Carbon and the Molecular Diversity of Life

Chapter Focus

Carbon, with its ability to bond to four other atoms, is the basis for the structural and functional diversity of organic molecules. A small number of monomers or subunits are joined to form a huge variety of large molecules, which can be grouped into four classes.

Class	Monomers or Components	Functions
Carbohydrates	Monosaccharides	Energy source, raw materials, energy storage, structural compounds
Lipids	Glycerol and fatty acids → fats; phospholipids; steroids	Energy storage (fats), membrane components (phospholipids), hormones (steroids)
Proteins	Amino acids	Enzymes, transport, movement, receptors, defense, structure, storage, hormones
Nucleic acids	Nucleotides	Heredity, various functions in gene expression

Chapter Review

Organic compounds are those containing carbon and usually hydrogen. These compounds include lipids and the huge **macromolecules** of carbohydrates, proteins, and nucleic acids.

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

The Formation of Bonds with Carbon How many covalent bonds must carbon (with an atomic number of 6) form to complete its valence shell? Carbon's **valence** of four is at the center of its ability to form large and complex molecules. When a carbon atom forms four single covalent bonds, the resulting molecule or portion of a molecule is in a tetrahedral shape. When two carbons are joined by a double bond, the other atoms bonded to the carbons are in the same plane, forming a flat molecule.

Molecular Diversity Arising from Variation in Carbon Skeletons Carbon skeletons can vary in length, branching, placement of double bonds, and the presence of rings. **Hydrocarbons** consist of only carbon and hydrogen. Hydrocarbon chains are hydrophobic due to their nonpolar C—H bonds, and they release energy when broken down.

The Chemical Groups Most Important to Life The properties of organic molecules are largely determined by characteristic chemical groups attached to a carbon skeleton. The first six **functional groups** described in the following text may participate in chemical reactions. Except for the sulfhydryl group, these hydrophilic groups also increase the solubility of organic compounds in water. A seventh group, the nonpolar methyl group, alters molecular shape and may serve as a signal on organic molecules.

The **hydroxyl group** consists of an oxygen and hydrogen (—OH). Organic molecules with hydroxyl groups are called alcohols, and their names usually end in *-ol*.

A **carbonyl group** consists of a carbon double-bonded to an oxygen (>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 an —OH group (—COOH). Compounds with a carboxyl group are called carboxylic acids or organic acids because they tend to release H^+, becoming a carboxylate ion ($—COO^-$).

An **amino group** consists of a nitrogen atom bonded to two hydrogen atoms ($—NH_2$). Compounds with an amino group, called amines, can act as bases, picking up a hydrogen ion and becoming $—NH_3^+$. Both the amino group and carboxyl group are ionized at normal cellular pH.

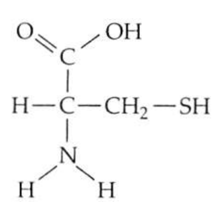
The **sulfhydryl group** consists of a sulfur atom bonded to a hydrogen (—SH). Thiols are compounds containing sulfhydryl groups.

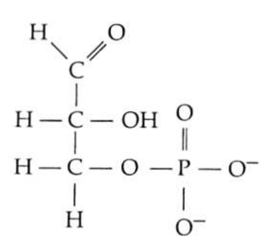
A **phosphate group** is bonded to a carbon skeleton by an oxygen attached to a phosphorus atom that is bonded to three other oxygen atoms ($—OPO_3^{2-}$). This anion contributes a negative charge to organic phosphates.

A **methyl group** is a carbon bonded to three hydrogens ($—CH_3$). Methylated compounds may have their function modified due to the addition of the methyl group.

FOCUS QUESTION 3.1

Practice recognizing the functional groups by circling and naming the groups you see in the following molecules.





ATP: An Important Source of Energy for Cellular Processes **Adenosine triphosphate**, or **ATP**, consists of the organic molecule adenosine to which three phosphate groups are attached. When ATP reacts with water, the third phosphate is split off and energy is released.

3.2 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 a **dehydration reaction**, in which one monomer provides a hydroxyl group (—OH) and the other contributes a hydrogen (—H) to release a water molecule. In **hydrolysis**, the bond between monomers is broken by the addition of water. The hydroxyl group of a water molecule is joined to one monomer while the hydrogen is bonded with the other. **Enzymes** catalyze both dehydration reactions and hydrolysis.

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

FOCUS QUESTION 3.2

Monomers are linked into polymers by __________, which involve the __________ of a water molecule.

Polymers are broken down to monomers by __________, which involves the __________ of a water molecule.

3.3 Carbohydrates serve as fuel and building material

Carbohydrates include sugars and their polymers.

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

FOCUS QUESTION 3.3

Fill in the blanks to review 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 five- and six-carbon sugars form (e) __________. The names for most sugars end in (f) __________.

Glucose is broken down to yield energy in cellular respiration. Monosaccharides also serve as the raw materials for the synthesis of other organic molecules. Two monosaccharides are joined by a **glycosidic linkage** to form a **disaccharide**.

Polysaccharides **Polysaccharides** are storage or structural macromolecules. **Starch**, a storage molecule in plants, is a polymer made of glucose molecules joined by 1–4 linkages that give starch a helical shape. Animals use **glycogen**, a highly branched polymer of glucose, as their energy storage molecule.

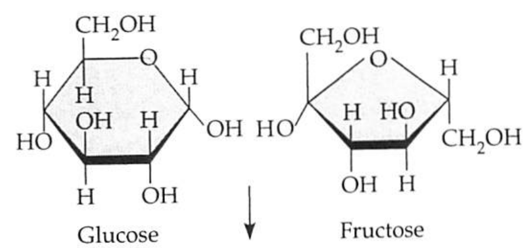
Cellulose, the major component of plant cell walls, is the most abundant organic compound on Earth. It differs from starch and glycogen by the configuration of the ring form of glucose (beta instead of alpha) and the resulting geometry of the glycosidic bonds. In a plant cell wall, hydrogen bonds between 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 prokaryotes, protists, and fungi) have enzymes that can digest cellulose.

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

FOCUS QUESTION 3.4

Number the carbons in the following glucose and fructose molecules. (Each unlabeled corner of the ring represents a carbon. In glucose, carbon 1 is to the right of the O in the ring; in fructose, carbon 1 extends up from the ring on the left side.) Circle the atoms that will be removed by a dehydration reaction. Then draw the resulting sucrose molecule with its 1–2 glycosidic linkage.



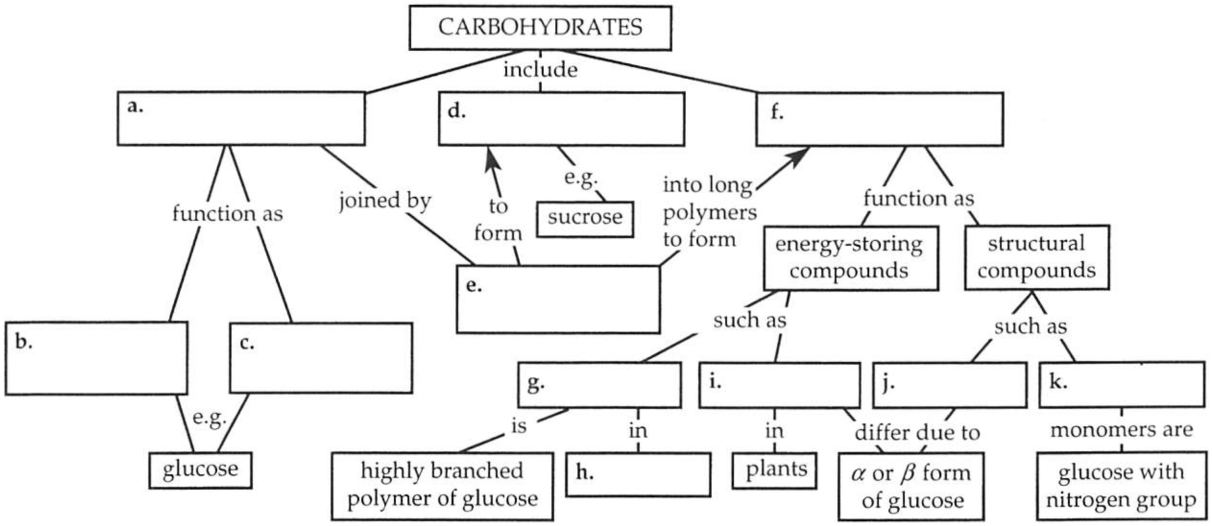
Glucose

Fructose

Sucrose

FOCUS QUESTION 3.5

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



3.4 Lipids are a diverse group of hydrophobic molecules

Fats, phospholipids, and steroids are part of a diverse assemblage of biological molecules that are grouped 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 chain are called **unsaturated fatty acids**. The double bond creates a kink in the hydrocarbon chain and prevents fat molecules with unsaturated fatty acids from packing closely together and becoming solidified at room temperature. The fats of plants and fish are generally unsaturated and are called oils. **Saturated fatty acids** have no double bonds in their carbon chains. Most animal fats are saturated and solid at room temperature. Diets rich in saturated fats have been linked to cardiovascular disease.

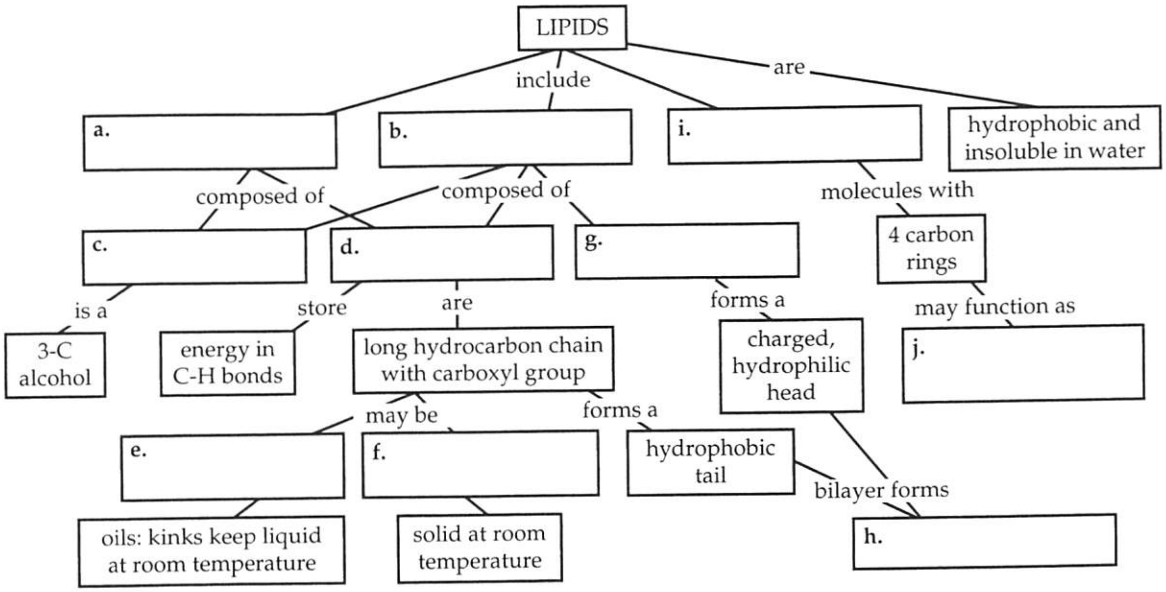
Fats are excellent energy storage molecules, containing twice the energy of carbohydrates such as starch.

Phospholipids **Phospholipids** consist of a glycerol linked to two fatty acids and a negatively charged phosphate group, to which other small molecules are 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. The hydrophilic heads face the aqueous environment on either side of a membrane; the hydrophobic tails associate in the center of the phospholipid bilayer, shielded from water.

Steroids **Steroids** are a class of lipids distinguished by four connected carbon rings with various chemical groups attached. **Cholesterol** is a common component of animal cell membranes and a precursor for other steroids, including many hormones.

FOCUS QUESTION 3.6

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



3.5 Proteins include a diversity of structures, resulting in a wide range of functions

Proteins are central to almost every function of life. Most enzymes, which function as **catalysts** that selectively speed up the chemical reactions of a cell, are proteins. A **protein** is a functional molecule that consists of one or more polypeptides, each folded into a specific three-dimensional shape. A **polypeptide** is a polymer of amino acids.

Amino Acids **Amino acids** are composed of a central carbon, called the *alpha (α) carbon*, bonded to four partners: a hydrogen atom, 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.

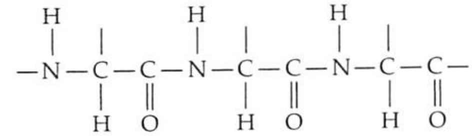
Polypeptides A **peptide bond** links the carboxyl group of one amino acid with the amino group of another. A string of amino acids making up a polypeptide has an amino end (N-terminus) and a carboxyl end (C-terminus).

FOCUS QUESTION 3.7

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 the following molecular segment represent? (Note the N—C—C—N—C—C sequence.)



Protein Structure and Function A protein has a unique three-dimensional shape, or structure, created by the twisting or folding of one or more polypeptide chains. Protein structure usually arises spontaneously. Depending on the sequence of amino acids, various types of bonds form between parts of the chain as the protein is synthesized in the cell. The unique structure of a protein enables it to recognize and bind to other molecules. *Globular proteins* are roughly spherical; *fibrous proteins* are long fibers.

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

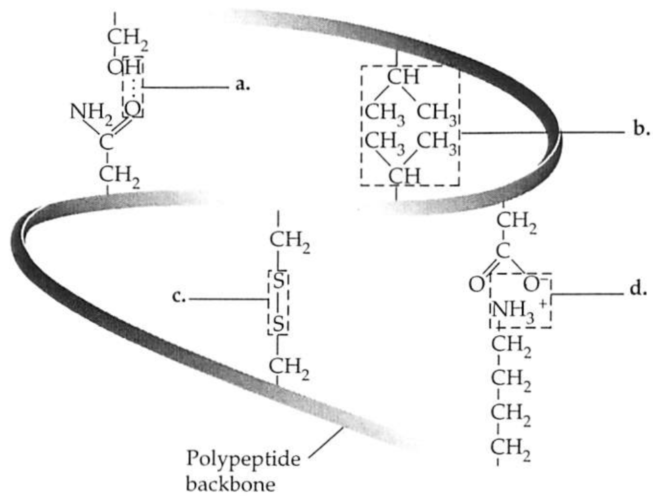
Secondary structure involves regions of coiling or folding of the polypeptide backbone, stabilized by hydrogen bonds between the oxygen (with a partial negative charge) of one peptide bond and the partially positive hydrogen attached to the nitrogen of another peptide bond. An α **helix** is a coil produced by hydrogen bonding between every fourth amino acid. A β **pleated sheet** is held by repeated hydrogen bonds along regions of the polypeptide backbone lying parallel to each other.

Tertiary structure, the three-dimensional shape of a protein, results from interactions between the various side chains (R groups) of the constituent amino acids. The following chemical interactions help produce the stable and unique shape of a protein: **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. 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. The individual polypeptide subunits are held together in a precise structural arrangement to form a functional protein.

FOCUS QUESTION 3.8

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



In the inherited blood disorder **sickle-cell disease**, a change in one amino acid affects the structure of a hemoglobin molecule, causing red blood cells to deform into a sickle shape that clogs tiny blood vessels.

The bonds and interactions that maintain the three-dimensional shape of a protein may be disrupted by changes in pH, salt concentration, or temperature, causing a protein to unravel. **Denaturation** also occurs if a protein is transferred to an organic solvent; in that case, its hydrophobic regions are on the outside interacting with the nonpolar solvent.

Using the technique of **X-ray crystallography** biochemists have identified the structure of thousands of proteins. These structures can then be related to the specific functions of different regions of a protein.

FOCUS QUESTION 3.9

Now that you have gained experience with concept maps, create your own map to review what you have learned about proteins. Try to include the concepts of structure and function, and look for cross-links on your map. You may want to include the functions of proteins. *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.*

3.6 Nucleic acids store, transmit, and help express hereditary information

Genes are the units of inheritance that determine the primary structure of proteins. **Nucleic acids** are polymers made of nucleotide monomers.

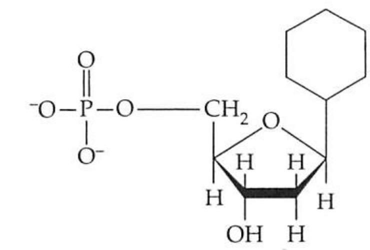
The Roles of Nucleic Acids **DNA, deoxyribonucleic acid,** is the genetic material that is inherited from one generation to the next and is replicated whenever a cell divides so that all cells of an organism contain identical DNA. The instructions coded in DNA are transcribed to **RNA, ribonucleic acid,** which directs the synthesis of proteins, the ultimate enactors of the genetic program. In a eukaryotic cell, DNA resides in the nucleus. *Messenger RNA (mRNA)* carries the instructions for protein synthesis to ribosomes located in the cytoplasm. Recent research has revealed other important functions of RNA.

The Components of Nucleic Acids **Polynucleotides** are polymers of **nucleotides**—monomers that consist of a pentose (five-carbon sugar) covalently bonded to a phosphate group and to a nitrogenous (nitrogen-containing) base. A nucleotide may contain more than one phosphate group; without the phosphate group it is called a *nucleoside.*

Nitrogenous bases are either **pyrimidines** or **purines,** which consist respectively of one or two nitrogen-containing rings. Adenine, guanine, and cytosine are present in DNA and RNA. The base thymine is present only in DNA; uracil is only in RNA. In DNA, the sugar is **deoxyribose**; in RNA, it is **ribose**. In a nucleotide, the base attaches to the 1′ carbon and a phosphate group attaches to the 5′ carbon of the sugar.

Nucleotide Polymers Nucleotides are linked together into a polynucleotide by phosphodiester linkages, which join the sugar of one nucleotide with the phosphate of the next. The polymer has two distinct ends: a 5′ end with a phosphate attached to the 5′ carbon of a sugar, and a 3′ end with a hydroxyl group on the 3′ carbon of a sugar. 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.

FOCUS QUESTION 3.10



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.

b. Is the base of this nucleotide a purine or a pyrimidine? How do you know?

c. Is this a DNA nucleotide or an RNA nucleotide? How do you know?

The Structure of DNA and RNA Molecules DNA molecules consist of two polynucleotides (strands) spiraling in a **double helix**. The two sugar-phosphate backbones run in opposite 5′ to 3′ directions, an arrangement called **antiparallel**. The nitrogenous bases pair and hydrogen-bond together in the inside of the molecule. 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 precisely replicate itself.

RNA molecules are usually single polynucleotides, although base-pairing within or between RNA molecules is common. For example, the functional shape of *transfer RNA (tRNA),* an RNA involved in protein synthesis, involves several regions of complementary base-pairing.

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.

FOCUS QUESTION 3.11

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. Refer to Figures 3.26 and 3.27 in your textbook to help you visualize polynucleotides and the three-dimensional structures of DNA and RNA.

Word Roots

carb- = coal (*carboxyl group:* a chemical group present in organic acids, consisting of a single carbon atom double-bonded to an oxygen atom and also bonded to a hydroxyl group)

di- = two; **-sacchar** = sugar (*disaccharide:* a double sugar, consisting of two monosaccharides joined through a dehydration reaction)

glyco- = sweet (*glycogen:* an extensively branched glucose polysaccharide that stores energy in animals)

hydro- = water; **-lyse** = break (*hydrolysis:* a chemical reaction that breaks bonds between two molecules by the addition of water; functions in disassembly of polymers to monomers)

macro- = large (*macromolecule:* a giant molecule formed by the joining of smaller molecules, such as a polysaccharide, a protein, or a nucleic acid)

poly- = many; **meros-** = part (*polymer:* a long molecule consisting of many similar or identical monomers linked together by covalent bonds)

sulf- = sulfur (*sulfhydryl group:* a chemical group consisting of a sulfur atom bonded to a hydrogen atom)

tri- = three (*triacylglycerol:* a lipid consisting of three fatty acids linked to one glycerol molecule; also called a fat or triglyceride)

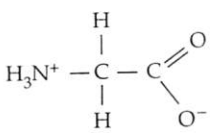
Structure Your Knowledge

1. The diversity of life is amazing. Yet the molecular logic of life is simple: Small molecules common to all organisms are ordered into unique large biological molecules. Explain why carbon is central to the molecular diversity of life. How do carbon skeletons, chemical groups, monomers, and polymers relate to this diversity?

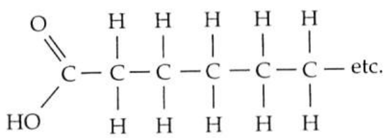
2. Fill in the following table on the important chemical groups of organic compounds.

Chemical Group	Molecular Formula	Names and Characteristics of Compounds Containing Group
	—OH	
		Aldehyde or ketone; polar group
Carboxyl		
	$—NH_2$	
		Thiols; cross-links stabilize proteins
Phosphate		
	$—CH_3$	

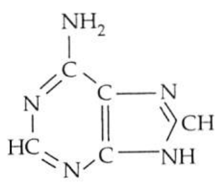
3. Identify the type of monomer or group shown by the formulas a–g. Then match the chemical formulas with their descriptions. Answers may be used more than once.



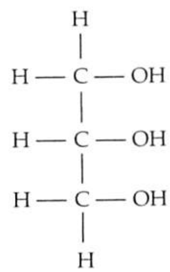
a. ____________________



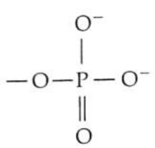
b. ____________________



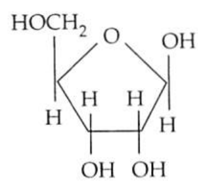
c. ____________________



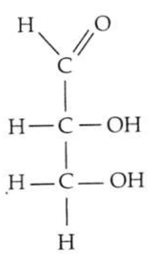
d. ____________________



e. ____________________



f. ____________________



g. ____________________

_____ 1. molecules that would combine to form a fat

_____ 2. monomer 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. monomer of a protein

_____ 6. most nonpolar (hydrophobic) molecule

4. Describe the four structural levels that produce the functional shape of a protein.

Test Your Knowledge

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

_________ 1. glycogen

_________ 2. cholesterol

_________ 3. RNA

_________ 4. collagen

_________ 5. hemoglobin

_________ 6. a gene

_________ 7. triacylglycerol

_________ 8. enzyme

_________ 9. cellulose

_________ 10. chitin

A. carbohydrate

B. lipid

C. protein

D. nucleic acid

MULTIPLE CHOICE: *Choose the one best answer.*

1. Carbon's valence of four 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. their C—H bonds are 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. The chemical group that can cause an organic molecule to act as a base is
   a. —COOH.
   b. —OH.
   c. —SH.
   d. $—NH_2$.
   e. $—CH_3$.

4. The chemical group that confers acidic properties to organic molecules is
   a. —COOH.
   b. —OH.
   c. —SH.
   d. $—NH_2$.
   e. $—CH_3$.

5. Polymerization (the formation of polymers) is a process that
   a. creates bonds between glucose monomers in the formation of a polypeptide.
   b. involves the addition of a water molecule.
   c. links the nitrogenous base of one nucleotide with the phosphate of the next.
   d. involves a dehydration reaction.
   e. may involve all of the above.

6. Which of the following statements is *not* true of a hexose?
   a. It may be found in nucleic acids.
   b. It can occur in a ring structure.
   c. It has the formula $C_6H_{12}O_6$.
   d. It has one carbonyl and five hydroxyl groups.
   e. It may be an aldehyde or a ketone sugar.

7. Which of the following statements 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.

8. Plants store most of their energy for later use as
   a. unsaturated fats.
   b. glycogen.
   c. starch.
   d. sucrose.
   e. cellulose.

9. Maltose is made from joining two glucose molecules in a dehydration reaction. What is the molecular formula for this disaccharide?
   a. $C_6H_{12}O_6$
   b. $C_{10}H_{20}O_{10}$
   c. $C_{12}H_{22}O_{11}$
   d. $C_{12}H_{24}O_{12}$
   e. $C_{12}H_{24}O_{13}$

10. A cow can derive nutrients from cellulose because
    a. it can produce the enzymes that break the β linkages between glucose molecules.
    b. it chews and rechews its cud so that cellulose fibers are finally broken down.
    c. its rumen contains prokaryotes and protists that can hydrolyze the bonds of cellulose.
    d. its intestinal tract contains termites, which harbor microbes that hydrolyze cellulose.
    e. it has enzymes that convert cellulose to starch and then hydrolyze starch to glucose.

11. Which of the following substances is the major component of the cell membrane of a fungus?
    a. cellulose
    b. chitin
    c. cholesterol
    d. phospholipids
    e. unsaturated fatty acids

12. 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.

13. Three molecules of the fatty acid in question 12 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. $C_{51}H_{104}O_9$.

14. Which of the following molecules is the most hydrophobic?
    a. cholesterol
    b. nucleotide
    c. chitin
    d. phospholipid
    e. glucose

15. Which of the following molecules provides the most energy (kcal/g) when eaten and digested?
    a. glucose
    b. starch
    c. glycogen
    d. fat
    e. protein

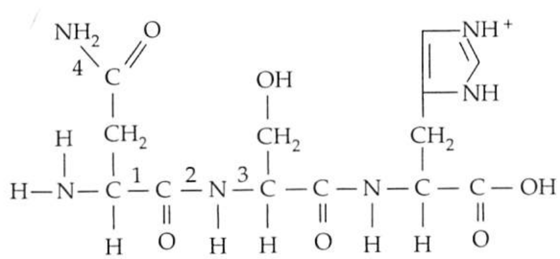
16. Which of the following is *not* one of the many functions performed by proteins?
    a. acting as signals and receptors
    b. acting as an enzymatic catalyst for metabolic reactions
    c. providing protection against disease
    d. serving as contractile components of muscle
    e. forming primary energy storage in plant seeds

17. What happens when a protein denatures?
    a. Its primary structure is disrupted.
    b. Its secondary and tertiary structures are disrupted.
    c. It always flips inside out.
    d. It hydrolyzes into component amino acids.
    e. Its hydrogen bonds, ionic bonds, hydrophobic interactions, disulfide bridges, and peptide bonds are disrupted.

18. The α helix of proteins is
    a. part of the protein's tertiary structure and is stabilized by disulfide bridges.
    b. a double helix.
    c. stabilized by hydrogen bonds and is commonly found in fibrous proteins.
    d. found in some regions of globular proteins and is stabilized by hydrophobic interactions.
    e. a complementary sequence to messenger RNA.

19. 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.

20. What is the *best* description of the following molecule?



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

21. Which number(s) in the molecule in question 20 refer(s) to a peptide bond?
    a. 1
    b. 2
    c. 3
    d. 4
    e. both 2 and 4

22. 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

23. Both hydrophobic and hydrophilic interactions are important for which of the following types of molecules or structures?
    a. proteins
    b. cell membranes
    c. cellulose in plant cell walls
    d. a and b
    e. a, b, and c

24. How are nucleotide monomers connected to form a polynucleotide?
    a. by hydrogen bonds between complementary nitrogenous base pairs
    b. by ionic attractions between phosphate groups
    c. by disulfide bridges between cysteines
    d. by covalent bonds between the sugar of one nucleotide and the phosphate of the next
    e. by ester linkages between the carboxyl group of one nucleotide and the hydroxyl group on the ribose of the next

25. If the nucleotide sequence of one strand of a DNA helix is 5'GCCTAA3', what would be the 3'–5' sequence on the complementary strand?
    a. GCCTAA
    b. CGGAUU
    c. CGGATT
    d. ATTCGG
    e. TAAGCC

26. 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 evolved about the same time.