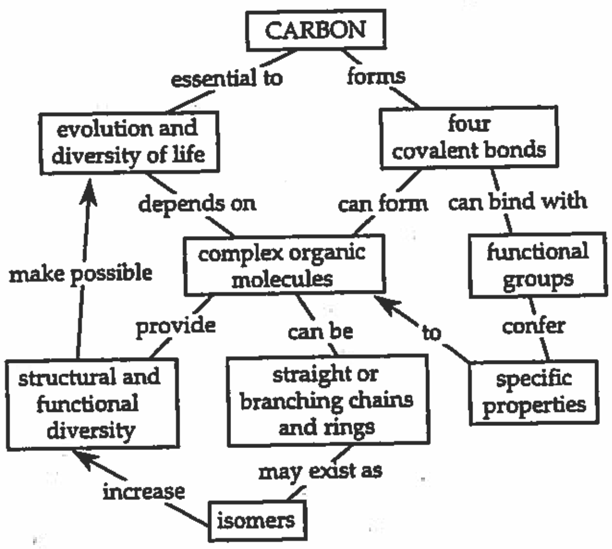
CHAPTER 4

CARBON AND THE MOLECULAR DIVERSITY OF LIFE

FRAMEWORK



CHAPTER REVIEW

The Importance of Carbon

Organic chemistry is the study of carbon compounds (52–53)

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 evolution of life.

Carbon atoms are the most versatile building blocks of molecules (53–55)

Carbon has six electrons. To complete its valence shell, carbon forms four covalent bonds with other atoms. This tetravalence 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.

Variation in carbon skeletons contributes to the diversity of organic molecules (55–57)

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 behavior.

■ **INTERACTIVE QUESTION 4.1**

From what you know about the valences of C, H, and O, sketch the structural formulas for the following molecules: C_3H_8O (propanol) and C_2H_4 (ethene). (Alcohols such as propanol always have an —OH group.)

Chapter 4 Review Sheet

carb- = coal (*carboxyl group:* a functional group present in organic acids, consisting of a carbon atom double-bonded to an oxygen atom)
sulf- = sulfur (*sulfhydryl group:* a functional group that consists of a sulfur atom bonded to an atom of hydrogen)
thio- = sulfur (*thiol:* organic compounds containing sulfhydryl 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.

Functional Group	Molecular Formula	Names and Characteristics of Organic Compounds Containing Functional Group
	—OH	
		Aldehyde or ketone; polar group
Carboxyl		
	$—NH_2$	
		Thiols; cross-links stabilize protein structure
Phosphate		

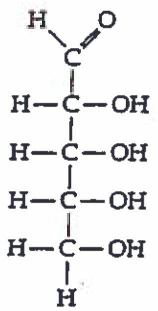
TEST YOUR KNOWLEDGE

MULTIPLE CHOICE: *Choose the one best answer.*

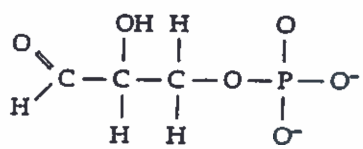
1. The tetravalence of carbon most directly results from
   a. its tetrahedral shape.
   b. its very slight electronegativity.
   c. its four electrons in the valence shell that can form four covalent bonds.
   d. its ability to form single, double, and triple bonds.
   e. its ability to form chains and rings of carbon atoms.
2. Hydrocarbons are not soluble in water because
   a. they are hydrophilic.
   b. the C—H bond is very 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 create enantiomers.
   d. Its configuration is in the shape of a tetrahedron.
   e. It can create 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. —OPO322.
   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. $—NH_2$.

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.

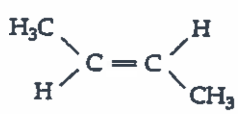
8. How many asymmetric carbons are there in the sugar ribose?
   a. 1
   b. 2
   c. 3
   d. 4
   e. 5



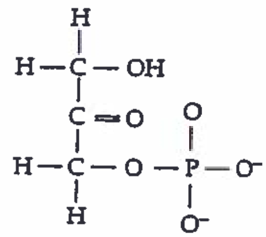
MATCHING: *Match the formulas (a–f) to the terms at the right. Choices may be used more than once; more than one right choice may be available.*



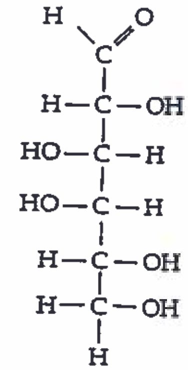
a.



b.



c.



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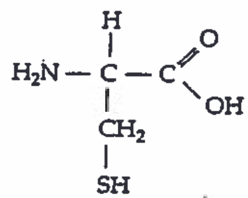
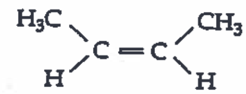


e.



f.

________ 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

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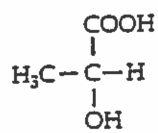
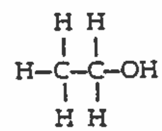
■ INTERACTIVE QUESTION 4.2

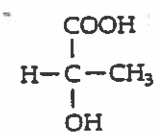
Identify the structural isomers, geometric isomers, and enantiomers from the following compounds.



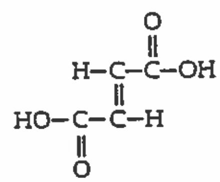
l-lactic acid



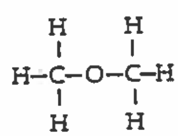
ethanol



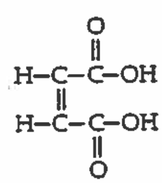
d-lactic acid



fumaric acid



dimethyl ether



maleic acid

CHAPTER 5

THE STRUCTURE AND FUNCTION OF MACROMOLECULES

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.

CHAPTER REVIEW

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

Polymer Principles

Most macromolecules are polymers (62–63)

Polymers are chainlike molecules formed from the linking together of many similar or identical small molecules, called **monomers**. Monomers are joined by **condensation reactions (or dehydration reactions)**, in which one monomer provides a hydroxyl (–OH) and the other contributes a hydrogen (–H) to release a water molecule, and a covalent bond between the monomers is formed. Energy is required to join monomers, and the process is facilitated by enzymes.

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

An immense variety of polymers can be built from a small set of monomers (63–64)

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 subunits.

Carbohydrates—Fuel and Building Material

Carbohydrates include sugars and their polymers.

Sugars, the smallest carbohydrates, serve as fuel and carbon sources (64–65)

Monosaccharides have the general formula of $(CH_2O)_n$. The number of these units forming a sugar varies from three to seven, with hexoses ($C_6H_{12}O_6$), trioses, and pentoses found most commonly. Sugar

Class	Monomers or subunits	Functions
Carbohydrates	Monosaccharides	Energy, raw materials, energy storage, structural compounds
Lipids	Glycerol and fatty acids → fats	Energy storage, membranes, steroids, hormones
Proteins	Amino acids	Enzymes, transport, movement, receptors, defense, structure
Nucleic acids	Nucleotides	Heredity, code for amino acid sequence

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, the polymers of sugars, have storage and structural roles (66–68)

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.

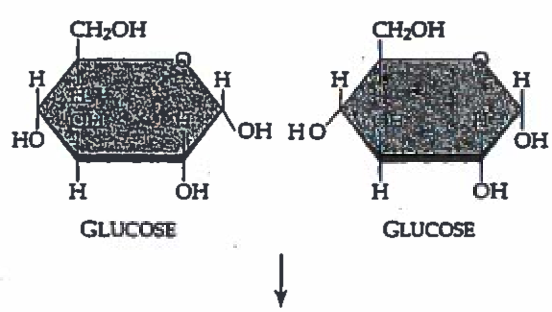
Cellulose, the major component of plant cell walls, is the most abundant organic compound on Earth. It differs from starch by the configuration of the ring form of glucose and the resulting geometry of the glycosidic bonds. In a plant cell wall, hydrogen bonds between hydroxyl groups hold parallel cellulose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

Enzymes that digest 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 nitrogen-containing groups and found in the exoskeleton of arthropods and the cell walls of many fungi.

■ INTERACTIVE QUESTION 5.2

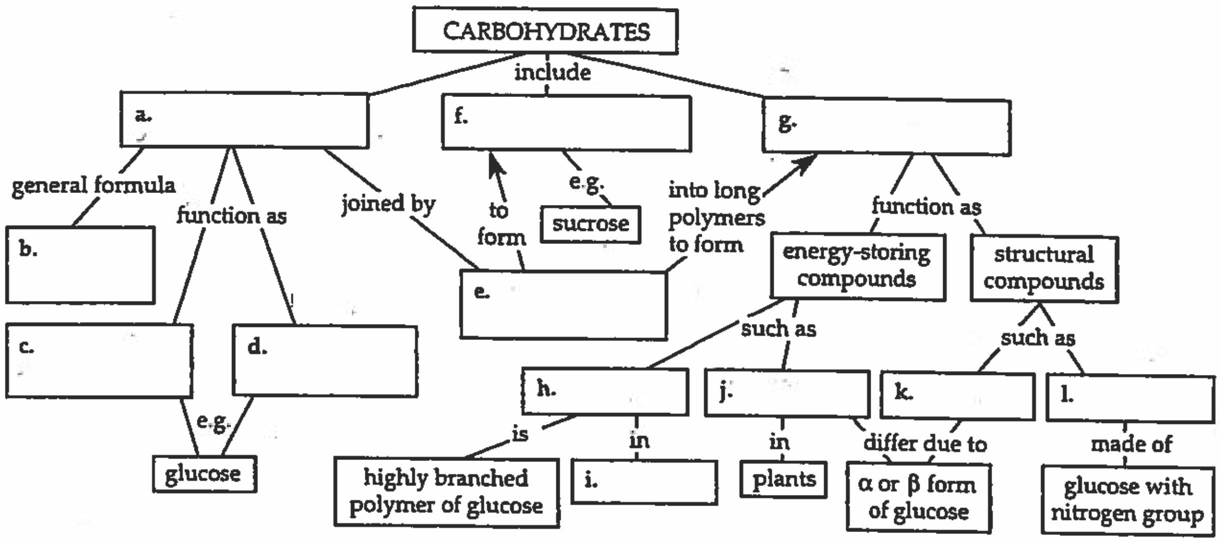
Circle the atoms of these two glucose molecules that will be removed by a dehydration reaction. Then draw the resulting maltose molecule with its 1–4 glycosidic linkage (between the number 1 carbon of the first glucose and the number 4 carbon of the second).



MALTOSE

■ INTERACTIVE QUESTION 5.3

Fill in the following concept map that summarizes this section on carbohydrates.



Lipids—Diverse 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 store large amounts of energy (69–70)

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

A **triacylglycerol,** or fat, consists of three fatty acids, 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 double bonds create a kink in the shape of the molecule and prevent the fat molecules 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 fishes are generally unsaturated and are called oils. Diets rich in saturated fats 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 are major components of cell membranes (70–71)

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.

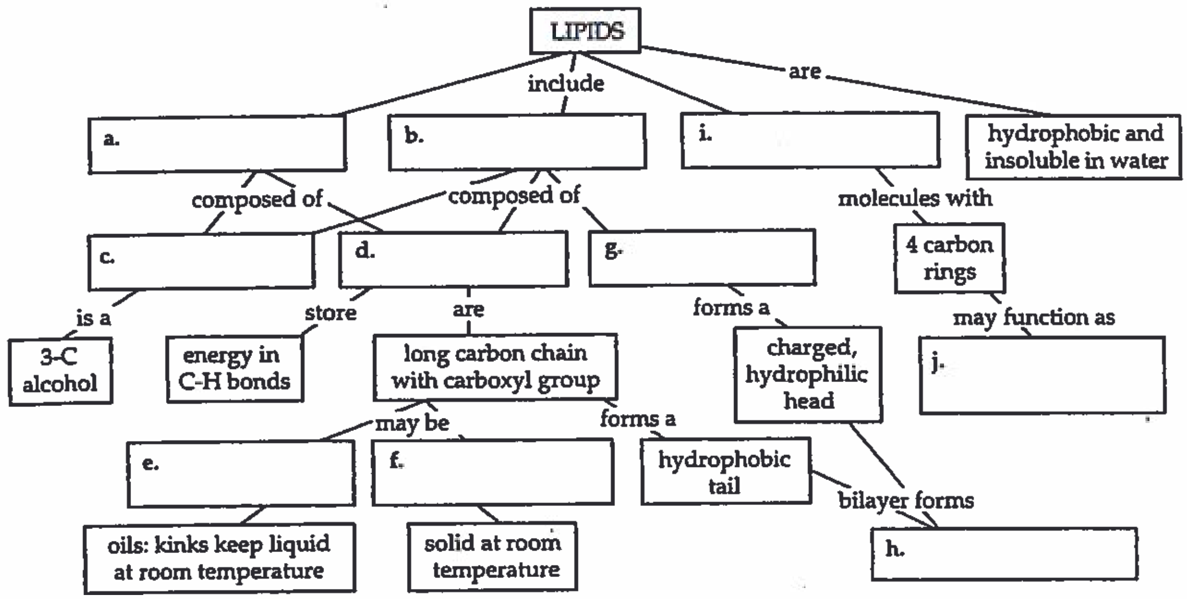
The unique structure of phospholipids makes them ideal constituents of cell membranes. Arranged in a bilayer, the hydrophilic heads face toward the aqueous solutions inside and outside the cell, and the hydrophobic tails mingle in the center of the membrane, forming a boundary between the cell and its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

■ INTERACTIVE QUESTION 5.4

Sketch a section of a phospholipid bilayer of a membrane, and label the hydrophilic head and hydrophobic tail of one of the phospholipids.

■ **INTERACTIVE QUESTION 5.5**

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



Steroids include cholesterol and certain hormones (71)

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.

Proteins—Many Structures, Many Functions

Proteins are central to almost every function of life. A **polypeptide** is a polymer of amino acids. Proteins consist of one or more polypeptide chains folded into a unique three-dimensional shape or conformation.

A polypeptide is a polymer of amino acids connected in a specific sequence (71–74)

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. 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.

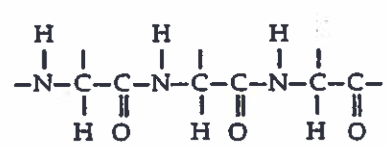
A **peptide bond** links the amino group of one amino acid with the carboxyl group of another. A polypeptide chain has a free carboxyl group at one end and a free amino group at the other. Polypeptides vary in length from a few to a thousand or more amino acids.

■ **INTERACTIVE QUESTION 5.6**

a. Draw the amino acids alanine (R group—CH_3) and serine (R group—CH_2OH) 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.



TEST YOUR KNOWLEDGE

MATCHING: *Match the molecule with its class of macromolecules.*

______	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. involves 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 formulae.

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. glucose.
   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 structure.
   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. $C_{48}H_{96}O_6$.
   b. $C_{48}H_{98}O_9$.
   c. $C_{51}H_{102}O_8$.
   d. $C_{51}H_{98}O_6$.
   e. $C_{51}H_{104}O_9$.

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 b 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 hydrolyze 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

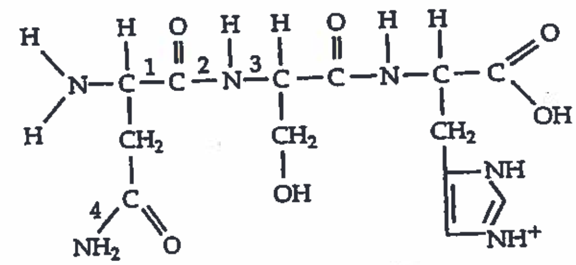
13. What *determines* the sequence of the amino acids in a particular protein?
    a. its primary structure
    b. the sequence of nucleotides in RNA, which was determined by the sequence of nucleotides in the gene for that protein
    c. the sequence of nucleotides in DNA, which was determined by the 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. $C_6H_{12}O_6$
    b. $C_{12}H_{24}O_{12}$
    c. $C_{12}H_{24}O_{13}$
    d. $C_{12}H_{22}O_{11}$
    e. $C_{10}H_{20}O_{10}$

15. How are the nucleotide monomers connected to form a polynucleotide?
    a. hydrogen bonds between complementary nitrogenous base pairs
    b. ionic attractions between phosphate groups
    c. disulfide bridges between cysteine amino acids
    d. covalent bonds between the sugar of one nucleotide 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 a hydrophobic molecule?
    a. cholesterol
    b. nucleotide
    c. amino acid
    d. chitin
    e. glucose

17. What is the best description of this molecule?



    a. chitin
    b. amino acid
    c. polypeptide (tripeptide)
    d. nucleotide
    e. protein

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

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 5.29 and 5.30 in your textbook to help you visualize polynucleotides and the double helix of DNA.

We can use DNA and proteins as tape measures of evolution (84)

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.

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)

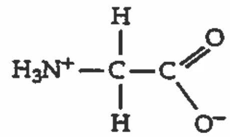
mono- = single; **-sacchar** = sugar (*monosaccharide:* simplest type of sugar)

poly- = many (*polysaccharide:* many monosaccharides joined together)

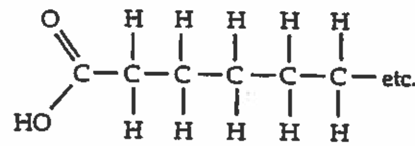
tri- = three (*triacylglycerol:* three fatty acids linked to one glycerol molecule)

STRUCTURE YOUR KNOWLEDGE

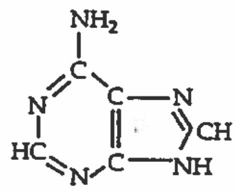
1. Describe the four structural levels in the conformation of a protein.
2. Identify the type of monomer or group shown by these formulae. Then match the chemical formulae with their description. Answers may be used more than once.



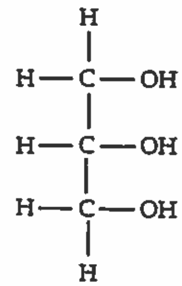
a. ____________



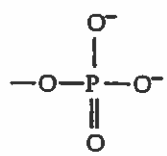
b. ____________



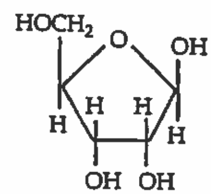
c. ____________



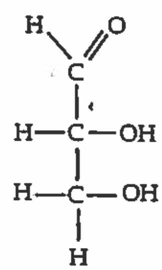
d. ____________



e. ____________



f. ____________



g. ____________

_______ 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