic linkages.
   e. Its monomers are glucose with nitrogen-containing appendages.

5. Plants store most of their energy as
   a. unsaturated fats.
   b. glycogen.
   c. starch.
   d. sucrose.
   e. cellulose.

6. What happens when a protein denatures?
   a. It loses its primary structure.
   b. It loses its secondary and tertiary structures.
   c. It becomes irreversibly insoluble and precipitates.
   d. It hydrolyzes into component amino acids.
   e. Its hydrogen bonds, ionic bonds, hydrophobic interactions, disulfide bridges, and peptide bonds are disrupted.

7. The \( \alpha \) helix of proteins is
   a. part of the tertiary structure and is stabilized by disulfide bridges.
   b. a double helix.
   c. stabilized by hydrogen bonds and commonly found in fibrous proteins.
   d. found in some regions of globular proteins and stabilized by hydrophobic interactions.
   e. a complementary sequence to messenger RNA.

8. A fatty acid that has the formula \( C_{16}H_{32}O_2 \) is
   a. saturated.
   b. unsaturated.
   c. branched.
   d. hydrophilic.
   e. part of a steroid molecule.

9. Three molecules of the fatty acid in question 8 are joined to a molecule of glycerol (\( C_3H_8O_3 \)). The resulting molecule has the formula
   a. \( C_{48}H_{96}O_{10} \).
   b. \( C_{48}H_{96}O_6 \).
   c. \( C_{51}H_{107}O_{10} \).
   d. \( C_{51}H_{98}O_{10} \).
   e. \( C_{51}H_{104}O_{10} \).
10. β pleated sheets are characterized by
   a. disulfide bridges between cysteine amino acids.
   b. parallel regions of the polypeptide chain held
      together by hydrophobic interactions.
   c. folds stabilized by hydrogen bonds between
      segments of the polypeptide backbone.
   d. membrane sheets composed of phospholipids.
   e. hydrogen bonds between adjacent cellulose
      molecules.

11. Cows can derive nutrients from cellulose because
   a. they can produce the enzymes that break the
      β linkages between glucose molecules.
   b. they chew and rechew their cud so that cellulose
      fibers are finally broken down.
   c. one of their stomachs contains bacteria that can
      hydrolyze the bonds of cellulose.
   d. their intestinal tract contains termites, which
      produce enzymes to hydrolyze cellulose.
   e. they can convert cellulose to starch and then hydrolize starch to glucose.

12. Which of these molecules would provide the most
    energy (kcal/g) when eaten?
    a. glucose
    b. starch
    c. glycogen
    d. fat
    e. protein

13. What determines the sequence of the amino acids in
    a particular protein?
    a. its primary structure
    b. the sequence of nucleotides in RNA, which was
       determined by the sequence of nucleotides in
       the gene for that protein
    c. the sequence of nucleotides in DNA, which was
       determined by the sequence of nucleotides in
       RNA
    d. the sequence of RNA nucleotides making up the
       ribosome
    e. the three-dimensional shape of the protein

14. Sucrose is made from joining a glucose and a fructose molecule in a dehydration reaction. What is
    the molecular formula for this disaccharide?
    a. C₁₂H₂₂O₁₁
    b. C₁₆H₂₄O₁₀
    c. C₁₅H₄₄O₇
    d. C₁₂H₂₄O₁₂
    e. C₁₀H₁₆O₆

15. How are the nucleotide monomers connected to
    form a polynucleotide?
    a. hydrogen bonds between complementary ni-
       trogenous base pairs
    b. ionic attractions between phosphate groups
    c. disulfide bridges between cysteine amino acids
    d. covalent bonds between the sugar of one nu-
       cleotide and the phosphate of the next
    e. ester linkages between the carboxyl group of
       one nucleotide and the hydroxyl group on the
       ribose of the next

16. Which of the following would be the most
    hydrophobic molecule?
    a. cholesterol
    b. nucleotide
    c. amino acid
    d. chitin
    e. glucose

17. What is the best description of this molecule?

18. Which number(s) in the molecule in question 17
    refer(s) to a peptide bond?
    a. 1       c. 3       e. both 2 and 4
    b. 2       d. 4

19. If the nucleotide sequence of one strand of a DNA
    helix is GCCTAA, what would be the sequence on
    the complementary strand?
    a. GCCTAA
    b. CGGAUU
    c. CCGATT
    d. ATTCGG
    e. TAAGCC
20. Monkeys and humans share many of the same DNA sequences and have similar proteins, indicating that
   a. the two groups belong to the same species.
   b. the two groups share a relatively recent common ancestor.
   c. humans evolved from monkeys.
   d. monkeys evolved from humans.
   e. the two groups first appeared on Earth at about the same time.

21. Which of the following would be the major component of the cell membrane of a fungus?
   a. cellulose
   b. chitin
   c. cholesterol
   d. phospholipids
   e. unsaturated fatty acids

22. Hydrophobic as well as hydrophilic interactions would be important for which of the following types of molecules?
   a. proteins
   b. unsaturated fats
   c. glycogen and cellulose
   d. polynucleotides
   e. all of the above

23. What are trans fats?
   a. hydrogenated vegetable oils that have been identified with health risks
   b. fats made from cholesterol that are components of plaques in the walls of blood vessels
   c. fats that are derived from animal sources and are associated with cardiovascular disease
   d. fats that contain trans double bonds and may contribute to atherosclerosis
   e. polyunsaturated fats produced by removing H from fatty acids and forming cis double bonds

24. Which of the following is not a function performed by proteins?
   a. transport of oxygen in blood
   b. catalyst for metabolic reactions
   c. protection against disease
   d. signals and receptors
   e. primary component of cell membranes

FILL IN THE BLANKS

1. The man who determined the amino acid sequence of insulin was ________.
2. Cytosine always pairs with ________.
3. Adenine and guanine are ________.
4. A pentose joined to a nitrogenous base and a phosphate group is called a ________.
5. The conformation of a protein is determined by its ________.
6. Proteins with more than one polypeptide chain have ________ structure.
7. The carbohydrate energy storage molecule of animals is ________.
8. Membranes are composed of a bilayer of ________.
9. The insoluble fiber listed on food packages consists primarily of ________.
10. Proteins that assist the proper folding of newly synthesized proteins are called ________.