AP Biology Summer Work

2020-2021

Congratulations on your decision to enroll in AP Biology. While the material can initially be trying, you shall gain a new perspective and a deepened understanding of life in and around you. By successfully completing this course, you should be capable of earning a 3 or higher on the AP Biology Exam in May, 2021. Passing the exam with a 3, 4, or 5 may allow you to get college credits while being in high school. This saves money and time in college. This class is time consuming and requires a lot of at home preparation. This class meets EVERY DAY! You need to commit to hard work from this assignment till the end of next school year.

Why summer work?

In order to best utilize the limited time available to cover a very extensive area of science, it is important that you retain and practice the skills and information accumulated in Honors Biology. In order to cover the breadth of content necessary to prepare for the AP Exam, there will be a summer assignment designed to reinforce and introduce concepts thought of as prerequisites for AP Biology (aka Chemistry).

What am I expected to know?

Coming into next year, it is expected that all AP Biology students review the major themes in biology (chapter 01). It is also expected that students have a firm background in the chemistry that regulates organisms (chapters 1-3).

What do I have to do?

This summer, you are to **watch 10 informational videos and take handwritten notes on each, read, create written chapter outlines (chapters 1-3), and complete study guides (Chapters 1-3).** All summer work will be handed in on the first day of school. In addition to your text, there is an electronic text book available online at masteringbiology.com/site/login.html

WEBSITE INSTRUCTIONS:

-go to the website listed in the paragraph above

-Sign in using the following information:

-User Name; hathawayma@watertownps.org

- password; WatertownIndians20 (type just as shown)

The screen will give you choices on viewing the ebook or "Explore the Study area".

When is this work due? Will I be tested on it?

The summer assignments are due the first day of class. You can expect a **test** on the material within the first week, (**probably the second day)** of class. **We will not be reviewing this material in class** so it is imperative that you master the material on your own. If the text is not enough, search online for more information. There are many videos on YouTube and other websites that help to visualize the concepts covered.

Enjoy your Summer Break! Although you may not want the summer to end, I hope you are looking forward to an exciting and challenging year of Advanced Placement Biology. I know I am. You can reach me throughout the summer via my email below.

Sincerely,

Ms. Hathaway

hathawayma@watertownps.org

Did I finish my summer work? Use this checklist to be sure all parts of summer work are done.

The first day of class, you will be expected to **submit the following**. There will be a comprehensive assessment within the first week of school (and we will not be going over this in class). Be sure you are studying. The video notes(1-10), chapter outlines and completed Study Guides for chapters 1-3 will be turned in on the first day of class.

Below is a checklist to ensure you have everything necessary for the first day of class:

Video viewing and notes:

1.___ 2.___ 3.___ 4.___ 5.___ 6.___ 7.___ 8.___ 9.____ 10.____

Chapter reading with reading notes:

Ch 1 ___ Ch2 ____ Ch 3____

Study Guide Packet Sections Completed:

Ch 1 ___ Ch 2 ___ Ch 3 ___

Watertown High School Science Department

AP Biology Summer Assignment

Assignment Requirements	-AP Biology video viewing and notes -Chapters 1-3 reading and reading notes -Chapters 1-3 Review Packets
Date due	-1st day of school
Estimated time for completion	10-20 hours
Resources needed to complete assignment	-AP Biology textbook -Chapters 1-3 review packets -Internet access for videos
How the assignment will be assessed	-The video notes will be scored using the rubric included. Reading notes and review packets will be graded on content and completion.
Purpose of the assignment	-Review of foundational material/concepts/skills. -Expose students to required material/concepts/skills/texts that cannot be covered during the academic year. -Have students read material that will be discussed or used in class at the beginning of the year.

Assignment #1 – Video Notes – due 1st day of AP Biology

Watch the videos listed below and take ***hand-written*** notes on each of them. The note should be your ***original work.*** EACH note sheet will be scored 0 to 5 based on completeness and thoroughness as shown in the rubric below. Note pages **will not** be accepted late nor will they be accepted typed.

#	Video Content	Links
1	The Natural of Science	https://youtu.be/77TFiYWPxoQ
2	The Scientific Method	https://youtu.be/SMGRe824kak
3	CER (Claim- Evidence-Reasoning)	https://youtu.be/5KKsLuRPsvU
4	AP Biology Science Practice 1 Model and Representations	https://youtu.be/v5Nemz_cVew
5	AP Biology Science Practice 2 Using Mathematics Appropriately	https://youtu.be/jgqYlSKoXak
6	AP Biology Science Practice 3 Formulate Questions	https://youtu.be/2zB272Ak63A
7	AP Biology Science Practice 4 Data Collection Strategies	https://youtu.be/AzTXnne40wU
8	AP Biology Science Practice 5 Analyze Data and Evaluate Evidence	https://youtu.be/0JqukouOtZA
9	AP Biology Science Practice 6 Scientific Explanations and Theories	https://youtu.be/3gK1xWNM7kk
10	AP Biology Science Practice 7 Connecting Knowledge	https://youtu.be/7l4bcs49JP8

0 **No Credit**	**2** **Below expectations**	**3-4** **Complete**	**5** **Exceeds expectations**
No notes OR copied from a peer.	Several criteria are missing from entry	All criteria are met, but there's room for improvement within criteria OR one criterion is missing from entry.	All criteria listed below are met or have been exceeded for each entry.

What does work that "exceeds expectations" have?

- ✓ Each video's notes are on a different page.
- ✓ The video's title is written as it appears in the video on the top line of the paper.
- ✓ The notes are legibly written.
- ✓ Highlighting or colors are used to emphasize key points, new vocabulary, and/or important concepts.
- ✓ Examples are documented in some way when given in the video.
- ✓ Pictures, charts, or graphs are used to display details provided in the video.
- ✓ A summary of the video content is provided at the end of the notes. Please emphasize the summary in some way (title it, star it, highlight it, etc.)

Notes are to be *original work* and are not to be copied from a peer – these serve as a log of what you have learned from the video. Copying them from a peer and not watching the video does you no good. You will receive zero credit if you are found submitting work that is too closely aligned with a classmate's work.

Chapter 1

Introduction: Evolution and the Foundations of Biology

Chapter Focus

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.

1.1 Studying the diverse forms of life reveals common themes

Theme: New properties emerge at successive levels of biological organization The scale of biology extends from the biosphere to molecules.

FOCUS 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 today combines the powerful and pragmatic strategy of *reductionism*, which breaks down complex systems into simpler components, with **systems biology,** which studies the interactions of the parts of a biological system and models the system's dynamic behavior.

The form of a biological structure is usually well matched to its function. Form fits function at all of life's structural levels.

The cell is an organism's basic unit of structure and function—the lowest structural level capable of performing all the activities of life. The simpler and smaller **prokaryotic cell,** unique to bacteria and archaea, lacks both a nucleus to enclose its DNA and other membrane-enclosed organelles. The **eukaryotic cell**—with a nucleus containing DNA, and numerous organelles—is typical of all other living organisms.

Theme: Life's Processes Involve the Expression and Transmission of Genetic Information The genetic 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 transcribed to RNA and then translated into a protein. Genes also code for RNAs that serve other functions, such as regulating gene expression. All forms of life use essentially the same genetic code of nucleotides.

FOCUS QUESTION 1.2

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.

The sequences of nucleotides in the human genome and the genomes of many other organisms have been determined. Using a systems approach called **genomics,** scientists study whole sets of genes in one or more species.

Three research developments contribute to genomics: "high-throughput" technology that can analyze biological materials rapidly; **bioinformatics,** which provides the computational tools to process and analyze the resulting data; and interdisciplinary research teams with specialists from many diverse scientific fields.

Theme: Life Requires Transfer and Transformation of Energy and Matter Life requires energy. Producers transform light energy to the chemical energy in sugars, 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 lost to the surroundings as heat.

FOCUS QUESTION 1.3

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

Theme: Organisms Interact with Other Organisms and the Physical Environment Both organisms and the environment are affected by interactions between them. Interactions between organisms may be mutually beneficial or may harm one or both participants.

Evolution, the Core Theme of Biology Evolution explains how diverse organisms of the past and the present are related through descent from common ancestors, and how organisms become adapted to their environment.

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

Classifying the Diversity of Life: The Three Domains of Life Of an estimated total of 10–100 million species, only about 1.8 million species have been identified and named. Biologists have grouped species into ever broader categories, from genera to family, order, class, phylum, and kingdom.

The number of kingdoms is an ongoing debate, but all of life is now grouped into three domains. The prokaryotes are divided into domains **Bacteria** and **Archaea.** All eukaryotes are placed in domain **Eukarya.** The mostly unicellular protists are being reorganized to better reflect evolutionary relationships.

Within this diversity of life, organisms share many similarities, including a universal genetic language of DNA.

FOCUS QUESTION 1.4

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

Charles Darwin and the Theory of Natural Selection In *On 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 **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 to the 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 the 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 those structures from a common ancestor. The diversity of species results from natural selection acting over millions of generations as populations adapted to 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.

FOCUS QUESTION 1.5

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 Biological inquiry entails forming and testing hypotheses based on observations of nature

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,** generalizations 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.

In science, the ideal is to frame two or more alternative hypotheses and design experiments to test each candidate explanation. A hypothesis cannot be *proven* true; 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.

A Case Study in Scientific Inquiry: Investigating Coat Coloration in Mouse Populations Beach and mainland mice are found in two distinct habitats in Florida and differ in coloration, although they are members of the same species. H. Hoekstra and her students tested the hypothesis that coloration patterns evolved as adaptations that protect mice from predation. To test the prediction that mice with coloration that did not match their habitat would be preyed on more than mice that were camouflaged by their coloration, they set out models of beach and mainland mice in both habitats. After recording signs of predation, they calculated the proportion of attacked mice in each habitat. In both cases, the mice whose coloration did not match their habitat had a higher predation rate. Thus, their experiment supports the camouflage hypothesis.

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.

FOCUS QUESTION 1.6

a. Identify the control and experimental groups in the mouse camouflage experiment.

b. Why were the results of this study presented as the proportion of attacks on camouflaged and non-camouflaged mice in each area rather than as the total number of attacks on non-camouflaged mice?

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.

Science as a Social Process: Community and Diversity 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. Science is 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** for specific purposes, and technological advances are used to extend scientific knowledge.

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.

FOCUS QUESTION 1.7

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)

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

pro- = before (*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 five unifying themes of biology presented in this chapter:
   a. emergent properties and levels of biological organization
   b. expression and transmission of genetic information
   c. the transfer and transformation of energy and matter
   d. interaction with other organisms and the physical environment
   e. 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. Suppose that, in an experiment similar to the mice study described in this chapter, a researcher found that more total predator attacks occurred on model beach mice placed in a beach habitat than in a mainland habitat. From this the researcher concluded that
   a. the camouflage hypothesis is false.
   b. the predators in the beach habitat were hungrier than the predators in the mainland habitat.
   c. model beach mice do not resemble living beach mice 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 mainland mice in both habitats.
   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. 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.

5. 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

6. 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.

7. 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. Organisms interact with other organisms and the physical environment.
   c. Life's processes involve the expression and transmission of genetic information.
   d. Life requires energy transfer and transformation.
   e. New properties emerge at successive levels of biological organization.

UNIT 1

Chemistry and Cells

Chapter 2

The Chemical Context of Life

Chapter Focus

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. The chapter also focuses on the properties of water, which emerge from the polarity and hydrogen bonding capacity of this small, essential molecule.

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. **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* arising in higher levels of organization.

The Elements of Life Your body is composed of 25 different elements. The elements needed for an organism to live and reproduce are called **essential elements** (the list varies somewhat for different organisms). Carbon (C), oxygen (O), hydrogen (H), and nitrogen (N) make up 96% of living matter. Some elements, like iron (Fe) and iodine (I), may be required in very minute quantities and are called **trace elements**.

FOCUS QUESTION 2.1

Fill in the names beside the symbols of the following elements that, along with a few others, make up about 4% of an organism's mass.

Ca _____ K _____

P _____ S _____

Evolution of Tolerance to Toxic Elements Some plants exhibit evolutionary adaptations that allow them to grow in soils containing toxic elements.

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

Each element has its own type of **atom**, the smallest unit of matter retaining the properties of that element.

Subatomic Particles Three *subatomic particles* are important to your 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 So what makes the atoms of different elements different? 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.

FOCUS 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. 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—to do work. **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**, each with a characteristic energy level and distance from the nucleus.

FOCUS 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 What determines the chemical behavior of an atom? It 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. (Remember that the first shell 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 in the outer shell.

FOCUS QUESTION 2.4

Draw an electron distribution diagram for the following atoms. *(Note that electrons do not pair up in the second and third shells until after four electrons are present.)*

a. $_1H$

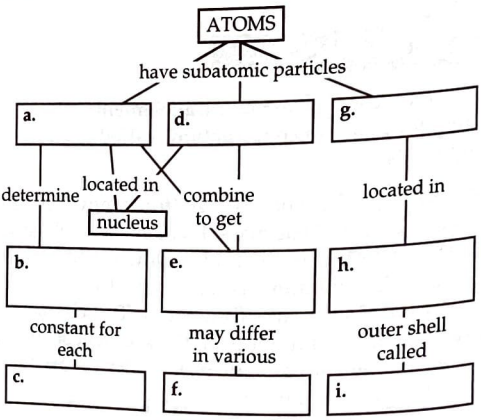
b. $_6C$

c. $_8O$

d. $_{11}Na$

FOCUS QUESTION 2.5

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. An electron distribution diagram shows the shared electrons in a molecule. In a *structural formula*, such as H—H, the line 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 electrons required to complete its valence shell.

FOCUS QUESTION 2.6

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

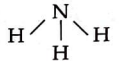
Electronegativity is the attraction of a particular atom for shared electrons. If the atoms in a molecule have similar electronegativities, the electrons remain equally shared, and the bond is said to be a **nonpolar covalent bond**. If one element is more electronegative, it pulls the shared electrons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

FOCUS QUESTION 2.7

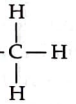
Explain whether the following molecules contain nonpolar or polar covalent bonds. (*Hint:* N and O both have high electronegativities. C and H have lower, and similar, electronegativities.)

a. nitrogen molecule $N \equiv N$

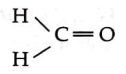
b. ammonia



c. methane



d. formaldehyde



Ionic Bonds What happens when two atoms are very unequal 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, or **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.

Covalent molecules that are electrically charged are also referred to as *ions*.

FOCUS QUESTION 2.8

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.

Molecular Shape and Function A molecule's characteristic size and shape affect how it interacts with other molecules. A carbon atom bonded to four other atoms has a tetrahedral shape.

FOCUS QUESTION 2.9

Draw the electron distribution diagram of a water molecule, showing its V shape and 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.

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 atoms causes the properties of these molecules to be different.

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.

FOCUS QUESTION 2.10

Fill in the missing coefficients for respiration, the conversion of glucose and oxygen to carbon dioxide and water, with the release of energy. Make sure that all atoms are conserved in the chemical reaction.

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

2.5 Hydrogen bonding gives water properties that help make life possible on Earth

The V-shaped water molecule is a **polar molecule** with a slight positive charge on each hydrogen atom (δ+) and a slight negative charge (δ–) associated with the oxygen. Hydrogen bonds between water molecules create a structural organization that leads to the emergent properties of water.

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, making the surface unusually difficult to break.

Moderation of Temperature by Water **Thermal energy** is a measure of the **kinetic energy** associated with the random movement of atoms and molecules. **Temperature** measures the *average* kinetic energy of the molecules in a body of matter; thermal energy reflects the *total* kinetic energy in that matter, which relates to the volume of the body of matter. The thermal energy that transfers from a warmer to a cooler body of matter is defined as **heat**.

A **calorie (cal)** is the amount of heat 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 equals 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; 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 with sufficient kinetic energy overcome their attraction to other molecules in a liquid and escape into the air as a 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's high heat of vaporization is again related to the large amount of heat 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.

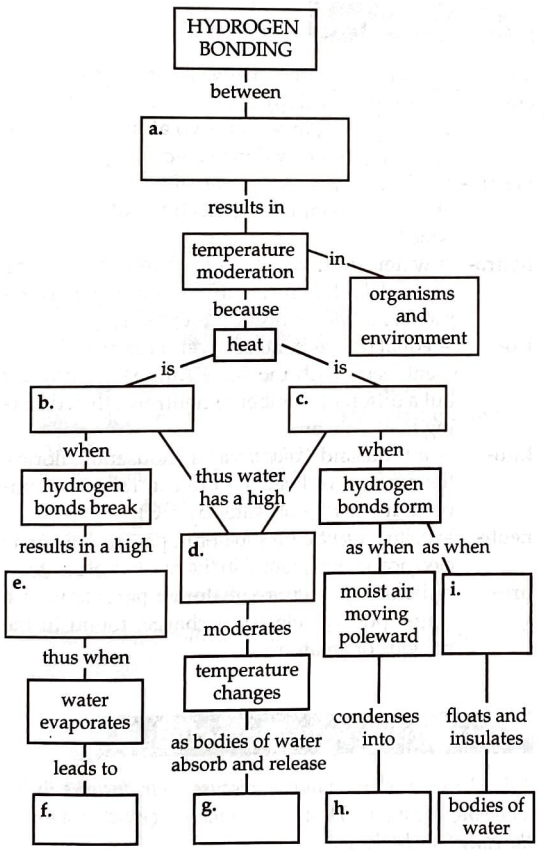
As a liquid vaporizes, the surface left behind loses the kinetic energy of the escaping molecules and cools down. **Evaporative cooling** helps to protect terrestrial organisms from overheating and contributes to the stability of temperatures in lakes and ponds.

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.

FOCUS QUESTION 2.11

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.



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

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). 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.

FOCUS QUESTION 2.12

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**?

Acids and Bases 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*.

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^+.

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 $[H^+]$: $pH = -\log [H^+]$. For a neutral aqueous solution, $[H^+]$ is 10^{-7} *M*, and the pH = 7. As the $[H^+]$ increases in an acidic solution, the pH value decreases. (This inverse relationship makes sense because the exponent becomes smaller: 10^{-4} indicates a higher $[H^+]$ than 10^{-7}.) The difference between each

unit of the pH scale represents a tenfold difference in the concentration of $[H^+]$ and $[OH^-]$.

FOCUS QUESTION 2.13

Complete the following table to review your understanding of pH.

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

Buffers within a cell maintain a stable pH (usually close to 7) 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.

FOCUS QUESTION 2.14

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?

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.

FOCUS QUESTION 2.15

a. Add to the formula in Focus Question 2.14 to show why increasing $[CO_2]$ dissolving in water leads to a lower pH.

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

$$HCO_3^- \rightleftharpoons CO_3^{2-} + H^+$$

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

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

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

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

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

iso- = equal (*isotope:* one of several forms of an element, each with the same number of protons but a different number of neutrons, thus differing in atomic mass)

kilo- = a thousand (*kilocalorie:* a thousand calories; the amount of heat required to raise the temperature of 1 kg of water by 1°C)

neutr- = neither (*neutron:* a subatomic particle having no electrical charge, found in the nucleus of an atom)

pro- = before (*proton:* a subatomic particle with a single positive electrical charge, found in the nucleus of an atom)

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. Fill in the following table, which summarizes the emergent properties of water that contribute to the fitness of the environment for life.

Property	Explanation of Property	Example of Benefit to Life
a.	Hydrogen bonds hold water molecules together and adhere them to a 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.

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 c. 12 e. 33
   b. 11 d. 23
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 c. 12 e. 18
   b. 8 d. 16
6. An atom of argon has three electron shells, all of which are full. Its atomic mass is 40. How many neutrons does it have?
   a. 8 c. 20 e. 24
   b. 16 d. 22
7. 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.

Use this information to answer questions 8 through 13.

The six elements most common in living organisms are

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

8. How many electrons does phosphorus have in its valence shell?

a. 3 **b.** 5 **c.** 7 **d.** 15 **e.** 16

9. What is the atomic mass of phosphorus?

a. 15 **b.** 16 **c.** 31 **d.** 46 **e.** 62

10. 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

11. How many covalent bonds is a sulfur atom most likely to form?

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

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

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

13. How many of the elements listed above 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

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.

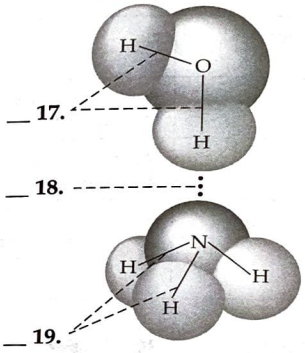
15. A triple covalent bond would

a. not be possible.
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 through 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

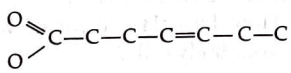
22. What is the molecular shape of methane (CH_4)?
    a. planar or flat, with the four H extending out from the carbon
    b. pentagonal, or a flat five-sided arrangement
    c. tetrahedral, with carbon in the center and H at each corner
    d. circular, with the four H attached in a ring around the 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 or compounds 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

31. 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.

32. What contributes to 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

33. 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.

34. 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.

35. 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.

36. 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.

37. 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.

38. 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.

39. 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

40. How many molecules of glucose would be in 1 liter of the 0.1 *M* solution made in question 39?
    a. 0.1
    b. 6
    c. 60
    d. 6×10^{23}
    e. 6×10^{22}

41. 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**.

42. 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.

43. 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.

44. In the past century, the average temperature of the oceans has increased by 0.74°C. Would you consider 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 thermal energy 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 of reef-building organisms is directly related to this temperature increase.

Chapter 3

Carbon and the Molecular Diversity of Life

Chapter Focus

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

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

Chapter Review

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

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

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

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

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

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

A **carbonyl group** consists of a carbon double-bonded to an oxygen ($>$CO). If the carbonyl group is at the end of the carbon skeleton, the compound is

called an aldehyde. Otherwise, the compound is called a ketone.

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

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

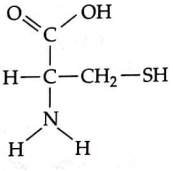
The **sulfhydryl group** consists of a sulfur atom bonded to a hydrogen (—SH). Thiols are compounds containing sulfhydryl groups.

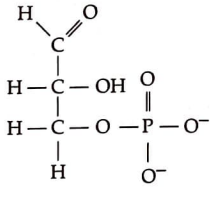
A **phosphate group** is bonded to a carbon skeleton by an oxygen attached to a phosphorus atom that is bonded to three other oxygen atoms ($—OPO_3^{2-}$). This anion contributes a negative charge to organic phosphates.

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

FOCUS QUESTION 3.1

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





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

3.2 Macromolecules are polymers, built from monomers

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

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

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

FOCUS QUESTION 3.2

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

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

3.3 Carbohydrates serve as fuel and building material

Carbohydrates include sugars and their polymers.

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

FOCUS QUESTION 3.3

Fill in the blanks to review monosaccharides.

You can recognize a monosaccharide by its multiple (a) _____ groups and its one (b) _____ group, whose location determines whether the sugar is an (c) _____ or a (d) _____. In aqueous solutions, most five- and six-carbon sugars form (e) _____. The names for most sugars end in (f) _____.

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

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

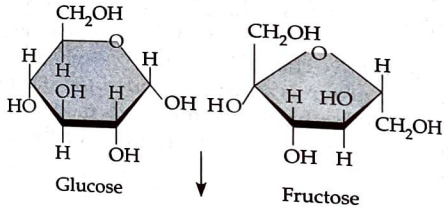
Cellulose, the major component of plant cell walls, is the most abundant organic compound on Earth. It differs from starch and glycogen by the configuration of the ring form of glucose (beta instead of alpha) and the resulting geometry of the glycosidic bonds. In a plant cell wall, hydrogen bonds between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

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

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

FOCUS QUESTION 3.4

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

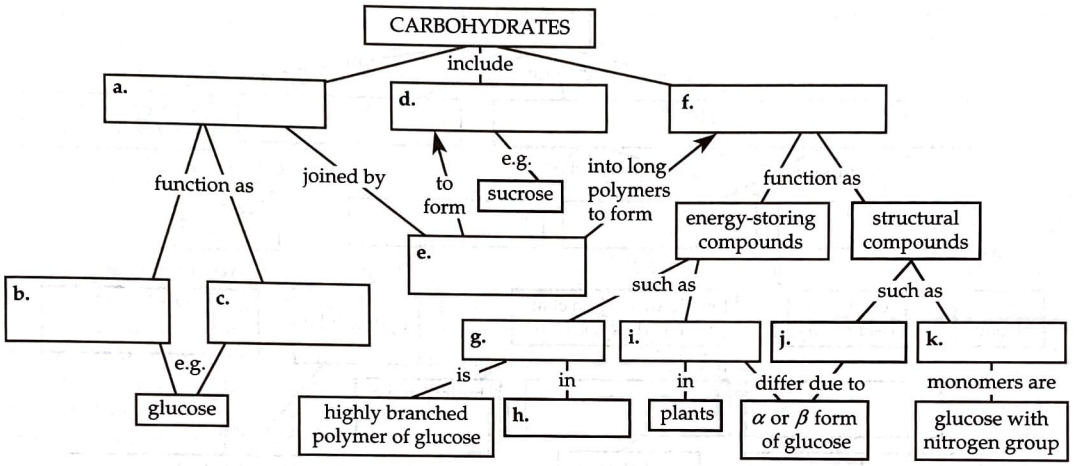


Glucose Fructose

Sucrose

FOCUS QUESTION 3.5

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



3.4 Lipids are a diverse group of hydrophobic molecules

Fats, phospholipids, and steroids are part of a diverse assemblage of biological molecules that are grouped together as **lipids** based on their hydrophobic behavior. Lipids do not form polymers.

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

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

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

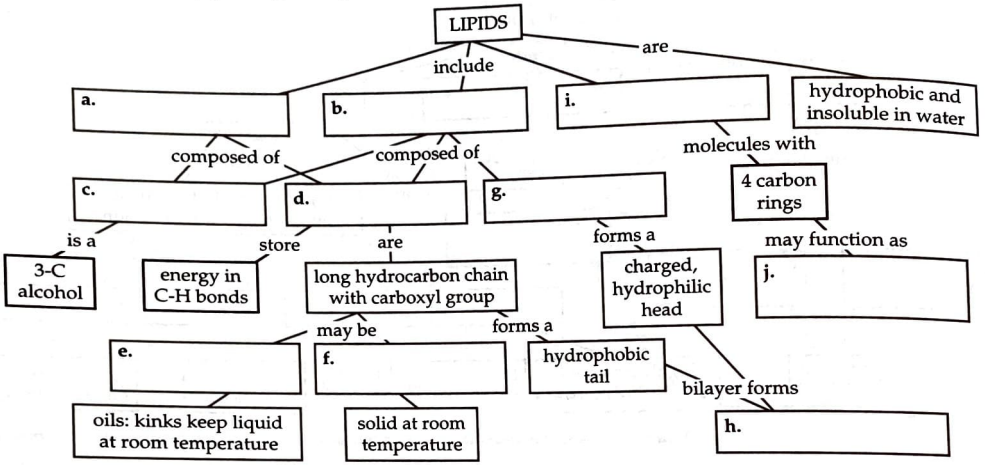
Fats are excellent energy storage molecules, containing twice the energy of carbohydrates such as starch.

Phospholipids **Phospholipids** consist of a glycerol linked to two fatty acids and a negatively charged phosphate group, to which other small molecules are attached. The phosphate head of this molecule is hydrophilic and water soluble, whereas the two fatty acid chains are hydrophobic. The unique structure of phospholipids makes them ideal constituents of cell membranes. The hydrophilic heads face the aqueous environment on either side of a membrane; the hydrophobic tails associate in the center of the phospholipid bilayer, shielded from water.

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

FOCUS QUESTION 3.6

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



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

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

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

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

FOCUS QUESTION 3.7

a. Draw the amino acids alanine (R group: $—CH_3$) and serine (R group: $—CH_2OH$) and then show how a dehydration reaction will form a peptide bond between them.

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

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