Chapter 1

Introduction: Themes in the Study of Life

Key Concepts

1.1 **The themes of this book make connections across different areas of biology**

1.2 **The Core Theme: Evolution accounts for the unity and diversity of life**

1.3 **In studying nature, scientists make observations and then form and test hypotheses**

1.4 **Science benefits from a cooperative approach and diverse viewpoints**

Framework

This chapter outlines the broad scope of biology, describes themes that unify the study of life, and examines the scientific construction of biological knowledge. A course in biology is neither a vocabulary course nor a classification exercise for the diverse forms of life. Biology is a collection of facts and concepts structured within theories and organizing principles. Recognizing the common themes within biology will help you structure your knowledge of the fascinating and challenging study of life.

Chapter Review

Biology is the scientific study of life, with **evolution,** the process of change that has shaped life from its origin on Earth to today's diversity, as its organizing principle. The properties and processes of life include highly ordered structure, evolutionary adaptation, response to the environment, regulation, energy processing, reproduction, and growth and development.

1.1 The themes of this book make connections across different areas of biology

Theme: New Properties Emerge at Each Level in the Biological Hierarchy The scale of biology extends from the biosphere to molecules.

INTERACTIVE QUESTION 1.1

Write a brief description of each of the following levels of biological organization.

a. biosphere

b. ecosystem

c. community

d. population

e. organism

f. organs and organ systems

g. tissues

h. cells

i. organelles

j. molecules

Interactions among components at each level of biological organization lead to the emergence of novel properties at the next level. These **emergent properties** result from the structural arrangement and interaction of parts.

Biology combines the powerful and pragmatic strategy of reductionism, which breaks down complex systems into simpler components, with the study of the holistic, highly complex interactions in higher levels of life.

Many researchers are seeking to understand the emergent properties of life by looking at the functional integration of a system's parts. **Systems biology** studies the interactions of the parts of a system and models the system's dynamic behavior.

INTERACTIVE QUESTION 1.2

Give examples of how systems biology may affect medical practice or environmental policy making.

Theme: Organisms Interact with Other Organisms and the Physical Environment Both organisms and the environment are affected by interactions between them. These interactions result in the cycling of chemical nutrients between organisms and the environment. The continual burning of fossil fuels, which releases increasing amounts of CO_2 to the atmosphere, is causing global warming and contributing to **global climate change.** The resulting increase in temperature affects organisms' habitats and interactions.

Theme: Life Requires Energy Transfer and Transformation Living organisms require energy. Producers transform light energy to the chemical energy in sugar, which powers the cellular activities of plants. Consumers eat plants and other organisms, using the chemical energy in their foods to power their movement, growth, and other activities. In each energy transformation, some energy is converted to thermal energy, which is dissipated to the surroundings as heat.

INTERACTIVE QUESTION 1.3

Compare the movement of chemical nutrients and energy in an ecosystem.

Theme: Structure and Function Are Correlated at All Levels of Biological Organization The form of a biological structure is usually well matched to its function. Form fits function at all of life's structural levels.

Theme: Cells Are an Organism's Basic Units of Structure and Function The cell is the lowest structural level capable of performing all the activities of life. Every cell uses DNA as its genetic information and is enclosed by a membrane. The simpler and smaller **prokaryotic cell,** unique to bacteria and archaea, lacks both a nucleus to enclose its DNA and cytoplasmic organelles. The **eukaryotic cell**—with a nucleus containing DNA, and numerous membrane-bound organelles—is typical of all other living organisms.

Theme: The Continuity of Life Is Based on Heritable Information in the Form of DNA The heritable information of a cell is coded in **DNA,** deoxyribonucleic acid, the substance of genes. **Genes** are the units of inheritance that transmit information from parents to offspring. Genes are located on chromosomes, long DNA molecules that replicate before cell division and provide identical copies to daughter cells.

The biological instructions for the development and functioning of organisms are coded in the arrangement of the four kinds of nucleotides on the two strands of a DNA double helix. Most genes program the cell's production of proteins, and almost all cellular structures and actions involve one or more proteins.

Gene expression is the process by which a gene's information is converted into a protein or an RNA product. All forms of life use essentially the same genetic code of nucleotides.

INTERACTIVE QUESTION 1.4

Describe the pathway from DNA nucleotides to proteins.

All the genetic instructions an organism inherits make up its **genome.** One set of human chromosomes contains about 3 billion nucleotide pairs, and codes for the production of about 75,000 proteins and a large number of non-protein-coding RNA molecules.

With the sequencing of the human genome and the genomes of many other organisms now complete, current research focuses on the coordination of the proteins coded for by the DNA sequences on a cellular and organismal level. Using a systems approach called **genomics,** scientists are analyzing whole sets of genes of a species and comparing genomes between species.

Three research developments contribute to genomics: "high-throughput" technology that can produce enormous amounts of data, such as the automatic DNA-sequencing machines; **bioinformatics,** which provides the computational tools to process and integrate data from large data sets; and interdisciplinary research teams with specialists from many diverse scientific fields.

Theme: Feedback Mechanisms Regulate Biological Systems Protein enzymes catalyze a cell's chemical reactions. Many biological systems self-regulate by a mechanism called feedback. In **negative feedback,** an end product slows down a process, often by inhibiting an enzyme early in a chemical pathway. In **positive feedback,** less common in biological processes, an end product speeds up its own production. Regulatory mechanisms operate at all levels of the biological hierarchy.

Evolution, the Overarching Theme of Biology Evolution explains how diverse organisms of the past and the present are related through common ancestry, and it presents the mechanism through which organisms come to fit their environments.

1.2 The Core Theme: Evolution accounts for the unity and diversity of life

Classifying the Diversity of Life Of an estimated total of 10–100 million species, only about 1.8 million species have been identified and named. Taxonomy is the branch of biology that names organisms and groups species into ever broader categories, from genera to family, order, class, phylum, kingdom, and domain.

The number of kingdoms is an ongoing debate, but all of life is now grouped into three domains. The prokaryotes are divided into domains **Archaea** and **Bacteria.** All eukaryotes are placed in domain **Eukarya.** Within the Eukarya, the traditional kingdom Protista is being split to better reflect evolutionary relationships.

Within this diversity, living forms share a universal genetic language of DNA and similarities in cell structure.

INTERACTIVE QUESTION 1.5

What is a commonly used criterion for placing plants, fungi, and animals into separate kingdoms?

Charles Darwin and the Theory of Natural Selection In *The Origin of Species*, published in 1859, Charles Darwin presented his case for "descent with modification," the idea that present forms have diverged from a succession of ancestral forms. Darwin proposed the theory of **natural selection** as the mechanism of evolution by drawing an inference from three observations: Individuals vary in many heritable traits, the overproduction of offspring sets up a competition for survival, and species are generally matched to their environments. From this, Darwin inferred that individuals with traits best suited for an environment leave more offspring than do less-fit individuals. This natural selection, or unequal reproductive success within a population, results in the gradual accumulation of favorable adaptations to an environment.

The Tree of Life The underlying unity seen in the structures of related species, both living and in the fossil record, reflects the inheritance of that structure from a common ancestor. The diversity of species results from natural selection acting over millions of generations in different environments. The tree-like diagrams of evolutionary relationships reflect the branching genealogy extending from ancestral species. Similar species share a common ancestor at a more recent branch point on the tree of life. Distantly related species share a more ancient common ancestor.

INTERACTIVE QUESTION 1.6

Describe in your own words Darwin's theory of natural selection as the mechanism of evolutionary adaptation and the origin of new species.

1.3 In studying nature, scientists make observations, and then form and test hypotheses

Science is an approach to understanding the natural world that involves **inquiry,** the search for information by asking questions and endeavoring to answer them.

Making Observations Careful and verifiable observation and analysis of data are the basis of scientific inquiry. Observations involve our senses and tools that extend our senses; **data,** both *quantitative* and *qualitative*, are recorded observations. Using **inductive reasoning,** a generalized conclusion can often be drawn from collections of observations.

Forming and Testing Hypotheses Observations and inductions lead to the search for natural causes and explanations. A **hypothesis** is a tentative answer to a question or an explanation of observations, and it leads to predictions that can be tested. **Deductive reasoning** uses "if . . . then" logic to proceed from the general to the specific—from a general hypothesis to specific predictions of results if the general premise is correct.

A hypothesis must be *testable* and *falsifiable*—that is, there must be some observation or experiment that can reveal if the hypothesis is actually not true. The ideal is to frame two or more alternative hypotheses and design experiments to test each candidate explanation. A hypothesis cannot be *proven;* the more attempts to falsify it that fail, however, the more a hypothesis gains credibility.

Science seeks natural causes for natural phenomena; it does not address questions of the supernatural.

The Flexibility of the Scientific Method The *scientific method,* as outlined by a structured series of steps, is rarely adhered to rigidly in scientific inquiry. Scientists often backtrack to make more observations, or make progress in answering a question only after other research provides a new context.

A Case Study in Scientific Inquiry: Investigating Mimicry in Snake Populations The scarlet king snake mimics the ringed coloration of the venomous coral snake. D. and K. Pfennig and W. Harcombe tested the hypothesis that mimicry is an adaptation that reduces a harmless animal's risk of being eaten. To test the prediction that predators will attack king snakes less frequently in areas where predators have adapted to the warning coloration of coral snakes, they placed equal numbers of plain brown and ringed-colored artificial king snakes in regions with and without coral snakes. Compared to the brown snakes, the ringed snakes were attacked less frequently only in field sites within the range of the venomous coral snakes.

This experimental design illustrates a **controlled experiment** in which subjects are divided into an *experimental group* and a *control group.* Both groups are alike except for the one variable that the experiment is trying to test. Another characteristic of science is that observations and experimental results must be repeatable.

INTERACTIVE QUESTION 1.7

a. How did predators "learn" to avoid coral snakes?

b. Why were the results of the mimicry study presented as the percent of attacks on king snakes in each area rather than as the total number of attacks?

Theories in Science A **theory** is broader in scope than a hypothesis, generates many specific hypotheses, and is supported by a large body of evidence. Still, a theory can be modified or even rejected when results and new evidence no longer support it.

1.4 Science benefits from a cooperative approach and diverse viewpoints

Building on the Work of Others Most scientists work in teams and share their results with a broader research community in seminars, publications, and websites. Scientists often attempt to confirm the observations and experimental results of other colleagues. Scientists often share data on **model organisms,** which are easy to grow in the lab and are useful for answering particular questions that may have broad applications. Biological questions can be approached from different angles and levels of biological organization.

Science, Technology, and Society The political and cultural environment influences the ways in which scientists approach their work. But science is still distinguished by adherence to the criteria of verifiable observations and hypotheses that are testable and falsifiable.

Science and technology are interdependent: The information generated by science is applied by **technology** in the development of goods and services, and technological advances are used to extend scientific knowledge. The uses of scientific knowledge and technologies are influenced by and in turn influence politics, economics, and cultural values.

The Value of Diverse Viewpoints in Science Women and many racial and ethnic groups have been underrepresented in scientific professions. A diversity of backgrounds and viewpoints is important to the progress of science.

INTERACTIVE QUESTION 1.8

a. Compare hypotheses and theories.

b. Compare science and technology.

Word Roots

bio- = life (*biology:* the scientific study of life; *bioinformatics:* the use of computers, software, and mathematical models to process and integrate biological information from large data sets)

-ell = small (*organelle:* a small membrane-enclosed structure with a specialized function, found in eukaryotic cells)

eu- = true (*eukaryotic cell:* a type of cell with a membrane-enclosed nucleus and organelles)

pro- = before; **karyo-** = nucleus (*prokaryotic cell:* a type of cell lacking a membrane-enclosed nucleus and organelles)

Structure Your Knowledge

1. Briefly describe in your own words each of the eight unifying themes of biology presented in this chapter:
   a. emergent properties
   b. interaction with the biotic and physical environment
   c. energy transfer and transformation
   d. structure and function
   e. cells
   f. heritable information
   g. feedback mechanisms of regulation
   h. evolution

Test Your Knowledge

MULTIPLE CHOICE: *Choose the one best answer.*

1. The core idea that makes sense of the unity and the diversity of life is
   a. the scientific method.
   b. inductive reasoning.
   c. deductive reasoning.
   d. evolution.
   e. systems biology.

2. In an experiment similar to the mimicry experiment performed by the Pfennigs, a researcher found that more total predator attacks occurred on model king snakes in areas with coral snakes than in areas outside the range of coral snakes. From this the researcher concluded that
   a. the mimicry hypothesis is false.
   b. the predators in the areas with coral snakes were hungrier than the predators in other areas.
   c. king snakes do not resemble coral snakes enough to protect them from attack.
   d. the data that should be compared to draw a conclusion must include a control—a comparison with the number of attacks on model brown snakes.
   e. more data must be collected before a conclusion can be drawn.

3. Why can a hypothesis never be "proven" to be true?
   a. One can never collect enough data to be 100% sure.
   b. There may always be alternative untested hypotheses that might account for the results.
   c. Science is limited by our senses.
   d. Experimental error is involved in every research project.
   e. Science "evolves"; hypotheses and even theories are always changing.

4. Which of the following statements is an example of positive feedback regulation?
   a. The hormones insulin and glucagon regulate blood-sugar levels.
   b. In the birth of a baby, uterine contractions stimulate release of chemicals that stimulate more uterine contractions.
   c. A rise in temperature when you exercise stimulates sweating and increased blood flow to the skin.
   d. When cells have sufficient energy available, the pathways that break down sugars are turned off.
   e. A rise in CO_2 in the atmosphere correlates with increasing global temperature.

5. Which of the following areas is mismatched with its description?
   a. model organisms—using type organisms to characterize each domain and kingdom
   b. scientific inquiry—generating hypotheses; formulating predictions; conducting experiments or making observations
   c. genomics—studying whole sets of genes of a species and between species
   d. taxonomy—identifying and naming organisms, and placing them in hierarchical categories
   e. technology—inventing practical uses of scientific knowledge

6. In a pond sample, you find a unicellular organism that has numerous chloroplasts and a whiplike flagellum. In which of the following groups do you think it should be classified?
   a. plant
   b. animal
   c. domain Archaea
   d. one of the proposed kingdoms of protists
   e. You cannot tell unless you see if it has a nucleus.

7. What is DNA?
   a. the substance of heredity
   b. a double helix made of four types of nucleotides
   c. a code for protein synthesis
   d. a component of chromosomes
   e. all of the above

8. Which of the following sequences correctly lists life's hierarchical levels from lowest to highest?
   a. organ, tissue, organ system, organism, population
   b. organism, community, population, ecosystem, biosphere
   c. molecule, organelle, cell, tissue, organ, organism
   d. tissue, cell, organ, organism, community
   e. Both b and c are correct sequences.

9. Which of the following themes of biology is most related to the goals and practices of systems biology?
   a. Evolution accounts for the unity and diversity of life.
   b. Cells are an organism's basic units of structure and function.
   c. The continuity of life is based on heritable information in the form of DNA.
   d. Life requires energy transfer and transformation.
   e. New properties emerge at each level in the biological hierarchy.

UNIT 1

The Chemistry of Life

Chapter 2

The Chemical Context of Life

Key Concepts

2.1 Matter consists of chemical elements in pure form and in combinations called compounds

2.2 An element's properties depend on the structure of its atoms

2.3 The formation and function of molecules depend on chemical bonding between atoms

2.4 Chemical reactions make and break chemical bonds

Framework

This chapter considers the basic principles of chemistry that explain the behavior of atoms and molecules. You will learn how the subatomic particles—protons, neutrons, and electrons—are organized in atoms, how atoms are connected by covalent bonds, and how ions are attracted to each other in ionic bonds. Weak chemical bonds help to create the shapes and functions of molecules. Emergent properties are associated with each new level of structural organization in the hierarchy from atoms to life.

Chapter Review

2.1 Matter consists of chemical elements in pure form and in combinations called compounds

Elements and Compounds **Matter** is anything that takes up space and has mass. (Although sometimes used interchangeably, mass is the amount of matter in an object, whereas weight reflects gravity's pull on that mass.) **Elements** are substances that cannot be chemically broken down to other types of matter. A **compound** is made up of two or more elements combined in a fixed ratio. The characteristics of a compound differ from those of its constituent elements, an example of emergent properties in higher levels of organization.

The Elements of Life Carbon (C), oxygen (O), hydrogen (H), and nitrogen (N) make up 96% of living matter. The seven elements listed in Interactive Question 2.1 make up most of the remaining 4%. Some elements, like iron (Fe) and iodine (I), may be required in very minute quantities and are called **trace elements.**

INTERACTIVE QUESTION 2.1

Fill in the names beside the symbols of the following elements commonly found in living matter.

Ca	Na
P	Cl
K	Mg
S	

Evolution of Tolerance to Toxic Elements Serpentine soil contains toxic elements and low levels of essential elements. Serpentine plant communities exhibit evolutionary adaptations that allow such plants to grow in toxic soils.

2.2 An element's properties depend on the structure of its atoms

An **atom** is the smallest unit of matter retaining the properties of a particular element.

Subatomic Particles Three stable *subatomic particles* are important to our understanding of atoms. Uncharged **neutrons** and positively charged **protons** are packed tightly together to form the **atomic nucleus** of an atom. Negatively charged **electrons** form a cloud around the nucleus.

Protons and neutrons have a similar mass of about 1.7×10^{-24} g, or close to 1 dalton each. A **dalton** is the measurement unit for atomic mass. Electrons have negligible mass.

Atomic Number and Atomic Mass Each element has a characteristic **atomic number,** or number of protons in the nucleus of each of its atoms. Unless otherwise indicated, an atom has a neutral electrical charge, and thus the number of protons is equal to the number of electrons. A subscript to the left of the symbol for an element indicates its atomic number; a superscript indicates its mass number. The **mass number** is equal to the number of protons and neutrons in the nucleus and approximates the mass of an atom of that element in daltons. The term **atomic mass** refers to the total mass of an atom.

INTERACTIVE QUESTION 2.2

The difference between the mass number and the atomic number of an atom is equal to the number of __________. An atom of phosphorus, $^{31}_{15}P$, contains __________ protons, __________ electrons, and __________ neutrons. The atomic mass of phosphorus is approximately __________.

Isotopes Although the number of protons is constant, the number of neutrons can vary among the atoms of an element, creating different **isotopes** that have slightly different masses but the same chemical behavior. Some isotopes are unstable; the nuclei of **radioactive isotopes** spontaneously decay, giving off particles and energy. Radioactive isotopes are important tools in biological research and medicine. Too great an exposure to radiation from decaying isotopes poses a significant health hazard.

The Energy Levels of Electrons **Energy** is defined as the capacity to cause change. **Potential energy** is energy stored in matter as a consequence of its position or structure. The potential energy of electrons increases as their distance from the positively charged nucleus increases. Electrons can be located in different **electron shells** surrounding the nucleus.

INTERACTIVE QUESTION 2.3

To move to a shell farther from the nucleus, an electron must __________ energy; an electron __________ energy when it moves to a closer shell.

Electron Distribution and Chemical Properties The chemical behavior of an atom is a function of the distribution of its electrons—in particular, the number of **valence electrons** in its outermost electron shell, or **valence shell.** A valence shell of eight electrons is complete, resulting in an unreactive or inert atom. (The first shell, however, can hold only two electrons.) Atoms with incomplete valence shells are chemically reactive. The elements in each row, or period, of the *periodic table of the elements* have the same number of electron shells and are arranged in order of increasing number of electrons.

INTERACTIVE QUESTION 2.4

Draw an electron shell diagram for the following atoms.

a. $_6C$ **c.** $_8O$

b. $_7N$ **d.** $_{12}Mg$

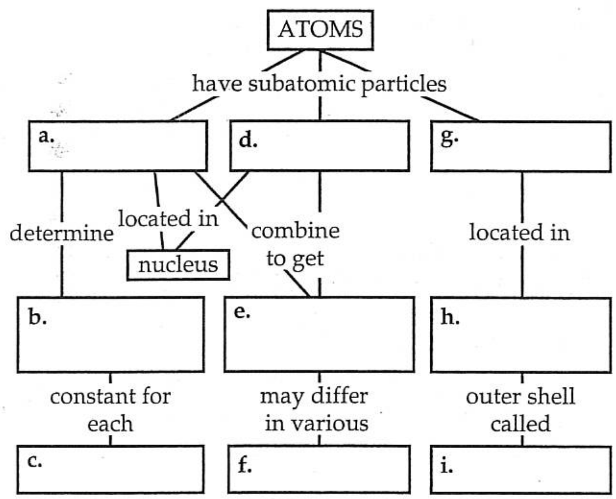
Electron Orbitals An **orbital** is the three-dimensional space or volume within which an electron is most likely to be found. No more than two electrons can occupy the same orbital. The first electron shell can contain two electrons in a single spherical orbital, called the 1*s* orbital. The second electron shell can hold a maximum of eight electrons in its four orbitals, which are a 2*s* spherical orbital and three dumbbell-shaped *p* orbitals located along the x, y, and z axes.

INTERACTIVE QUESTION 2.5

Look again at the electron shell diagram you drew for carbon (a) in Interactive Question 2.4. Did you show the outer shell electrons unpaired? Why?

INTERACTIVE QUESTION 2.6

Fill in the blanks in the following concept map to help you review the atomic structure of atoms.



2.3 The formation and function of molecules depend on chemical bonding between atoms

Atoms with incomplete valence shells can either share electrons with or completely transfer electrons to or from other atoms such that each atom is able to complete its valence shell. These interactions usually result in attractions called **chemical bonds,** which hold the atoms close together.

Covalent Bonds When two atoms share a pair of valence electrons, a **covalent bond** is formed. A **molecule** consists of two or more atoms held together by covalent bonds. A *structural formula,* such as H—H, indicates both the atoms and bonds in a molecule. The dash indicates a **single bond.** A *molecular formula,* such as O_2, indicates only the kinds and numbers of atoms. In an oxygen molecule, two pairs of valence electrons are shared between oxygen atoms, forming a double covalent bond, or simply a **double bond** (O=O). The **valence,** or bonding capacity, of an atom usually equals the number of unpaired electrons in its valence shell.

INTERACTIVE QUESTION 2.7

a. What are the valences of the four most common elements of living matter?

b. Draw the *Lewis dot structures* for the following molecules.

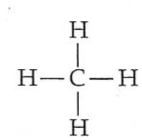
H_2 O_2 N_2 CH_4

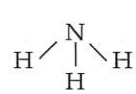
Electronegativity is the attraction of a particular atom for shared electrons. If the atoms in a molecule have similar electronegativities, the electrons remain equally shared, and the bond is said to be a **nonpolar covalent bond.** If one element is more electronegative, it pulls the shared electrons closer to itself, creating a **polar covalent bond.** This unequal sharing of electrons results in a slight negative charge (δ−) associated with the more electronegative atom and a slight positive charge (δ+) associated with the atom from which the electrons are pulled.

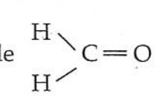
INTERACTIVE QUESTION 2.8

Explain whether the following molecules contain nonpolar or polar covalent bonds. (Hint: N and O both have high electronegativities.)

a. nitrogen molecule $N\equiv N$

c. methane 

b. ammonia 

d. formaldehyde 

Ionic Bonds If two atoms are very different in their attraction for valence electrons, the more electronegative atom may completely transfer an electron from the other atom, resulting in the formation of charged atoms called **ions.** The atom that lost the electron is a positively charged **cation.** The negatively charged atom that gained the electron is called an **anion.** An **ionic bond** may hold these ions together because of the attraction of their opposite charges.

Ionic compounds, called **salts,** often exist as three-dimensional crystalline lattice arrangements held together by electrical attractions. The number of ions present in a salt crystal is not fixed, but the atoms are present in specific ratios. Salts have strong ionic bonds when dry, but the crystal dissolves in water.

Ion also refers to entire covalent molecules that are electrically charged.

INTERACTIVE QUESTION 2.9

Calcium ($_{20}Ca$) and chlorine ($_{17}Cl$) can combine to form the salt calcium chloride. Based on the number of electrons in their valence shells and their bonding capacities, what would the formula for this salt be? **a.** ________ Which atom becomes the cation? **b.** ________

Weak Chemical Bonds Ionic bonds and other weak bonds may form temporary interactions between molecules. Weak bonds within many large molecules help to create those molecules' three-dimensional functional shapes.

A hydrogen atom that is covalently bonded to an electronegative atom has a partial positive charge and can be attracted to another nearby electronegative atom. This attraction is called a **hydrogen bond.**

All atoms and molecules are attracted to each other when in close contact by **van der Waals interactions.** Momentary uneven electron distributions produce changing positive and negative regions that create these weak attractions.

INTERACTIVE QUESTION 2.10

Sketch a water molecule, showing oxygen's electron shells and the covalently shared electrons. Indicate the areas with slight negative and positive charges that enable a water molecule to form hydrogen bonds with other polar molecules. Then draw a second water molecule and indicate a hydrogen bond between the two.

Molecular Shape and Function A molecule's characteristic size and shape affect how it interacts with other molecules. When atoms form covalent bonds, their *s* and three *p* orbitals hybridize to form four teardrop-shaped orbitals in a tetrahedral arrangement. These hybrid orbitals dictate the specific shapes of different molecules.

INTERACTIVE QUESTION 2.11

Look at your diagram of a water molecule in Interactive Question 2.10. Why is it roughly V shaped?

2.4 Chemical reactions make and break chemical bonds

Chemical reactions involve the making or breaking of chemical bonds. Matter is conserved in chemical reactions; the same number and kinds of atoms are present in both **reactants** and **products,** although the rearrangement of electrons and atoms causes the properties of these molecules to be different.

INTERACTIVE QUESTION 2.12

Fill in the missing coeffcients for respiration, the conversion of glucose and oxygen to carbon dioxide and water, so that all atoms are conserved in the chemical reaction.

$$C_6H_{12}O_6 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O$$

Chemical reactions are reversible—the products of the forward reaction can become reactants in the reverse reaction. Increasing the concentrations of reactants can speed up the rate of a reaction. **Chemical equilibrium** is reached when the forward and reverse reactions proceed at the same rate, and the relative concentrations of reactants and products no longer change.

Word Roots

an- = not (*anion:* a negatively charged ion)

co- = together; **-valent** = strength (*covalent bond:* a strong bond between atoms that share one or more pairs of valence electrons)

electro- = electricity (*electronegativity:* the attraction of a given atom for the electrons of a covalent bond)

iso- = equal (*isotope:* one of several forms of an element, each with the same number of protons but a different number of neutrons)
neutr- = neither (*neutron:* a subatomic particle with a neutral electrical charge)
pro- = before (*proton:* a subatomic particle with a single positive electrical charge)

Structure Your Knowledge

Take the time to write out or discuss your answers to the following questions. Then refer to the suggested answers at the end of the book.

1. Fill in the following chart concerning the major subatomic particles of an atom.

Particle	Charge	Mass	Location

2. Atoms can have various numbers associated with them.
   a. Define the following and show where each of them is placed relative to the symbol of an element such as C (use the most common isotope, C-12): atomic number, mass number, atomic mass.
   b. Define valence.
   c. Which of these four numbers is most related to the chemical behavior of an atom? Explain.
3. Arrange the two types of covalent bonds and ionic bonds in an order that reflects the degree of electron sharing.

Test Your Knowledge

MULTIPLE CHOICE: *Choose the one best answer.*

1. Each element has its own characteristic atom in which
   a. the atomic mass is constant.
   b. the atomic number is constant.
   c. the mass number is constant.
   d. Two of the above are correct.
   e. All of the above are correct.

2. Which of the following is *not* a trace element in the human body?
   a. iodine
   b. zinc
   c. iron
   d. calcium
   e. fluorine

3. A sodium ion (Na^+) contains 10 electrons, 11 protons, and 12 neutrons. What is the atomic number of sodium?
   a. 10 b. 11 c. 12 d. 23 e. 33

4. Radioactive isotopes can be used in studies of metabolic pathways because
   a. their half-life allows a researcher to time an experiment.
   b. they are more reactive.
   c. the cell does not recognize the extra protons in the nucleus, so isotopes are readily used in metabolism.
   d. their location or quantity can be experimentally determined because of their radioactivity.
   e. their extra neutrons produce different colors that can be traced through the body.

5. Which of the following atomic numbers would describe the element that is least reactive?
   a. 1 b. 8 c. 12 d. 16 e. 18

Use this information to answer questions 6 through 11.

The six elements most common in living organisms are

$^{12}_{6}C$ $^{16}_{8}O$ $^{1}_{1}H$ $^{14}_{7}N$ $^{32}_{16}S$ $^{31}_{15}P$

6. How many electrons does phosphorus have in its valence shell?
   a. 3 b. 5 c. 7 d. 15 e. 16

7. What is the atomic mass of phosphorus?
   a. 15 b. 16 c. 31 d. 46 e. 62

8. A radioactive isotope of carbon has the mass number 14. How many neutrons does this isotope have?
   a. 2 b. 6 c. 8 d. 12 e. 14

9. How many covalent bonds is a sulfur atom most likely to form?
   a. 1 b. 2 c. 3 d. 4 e. 5

10. Based on electron configuration, which of the following elements would have chemical behavior most like that of oxygen?

a. C c. N e. S
b. H d. P

11. How many of the elements listed on the previous page are found next to each other (side by side) on the periodic table?

a. one group of two
b. two groups of two
c. one group of two and one group of three
d. one group of three
e. all of them

12. Which of the following describes what happens as a chlorophyll pigment absorbs energy from sunlight?

a. An electron moves to a higher electron shell and the electron's potential energy increases.
b. An electron moves to a higher electron shell and its potential energy decreases.
c. An electron drops to a lower electron shell and releases its energy as heat.
d. An electron drops to a lower electron shell and its potential energy increases.
e. An electron of sunlight is transferred to chlorophyll, producing a chlorophyll ion with higher potential energy.

13. How are the electrons of an oxygen atom arranged?

a. eight in the second electron shell, creating an inert element
b. two in the first electron shell and six in the second, creating a valence of six
c. two in the 1s orbital and two each in the three 2*p* orbitals, creating a valence of two
d. two in the 1*s* orbital, one each in the 2*s* and three 2*p* orbitals, and two in the 3*s* orbital, creating a valence of two
e. two in the 1*s* orbital, two in both the 2*s* and 2*px* orbitals, and one each in the 2*py* and 2*pz* orbitals, creating a valence of two

14. A covalent bond between two atoms is likely to be nonpolar if

a. one of the atoms is much more electronegative than the other.
b. the two atoms are about equally electronegative.
c. the two atoms are of the same element.
d. one atom is an anion and the other is a cation.
e. Both b and c are correct.

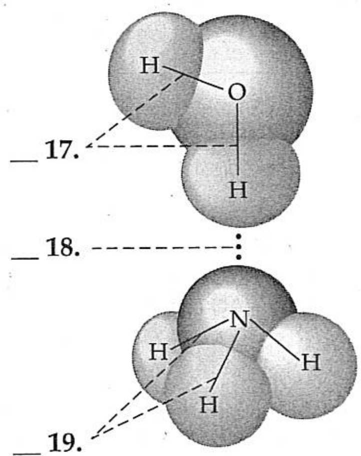
15. A triple covalent bond would

a. be very polar.
b. involve the bonding of three atoms.
c. involve the bonding of six atoms.
d. produce a triangularly shaped molecule.
e. involve the sharing of six electrons.

16. A cation

a. has gained an electron.
b. can easily form hydrogen bonds.
c. is more likely to form in an atom with seven electrons in its valence shell.
d. 'has a positive charge.
e. Both c and d are correct.

For questions 17–19, choose from the following answers to identify the types of bonds in this diagram of a water molecule interacting with an ammonia molecule.



a. nonpolar covalent bond
b. polar covalent bond
c. ionic bond
d. hydrogen bond
e. cannot determine without more information

20. In what type of bond would you expect potassium ($^{39}_{19}K$) to participate?

a. ionic; it would lose one electron and carry a positive charge
b. ionic; it would gain one electron and carry a negative charge
c. covalent; it would share one electron and make one covalent bond
d. covalent; it would share two electrons and form two bonds
e. none; potassium is an inert element

21. Which of the following may form between any closely aligned molecules?

a. nonpolar covalent bonds
b. polar covalent bonds
c. ionic bonds
d. hydrogen bonds
e. van der Waals interactions

22. What is the molecular shape of methane (CH_4)?

a. planar or flat, with the four H around the carbon
b. pentagonal, or a flat five-sided arrangement
c. tetrahedral, due to the hybridization of the *s* and three *p* orbitals of carbon
d. circular, with the four H attached in a ring around the carbon
e. linear, since all the bonds are nonpolar covalent bonds

23. The ability of morphine to mimic the effects of the body's endorphins is due to

a. a chemical equilibrium developing between morphine and endorphins.
b. the one-way conversion of morphine into endorphin.
c. molecular shape similarities that allow morphine to bind to endorphin receptors.
d. the similarities between morphine and heroin.
e. hydrogen bonding and other weak bonds forming between morphine and endorphins.

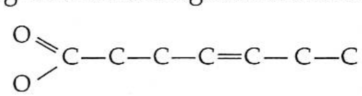
24. Which of the following molecules would you predict is capable of forming hydrogen bonds?

a. CH_4
b. CH_4O
c. NaCl
d. H_2
e. a, b, and d can form hydrogen bonds.

25. Chlorine has an atomic number of 17 and a mass number of 35. How many electrons would a chloride ion have?

a. 16
b. 17
c. 18
d. 33
e. 34

26. Taking into account the bonding capacities or valences of carbon (C) and oxygen (O), how many hydrogen (H) must be added to complete the following structural diagram of this molecule?



a. 9
b. 10
c. 11
d. 12
e. 13

27. What is the difference between a molecule and a compound?

a. There is no difference; the terms are interchangeable.
b. Molecules contain atoms of a single element, whereas compounds contain two or more elements.
c. A molecule consists of two or more covalently bonded atoms; a compound contains two or more atoms held by ionic bonds.
d. A compound consists of two or more elements in a fixed ratio; a molecule has two or more covalently bonded atoms of the same or different elements.
e. Compounds always consist of molecules, but molecules are not always compounds.

28. In a reaction in chemical equilibrium,

a. the forward and reverse reactions are occurring at the same rate.
b. the reactants and products are in equal concentration.
c. the forward reaction has gone further than the reverse reaction.
d. there are equal numbers of atoms on both sides of the equation.
e. a, b, and d are correct.

29. What would be the probable effect of adding more product to a reaction that is in equilibrium?

a. There would be no change because the reaction is in equilibrium.
b. The reaction would stop because excess product is present.
c. The reaction would slow down but still continue.
d. The forward reaction would increase and more product would be formed.
e. The reverse reaction would increase and more reactants would be formed.

30. What coefficients must be placed in the blanks to balance the following chemical reaction?

$$C_5H_{12} + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O$$

a. 5; 5; 5
b. 6; 5; 6
c. 6; 6; 6
d. 8; 4; 6
e. 8; 5; 6

Chapter 3

Water and Life

Key Concepts

3.1 **Polar covalent bonds in water molecules result in hydrogen bonding**

3.2 **Four emergent properties of water contribute to Earth's suitability for life**

3.3 **Acidic and basic conditions affect living organisms**

Framework

Water makes up 70% to 95% of the cell content of living organisms and covers 75% of Earth's surface. Its unique properties make the planet's environment suitable for life and the internal environments of organisms suitable 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. The $[H^+]$ in a solution is expressed as pH. Buffers regulate an organism's pH.

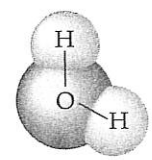
Chapter Review

3.1 Polar covalent bonds in water molecules result in hydrogen bonding

A water molecule consists of two hydrogen atoms, each bonded to a more electronegative oxygen atom by a **polar covalent bond.** This **polar molecule** has a shape like a wide V with a slight positive charge on each hydrogen atom ($\delta+$) and a slight negative charge ($\delta-$) 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 structural organization that leads to the emergent properties of water.

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.



3.2 Four emergent properties of water contribute to Earth's suitability for life

Cohesion of Water Molecules Liquid water is unusually cohesive due to the constant forming and reforming of hydrogen bonds that hold the molecules close 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.

Moderation of Temperature by Water 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 or released to change the temperature of 1 kg of water by 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 other common substances. Why does water absorb or release a relatively large quantity of heat as its temperature changes? 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 high proportion of water in the environment and within organisms keeps temperature fluctuations within limits that permit life.

Vaporization or evaporation occurs when molecules of a liquid 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. Water helps moderate Earth's climate as solar heat absorbed by tropical seas is dissipated during evaporation, and heat is released as moist tropical air moving poleward condenses to form rain.

As a liquid vaporizes, the surface 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.

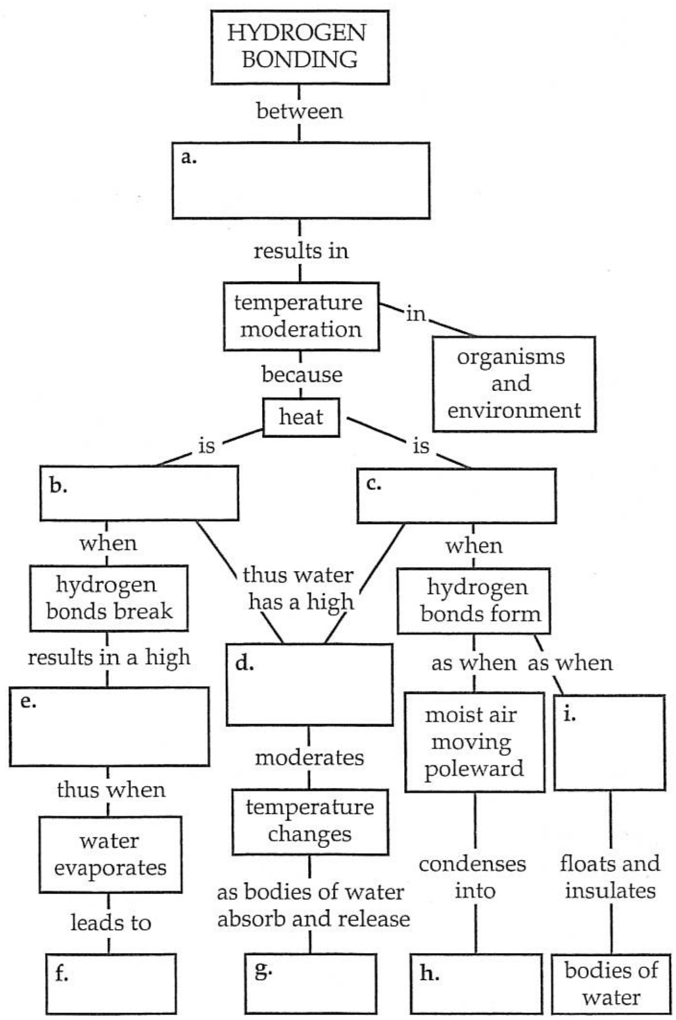
Floating of Ice on Liquid Water As water cools below 4°C, it expands. By 0°C, each water molecule is hydrogen-bonded to four other molecules, creating a crystalline lattice that spaces the molecules apart. Ice is thus less dense than liquid water and so it floats.

Water: 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.

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.** Nonpolar and nonionic substances are **hydrophobic;** they will not easily mix with or dissolve in water.

INTERACTIVE QUESTION 3.2

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



INTERACTIVE QUESTION 3.3

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

a. olive oil
b. sugar
c. salt
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** (the sum of the mass of all atoms in the molecule) in daltons. A mole of any substance has exactly the same number of molecules—6.02×10^{23}, 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 ($C_3H_6O_3$) are in 1 liter of a 0.5 *M* solution of lactic acid? (^{12}C, ^{1}H, ^{16}O)

b. How many molecules of lactic acid are in the solution in **a**?

Possible Evolution of Life on Other Planets with Water The emergent properties of water support life on Earth. In the search for extraterrestrial life, astrobiologists look for evidence of water, as has been recently confirmed on Mars.

3.3 Acidic and basic conditions affect living organisms

A water molecule can dissociate into a **hydrogen ion,** H^+ (which binds to another water molecule to form a **hydronium ion,** H_3O^+) and a **hydroxide ion,** OH^-. In pure water at 25°C, the concentrations of H^+ and OH^- are the same; both are equal to 10^{-7} *M*.

Acids and Bases 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 dissociates completely when mixed with water. A weak acid or base reversibly dissociates, either releasing or binding H^+.

The pH Scale 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, because the excess hydrogen ions combine with the hydroxide ions in solution and form water. Likewise, an increase in $[OH^-]$ causes an equivalent decrease in $[H^+]$.

The **pH** of a solution is defined as the negative log (base 10) of the $[H^+]$: $\text{pH} = -\log [H^+]$. 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 $[OH^-]$.

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

INTERACTIVE QUESTION 3.5

Complete the following table to review your understanding of pH.

$[H^+]$	$[OH^-]$	pH	Acidic, Basic, or Neutral?
	$[10^{-11}]$	3	
10^{-8}			
	$[10^{-7}]$		
		1	

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.

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

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?

Acidification: A Threat to Water Quality The increasing release of CO_2 to the atmosphere is linked to fossil fuel combustion. The oceans absorb about 25% of this CO_2, which lowers the pH of seawater. The resulting **ocean acidification** decreases the concentration of carbonate (CO_3^{2-}), an important ion needed for coral reef calcification.

Acid precipitation—rain, snow, or fog with a pH lower than 5.2 (normal is 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 and terrestrial plants are damaged by acid precipitation.

INTERACTIVE QUESTION 3.7

a. Use a formula to explain why increasing [CO_2] in water leads to a lower pH.

b. Use a formula to explain how a lower pH would affect the [CO_3^{2-}] in the ocean.

c. Assuming a fairly constant [Ca^{2+}] in the ocean, how would a change in [CO_3^{2-}] affect the calcification rate—the production of calcium carbonate ($CaCO_3$)—by the coral in a reef ecosystem?

Word Roots

kilo- = a thousand (*kilocalorie:* a thousand calories)
hydro- = water; **-philos** = loving; **-phobos** = fearing (*hydrophilic:* having an affinity for water; *hydrophobic:* having no affinity for water)

Structure Your Knowledge

1. Fill in the following table, which summarizes the emergent 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, 0–14, 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.

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. four polar covalent bonds.

2. The polar covalent bonds of water molecules
   a. promote the formation of hydrogen bonds.
   b. help water to dissolve nonpolar solutes.
   c. lower the heat of vaporization and lead to evaporative cooling.
   d. create a crystalline structure in liquid water.
   e. do 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 cell walls
   e. all of the above

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

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 as hydrogen bonds break or form.
   e. all of the above are true.

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. You have three flasks containing 100 mL of different liquids. Each is warmed with 100 calories of heat. The temperature of the liquid in flask 1 rises 1°C; in flask 2 it rises 1.5°C; and in flask 3 it rises 2°C. Which of these liquids has the highest specific heat?
   a. the liquid in flask 1
   b. the liquid in flask 2
   c. the liquid in flask 3
   d. You cannot tell unless you know what liquid is in each flask.
   e. This type of experiment does not relate to the specific heat of a substance.

7. A burn from steam at 100°C is more severe than a burn from boiling water because
   a. the steam is hotter than boiling water.
   b. steam releases a great deal of heat as it condenses on the skin.
   c. steam has a higher heat of vaporization than does water.
   d. a person is more likely to come into contact with steam than with boiling water.
   e. steam stays on the skin longer than does boiling water.

8. Evaporative cooling is a result of
   a. a low heat of vaporization.
   b. the release of heat during the breaking of hydrogen bonds when water molecules escape.
   c. the absorption of heat as hydrogen bonds break.
   d. the reduction in the average kinetic energy of a liquid after energetic water molecules enter the gaseous state.
   e. both c and d.

9. 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.

10. 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 liquid and has a high surface tension.

11. 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

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

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

14. 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 molecules in 1 liter of solvent.
    e. 342 g if the solute is sucrose.

15. Which of the following substances would you add to enough water to yield 1 liter of solution in order to make a 0.1 *M* solution of glucose ($C_6H_{12}O_6$)? The mass numbers for these elements are approximately C = 12, O = 16, and H = 1.
    a. 6 g C, 12 g H, and 6 g O
    b. 72 g C, 12 g H, and 96 g O
    c. 18 g of glucose
    d. 29 g of glucose
    e. 180 g of glucose

16. How many molecules of glucose would be in 1 liter of the 0.1 *M* solution made in question 15?
    a. 0.1
    b. 6
    c. 60
    d. 6×10^{23}
    e. 6×10^{22}

17. 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.

18. Some archaea are able to live in lakes with pH values 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.

19. A buffer
    a. releases excess OH^-.
    b. releases excess H^+.
    c. is often a weak acid-base pair.
    d. always maintains a neutral pH.
    e. Both c and d are correct.

Use the following pH values to answer questions 20–22: cola–2; orange juice–3; beer–4; coffee–5; human blood–7.4.

20. 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 2 times higher.
    e. coffee is 100 times higher.

22. What is the concentration of hydroxide ions in 1 liter of beer?
    a. 1.0×10^{-4}
    b. 1.0×10^{-10}
    c. 6.02×10^{23}
    d. 6.02×10^{19}
    e. 6.02×10^{-13}

23. 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 industrial exhaust.

24. In the past century, the average temperature of the oceans has increased by 0.74°C. Is this evidence of global warming?
    a. No, the rise in temperature is too small to be significant.
    b. No, global warming affects air temperature, not water temperature.
    c. No, the change of average temperature does not reflect the quantity of heat in the oceans.
    d. Yes, because of the high specific heat of water and the huge volume of water in the oceans, a small rise in temperature would reflect a large amount of heat absorbed by the oceans.
    e. Yes, the decreased rate of calcification is directly related to this temperature increase.

Chapter 4

Carbon and the Molecular Diversity of Life

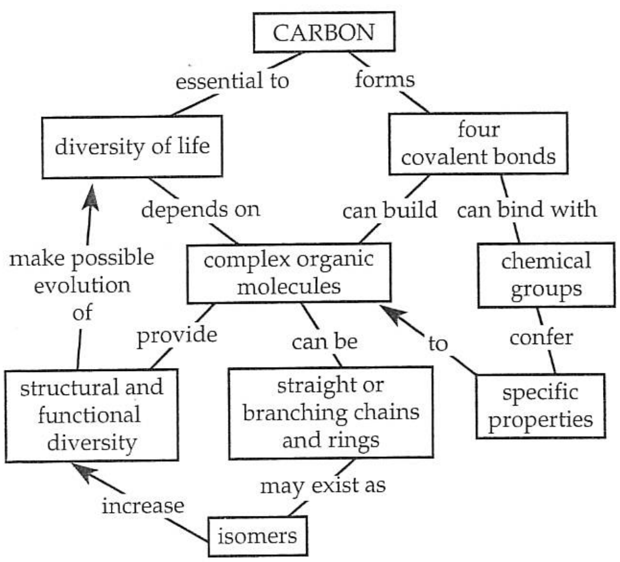
Key Concepts

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 A few chemical groups are key to the functioning of biological molecules

Framework



Chapter Review

4.1 Organic chemistry is the study of carbon compounds

Organic compounds are those containing carbon and usually hydrogen. Early chemists could not synthesize the complex molecules found in living organisms and therefore attributed their formation to a life force independent of physical and chemical laws, a belief known as *vitalism*.

Organic Molecules and the Origin of Life on Earth Stanley Miller's 1953 experiment showed that organic molecules could form under conditions believed to simulate those on early Earth. *Mechanism*, the philosophy underlying modern **organic chemistry,** holds that physical and chemical explanations are sufficient to account for all natural phenomena.

INTERACTIVE QUESTION 4.1

How did Miller's classic experiment apply mechanism to the origin of life?

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

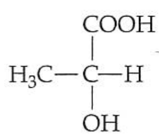
The Formation of Bonds with Carbon How many covalent bonds must carbon (with an atomic number of 6) form to complete its valence shell? Carbon's valence of four is at the center of its ability to form large and complex molecules. When carbon forms four single covalent bonds, its hybrid orbitals create 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 Carbon Skeleton Variation 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.

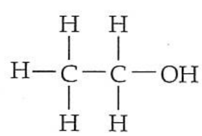
Isomers are compounds with the same molecular formula but different structural arrangements and thus different properties. **Structural isomers** differ in the covalent arrangement of atoms and often in the location of double bonds. ***Cis-trans* isomers** (formerly called geometric isomers) have the same sequence of covalently bonded atoms overall but differ in structure due to the inflexibility of double bonds. A *cis* isomer has the same atoms attached to the 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 a molecule 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, whose arrangement can result in mirror images.

INTERACTIVE QUESTION 4.2

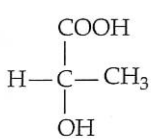
Identify the structural isomers, *cis-trans* isomers, and enantiomers from the following compounds. Which of the *cis-trans* isomers is the *cis* isomer?



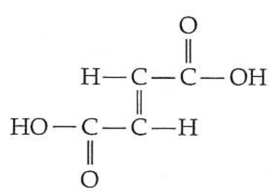
L-lactic acid



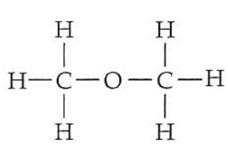
ethanol



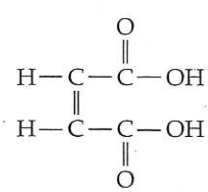
D-lactic acid



fumaric acid



dimethyl ether



maleic acid

4.3 A few chemical groups are key to the functioning of biological molecules

The Chemical Groups Most Important in the Processes of Life The properties of organic molecules are largely determined by characteristic chemical groups attached to the carbon skeleton. The following six **functional groups** may participate in chemical reactions. These hydrophilic groups 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 often 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 a hydroxyl 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 hydrogens ($—NH_2$). Compounds with an amino group, called amines, can act as bases, picking up a hydrogen ion and becoming $—NH_3^+$.

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 the carbon skeleton by an oxygen attached to a phosphorus atom that is bonded to three other oxygen atoms ($—OPO_3^{2-}$). This anion contributes 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.

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.

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.

Word Roots

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

enanti- = opposite (*enantiomer:* molecules that are mirror images of each other due to the presence of an asymmetric carbon)

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

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 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 protein structure
Phosphate		
	$—CH_3$	

Test Your Knowledge

MULTIPLE CHOICE: *Choose the one best answer.*

1. Which of the following did the results of Stanley Miller's experiments support?
   a. abiotic synthesis of organic compounds
   b. possible first stage in the origin of life
   c. mechanism
   d. vitalism
   e. Answers a, b, and c are correct.

2. 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.

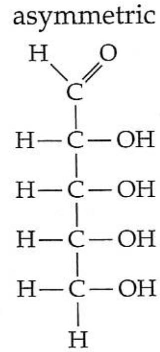
3. Hydrocarbons are not soluble in water because
   a. they are hydrophilic.
   b. the C—H bond is nonpolar.
   c. they do not ionize.
   d. they store energy in the many C—H bonds along the carbon backbone.
   e. they are lighter than water.

4. 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 is found in all enantiomers.
   d. Its configuration is in the shape of a tetrahedron.
   e. It is found in all *cis-trans* isomers.

5. Which statement 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.

6. The fats stored in your body consist mostly of
   a. methyl groups.
   b. alcohols.
   c. carboxylic acids.
   d. hydrocarbons.
   e. organic phosphates.

7. The following ribose molecule contains how many asymmetric carbons?



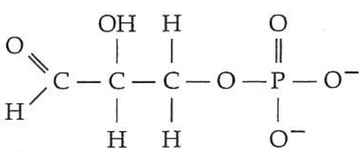
   a. 1 **b.** 2 **c.** 3 **d.** 4 **e.** 5

8. Which of the following is mismatched with its description?
   a. phosphate—forms bonds that stabilize protein structure
   b. hydroxyl and carbonyl—components of sugars
   c. ATP—source of energy for cellular processes
   d. methyl—its addition changes the shape and function of molecules
   e. amino and carboxyl—components of amino acids

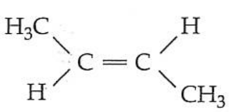
9. The chemical group that can cause an organic molecule to act as a base is
   a. —COOH. c. —SH. e. $—CH_3$.
   b. —OH. d. $—NH_2$.

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

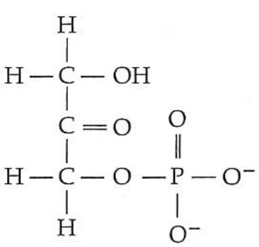
MATCHING: *Match the formulas (a–f) to the terms at the right. Choices may be used more than once, and terms may have more than one correct answer.*



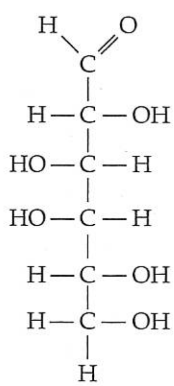
a.



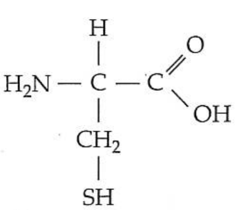
b.



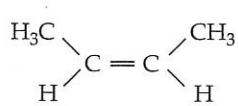
c.



d.



e.



f.

_______ 1. structural isomers
_______ 2. *cis-trans* 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 Large Biological Molecules

Key Concepts

5.1 **Macromolecules are polymers, built from monomers**

5.2 **Carbohydrates serve as fuel and building materials**

5.3 **Lipids are a diverse group of hydrophobic molecules**

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

5.5 **Nucleic acids store, transmit, and help express hereditary information**

Framework

A small number of monomers or subunits joined into unique sequences and forming three-dimensional structures create a huge variety of large molecules with diverse functions. The following table briefly summarizes the major characteristics of the four classes of biological molecules.

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, membrane components, hormones
Proteins	Amino acids	Enzymes, transport, movement, receptors, defense, structure
Nucleic acids	Nucleotides	Heredity, various functions in gene expression

Chapter Review

Smaller organic molecules are joined together to form carbohydrates, lipids, proteins, and nucleic acids. These molecules, many of which are giant **macromolecules,** have emergent properties that arise from their complex and unique structures.

5.1 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 and arrangement of these basic building blocks.

INTERACTIVE QUESTION 5.1

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.

5.2 Carbohydrates serve as fuel and building materials

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. Sugar molecules may also vary due to the spatial arrangement of parts around asymmetric carbons.

INTERACTIVE QUESTION 5.2

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) __________.

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 glycosidic linkages that give starch a helical shape. Animals use **glycogen,** a highly branched polymer of glucose, as their energy storage molecule.

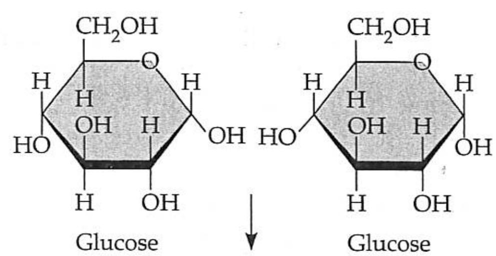
Cellulose, the major component of plant cell walls, is the most abundant organic compound on Earth. It differs from starch by the configuration of the ring form of glucose (beta instead of alpha) and the resulting geometry of the glycosidic bonds. In a plant cell wall, hydrogen bonds between hydroxyl 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 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.

INTERACTIVE QUESTION 5.3

Number the carbons in the following glucose molecules (each unlabeled corner of the ring represents a carbon). Circle the atoms that will be removed by a dehydration reaction. Then draw the resulting maltose molecule with its 1–4 glycosidic linkage.

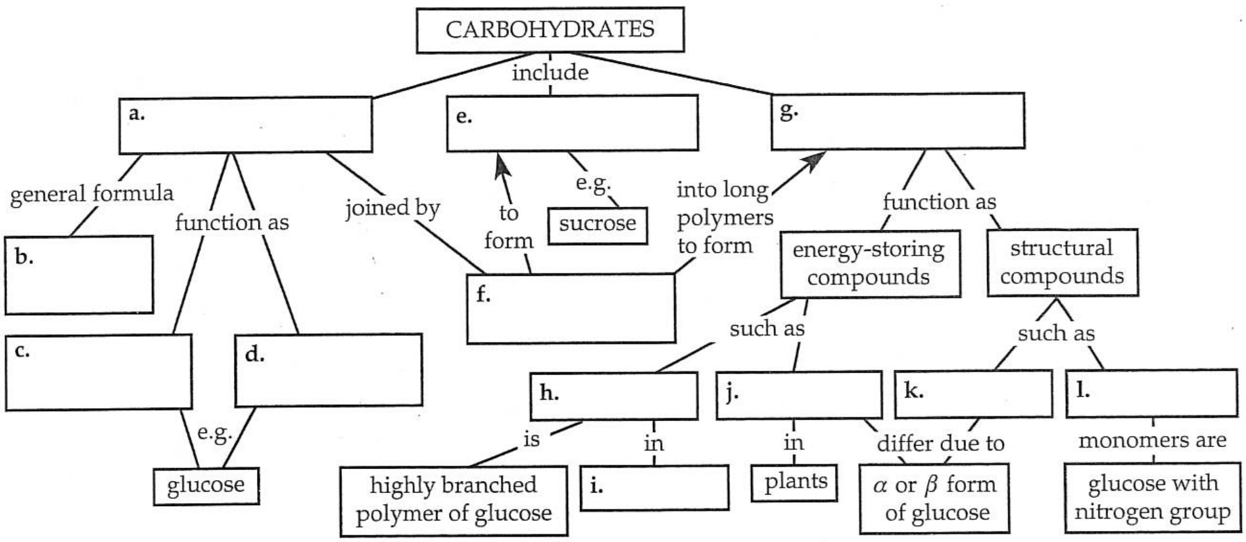


Glucose Glucose

Maltose

INTERACTIVE QUESTION 5.4

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



5.3 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 *cis* double bonds create a kink in the hydrocarbon chain and prevent 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 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 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.

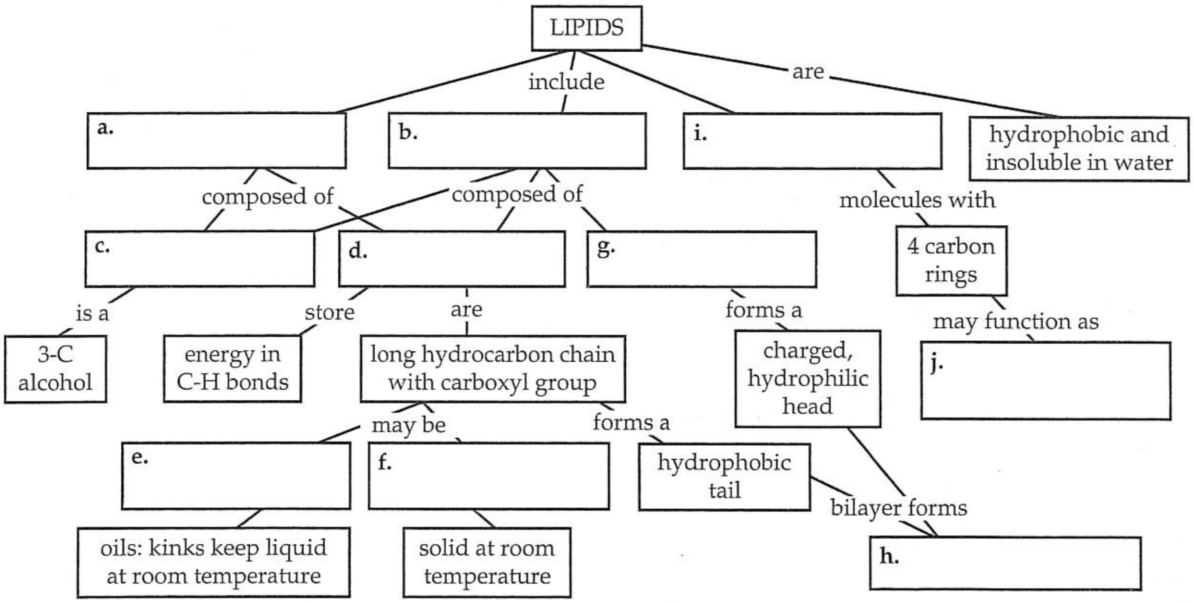
INTERACTIVE QUESTION 5.5

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

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.

INTERACTIVE QUESTION 5.6

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



5.4 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.

Polypeptides A **polypeptide** is a polymer of amino acids. A **protein** is a functional molecule that consists of one or more polypeptides, each folded into a specific three-dimensional shape.

Amino acids are composed of an asymmetric carbon (called the *alpha [α] carbon*) bonded to 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.

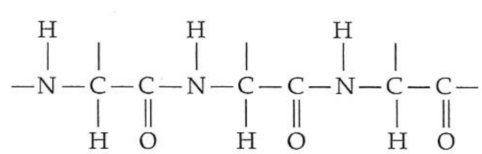
A **peptide bond** links the carboxyl group of one amino acid with the amino group of another.

INTERACTIVE QUESTION 5.7

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 molecule 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 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.

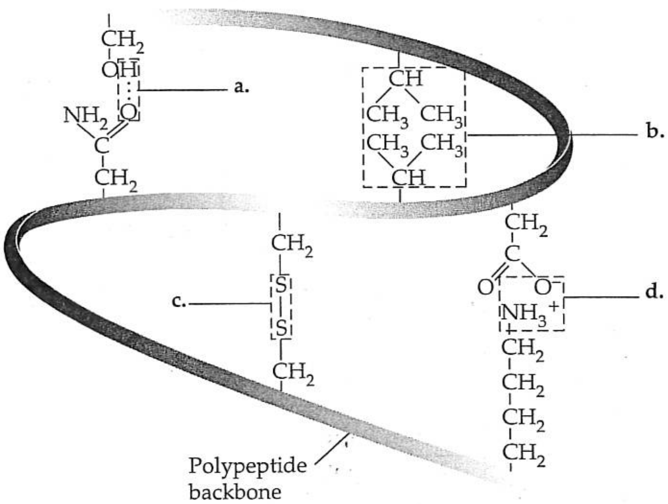
Secondary structure involves the coiling or folding of the polypeptide backbone, stabilized by hydrogen bonds between the oxygen (with a partial negative charge) of one peptide bond and the partially positive hydrogen attached to the nitrogen of another peptide bond. An **α helix** is a coil produced 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 overall 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 non-polar 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.

INTERACTIVE QUESTION 5.8

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 hydrophilic regions cluster on the inside while its hydrophobic regions are on the outside interacting with the nonpolar solvent.

The primary structure (sequence of amino acids) determines where the interactions and bonds that maintain a protein's shape can form. Within a cell, **chaperonins,** or chaperone proteins, assist newly made polypeptides during the folding process, perhaps by providing a sheltered environment.

Using the techniques of **X-ray crystallography,** nuclear magnetic resonance (NMR) spectroscopy, and bioinformatics, 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.

INTERACTIVE QUESTION 5.9

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.*

5.5 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 the polymers that carry and transmit this information.

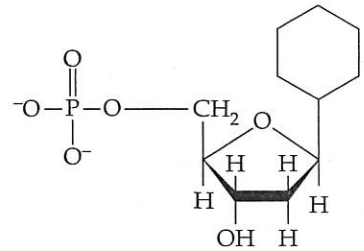
The Roles of Nucleic Acids **DNA, deoxyribonucleic acid,** is the genetic material that is inherited from one generation to the next and is replicated whenever a cell divides so that all cells of an organism contain identical DNA. The instructions coded in DNA are transcribed to **RNA, ribonucleic acid,** 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 a nitrogenous (nitrogen-containing) base. A nucleotide may contain more than one phosphate group; without the phosphate group it 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 sugar is **deoxyribose;** in RNA, it is **ribose.**

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.

INTERACTIVE QUESTION 5.10



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 this 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.** In 1953, Watson and Crick first proposed the double helix structure, with the nitrogenous bases pairing and hydrogen-bonding 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 replicate itself and precisely copy the genes of inheritance.

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 four 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.

INTERACTIVE QUESTION 5.11

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 5.26 and 5.27 in your textbook to help you visualize polynucleotides and the three-dimensional structures of DNA and RNA.

The Theme of Emergent Properties in the Chemistry of Life: A Review At each stage in the hierarchy from atoms through large biological molecules, we have seen that novel properties arise with increasing structural organization.

Word Roots

di- = two; **-sacchar** = sugar (*disaccharide:* two monosaccharides [simple sugars] 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)

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)

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

Structure Your Knowledge

1. Describe the four structural levels in the functional shape of a protein.
2. Identify the type of monomer or group shown by the formulas a–g. Then match the chemical formulas 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

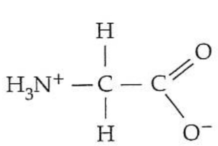
______ 4. molecules that are carbohydrates

______ 5. molecule that is a purine

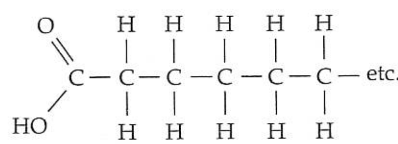
______ 6. monomer of a protein

______ 7. groups that would be joined by phosphodiester bonds

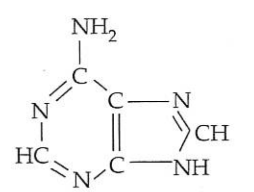
______ 8. most nonpolar (hydrophobic) molecule



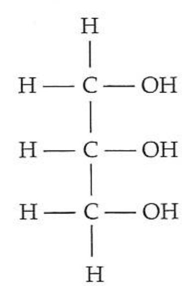
a. ______________



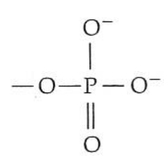
b. ______________



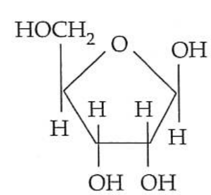
c. ______________



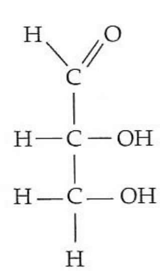
d. ______________



e. ______________



f. ______________



g. ______________

Test Your Knowledge

MATCHING: *Match the molecule with its class 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 (the formation of polymers) is a process that
   a. creates bonds between amino acids in the formation of a polypeptide.
   b. involves the removal of a water molecule.
   c. links the sugar of one nucleotide with the phosphate of the next.
   d. involves a dehydration reaction.
   e. may involve all of the above.

2. Which of the following statements 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. in their structural formulas.
   c. in the monomers involved.
   d. in the location of their glycosidic linkage.
   e. They can differ in all of these ways.

4. 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.

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

6. Sucrose is made from joining a glucose molecule and a fructose molecule 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. $C_{12}H_{24}O_{13}$

7. 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 that can hydrolyze the bonds of cellulose.
   d. its intestinal tract contains termites, which harbor microbes that hydrolyze cellulose.
   e. it can convert cellulose to starch and then hydrolyze starch to glucose.

8. 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

9. 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.

10. Three molecules of the fatty acid in question 9 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. $C_{51}H_{104}O_9$.

11. What are trans fats?
    a. hydrogenated fish 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

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

13. 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

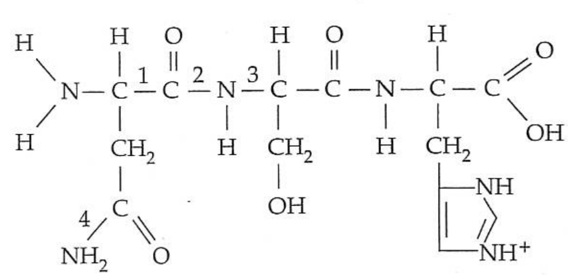
14. Which of the following is *not* one of the many functions performed by proteins?
   a. acting as signals and receptors
   b. acting as an enzymatic catalyst for metabolic reactions
   c. providing protection against disease
   d. serving as contractile components of muscle
   e. forming primary structural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

15. 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.

16. 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.

17. 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.

18. What is the best description of the following molecule?



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

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

20. 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

21. Both hydrophobic and hydrophilic interactions are important for which of the following types of molecules?
   a. proteins
   b. saturated fats
   c. glycogen and cellulose
   d. polynucleotides
   e. all of the above

22. 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

23. 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

24. 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.