CHAPTER 1

Biology: Exploring Life

Chapter Objectives

Opening Essay

Explain why Madagascar has so many species of lemurs.

Themes in the Study of Biology

1.1 Describe seven properties common to all life.
1.2 Describe the levels of biological organization from molecules to the biosphere, noting the interrelationships between levels.
1.2 Define the concept of emergent properties and describe an example of it.
1.3 Explain why cells are a special level in biological organization. Compare prokaryotic and eukaryotic cells.
1.4 Compare the dynamics of nutrients and energy in an ecosystem.

Evolution, the Core Theme of Biology

1.5 Explain how DNA encodes a cell's information.
1.6 Compare the three domains of life. Distinguish between the three multicellular kingdoms within Eukarya.
1.7 Describe the process and products of natural selection. Explain why individuals cannot evolve.

The Process of Science

1.8 Distinguish between quantitative and qualitative data. Compare the definitions and use of inductive and deductive reasoning in scientific investigations.
1.8 Distinguish between a scientific theory and a hypothesis.
1.8 Distinguish between the scientific definition and common use of the word *theory*.
1.9 Describe the structure of a controlled experiment and give an example.

Biology and Everyday Life

1.10 Compare the goals of science and technology. Explain why an understanding of science is essential to our lives.
1.11 Explain how evolution impacts the lives of all humans.

Lecture Outline

I. Introduction

A. Lemurs are primates that

1. are known for their distinctive tails, dark eye patches, and muzzles,

2. live in Madagascar, and

3. have ancestors who floated to Madagascar about 60 million years ago and diversified in a world

a. relatively free of predators and competitors and

b. with many different habitats.

II. Themes in the Study of Biology

A. 1.1 All forms of life share common properties

1. Biology is the scientific study of life.

2. Properties of life include

a. Order—the highly ordered structure that typifies life,

b. Reproduction—the ability of organisms to reproduce their own kind,

c. Growth and development—consistent growth and development controlled by inherited DNA,

d. Energy processing—the use of chemical energy to power an organism's activities and chemical reactions,

e. Response to the environment—an ability to respond to environmental stimuli,

f. Regulation—an ability to control an organism's internal environment within limits that sustain life, and

g. Evolutionary adaptation—adaptations evolve over many generations as individuals with traits best suited to their environments have greater reproductive success and pass their traits to offspring.

B. 1.2 In life's hierarchy of organization, new properties emerge at each level

1. Biological organization unfolds as follows:

a. Biosphere—all of the environments on Earth that support life,

b. Ecosystem—all the organisms living in a particular area and the physical components with which the organisms interact,

c. Community—the entire array of organisms living in a particular ecosystem,

d. Population—all the individuals of a species living in a specific area,

e. Organism—an individual living thing,

f. Organ system—several organs that cooperate in a specific function,

g. Organ—a structure that is composed of tissues and that provides a specific function for the organism,

h. Tissues—a group of similar cells that perform a specific function,

i. Cells—the fundamental unit of life,

j. Organelle—a membrane-bound structure that performs a specific function in a cell, and

k. Molecule—a cluster of small chemical units called atoms held together by chemical bonds.

2. Emergent properties are

a. new properties that arise in each step upward in the hierarchy of life,

b. from the arrangement and interactions among component parts.

C. 1.3 Cells are the structural and functional units of life

1. Cells are the level at which the properties of life emerge.

2. A cell can

a. regulate its internal environment,

b. take in and use energy,

c. respond to its environment,

d. develop and maintain its complex organization, and

e. give rise to new cells.

3. All cells

a. are enclosed by a membrane that regulates the passage of materials between the cell and its surroundings and

b. use DNA as their genetic information.

4. There are two basic types of cells.

a. Prokaryotic cells

i. were the first to evolve,

ii. are simpler, and

iii. are usually smaller than eukaryotic cells.

b. Eukaryotic cells

i. contain membrane-enclosed organelles, including a nucleus containing DNA, and

ii. are found in plants, animals, and fungi.

5. Systems biology models the complex interactions of biological systems, ranging

a. from the functioning of the biosphere

b. to the complex molecular machinery of a cell.

6. Cells illustrate another theme in biology: the correlation of structure and function.

7. Structure is related to function at all levels of biological organization.

D. 1.4 Living organisms interact with their environment, exchanging matter and energy

1. Living organisms interact with their environments, which include

a. other organisms and

b. physical factors.

2. In most ecosystems

a. plants are the *producers* that provide the food,

b. *consumers* eat plants and other animals, and

c. *decomposers* act as recyclers, changing complex matter into simpler mineral nutrients.

3. The dynamics of ecosystems include two major processes:

a. The recycling of chemical nutrients from the atmosphere and soil through producers, consumers, and decomposers back to the environment.

b. The one-way flow of energy through an ecosystem, entering as sunlight, converted to chemical energy by producers, passed on to consumers, and exiting as heat.

III. Evolution, the Core Theme of Biology

A. 1.5 The unity of life is based on DNA and a common genetic code

1. All cells have DNA, the chemical substance of genes.

2. Genes

a. are the unit of inheritance that transmits information from parents to offspring,

b. are grouped into very long DNA molecules called chromosomes, and
c. control the activities of a cell.

3. A species' genes are coded in the sequences of the four building blocks making up DNA's double helix.
a. All forms of life use essentially the same code to translate the information stored in DNA into proteins.
b. The diversity of life arises from differences in DNA sequences.

B. 1.6 The diversity of life can be arranged into three domains

1. We can think of biology's enormous scope as having two dimensions.
a. The "vertical" dimension is the size scale that stretches from molecules to the biosphere.
b. The "horizontal" dimension spans across the great diversity of organisms existing now and over the long history of life on Earth.

2. Diversity is the hallmark of life.
a. Biologists have identified about 1.8 million species.
b. Estimates of the actual number of species ranges from 10–100 million.

3. Taxonomy names species and classifies them into a system of broader groups.

4. The diversity of life can be arranged into three **domains**.
a. Bacteria are the most diverse and widespread prokaryotes.
b. Archaea are prokaryotes that often live in Earth's extreme environments.
c. Eukarya have eukaryotic cells and include
i. single-celled protists and
ii. multicellular fungi, animals, and plants.

C. 1.7 Evolution explains the unity and diversity of life

1. The history of life, as documented by fossils, is a saga of a changing Earth
a. billions of years old and
b. inhabited by an evolving cast of life forms.

2. Evolution accounts for life's dual nature of
a. kinship and
b. diversity.

3. In 1859, Charles Darwin published the book *On the Origin of Species by Means of Natural Selection*, which articulated two main points.
a. A large amount of evidence supports the idea of evolution, that species living today are descendants of ancestral species in what Darwin called "descent with modification."
b. Natural selection is a mechanism for evolution.

4. Natural selection was inferred by connecting two observations.
a. Individuals in a population vary in their traits, many of which are passed on from parents to offspring.
b. A population can produce far more offspring than the environment can support.

5. From these observations, Darwin inferred that
a. those individuals with heritable traits best suited to the environment are more likely to survive and reproduce than less well-suited individuals,
b. as a result of this unequal reproductive success over many generations, an increasing proportion of individuals will have the advantageous traits, and

c. the result will be evolutionary adaptation, the accumulation of favorable traits in a population over time.

IV. The Process of Science

A. 1.8 Scientific inquiry is used to ask and answer questions about nature

1. The word *science* is derived from a Latin verb meaning "to know." Science is a way of knowing.

2. Scientists

a. use **inductive reasoning** to draw general conclusions from many observations and

b. deductive reasoning to come up with ways to test a **hypothesis**, a proposed explanation for a set of observations. The logic flows from general premises to the specific results we should expect if the premises are true.

3. How is a theory different from a hypothesis? A scientific **theory** is

a. much broader in scope than a hypothesis,

b. usually general enough to generate many new, specific hypotheses, which can then be tested, and

c. supported by a large and usually growing body of evidence.

B. 1.9 Scientists form and test hypotheses and share their results

1. We solve everyday problems by using hypotheses.

a. A common example would be the reasoning we use to answer the question, "Why doesn't a flashlight work?"

b. Using deductive reasoning we realize that the problem is either (1) the bulb or (2) the batteries.

c. Further, a hypothesis must be

i. testable and

ii. falsifiable.

d. In this example, two hypotheses are tested.

2. An actual research project demonstrates the process of science.

3. Scientists began with a set of observations and generalizations that

a. poisonous animals are brightly colored and

b. imposters resemble poisonous species but are actually harmless.

4. They then tested the hypothesis that mimics benefit because predators confuse them with the harmful species.

5. The scientists conducted a **controlled experiment**, comparing

a. an experimental group consisting of artificial king snakes and

b. a control group consisting of artificial brown snakes.

c. The groups differed only by one factor, the coloration of the artificial snakes.

d. The data fit the key prediction of the mimicry hypothesis.

6. Science is a social activity with most scientists working in teams.

7. Scientists share information in many ways.

8. Science seeks natural causes for natural phenomena.

a. The scope of science is limited to the study of structures and processes that we can directly observe and measure.

b. Hypotheses about supernatural forces or explanations are outside the bounds of science because they generate hypotheses that cannot be tested by science.

V. Biology and Everyday Life

A. 1.10 CONNECTION: Biology, technology, and society are connected in important ways

1. Many issues facing society are related to biology. Most involve our expanding technology.

2. The basic goals of science and technology differ.

a. The goal of science is to understand natural phenomena.

b. The goal of **technology** is to apply scientific knowledge for some specific purpose.

3. Although their goals differ, science and technology are interdependent.

a. Technological advances stem from scientific research.

b. Research benefits from new technologies.

B. 1.11 EVOLUTION CONNECTION: Evolution is connected to our everyday lives

1. Evolution is a core theme of biology.

2. Evolutionary theory is useful in

a. medicine,

b. agriculture,

c. forensics, and

d. conservation.

3. Human-caused environmental changes are powerful selective forces that affect the evolution of many species, including

a. antibiotic-resistant bacteria,

b. pesticide-resistant pests,

c. endangered species, and

d. increasing rates of extinction.

AP Biology 005 – Essential Characteristics of Life
Video Review Sheet

www.bozemanscience.com/005-essential-characteristics-of-life

1. What does all life have?... and what does that mean?

2. What does it mean to be "conserved"?

3. Make and fill in the diagram/tree that he makes with "Life" at the top.

4. What is the genetic code? Where is it found?

5. What does it mean that DNA is "interchangeable"/universal?

6. Diagram (in the box) the "Central Dogma": (starts with DNA)

7. Concerning metabolism:
   a. What is the "energy coinage" that all life uses:

   b. What does it "mean" that all life uses the same/similar metabolic pathways?

8. Considering the evolution of eukaryotic cells:
   a. How could the endomembrane system been formed?

   b. What is the evidence for the process of endosymbiosis forming the mitochondria and chloroplast of the eukaryotic cell?

Name: _____ Hour: _____

The Scientific Method

Scientists use an experiment to search for cause and effect relationships in nature. In other words they design an experiment so that changes to one item cause something else to vary in a predictable way. These changing quantities are called variables. A **variable** is any factor, trait, or condition that can exist in differing amounts or types. An experiment usually has three kinds of variables: independent, dependent, and controlled.

The **independent variable** is a factor that is changed or manipulated by the scientist. To insure a fair test, a good experiment has only one independent variable. As the scientist changes the independent variable, he or she observes what happens. The scientist focuses his or her observations on the dependent variable to see how it responds to the change made to the independent variable. The **dependent variable** is measured to determine if the manipulation of the independent variable had any effect. The dependent variable "depends" on the independent variable. Experiments also have controlled variables. **A control group** or a **control** is quantities that a scientist wants to remain constant or unchanged. Most experiments have more than one controlled variable. Lastly, in a good experiment, the scientist must be able to **measure** the values for each variable. Weight or mass is an example of a variable that is very easy to measure.

Example: To test a hypothesis that eating carrots improves vision, the experimenter would manipulate whether or not subjects ate carrots. Thus, eating carrots is the independent variable. Each subject's vision would be tested to see if carrot eating had any effect. Thus, vision is the dependent variable. The subjects assigned to eat carrots are in the experimental group, whereas subjects not eating carrots are in the control group.

Identify the independent variable, dependent variable, experimental and control groups in the following studies.

1. The company Office Max thinks that a special juice will increase the productivity of its workers. The company creates two groups of 50 workers each and assigns each group the same task (in this case, they're supposed to staple a set of papers). Group A is given the special juice to drink while they work. Group B is not given the special juice. After an hour, the company counts how many stacks of papers each group has made. Group A made 3,587 stacks, Group B made 1,113 stacks.

Independent variable:

Dependent variable:

Experimental group:

Control group:

What should the company's conclusion be?

Name: _____ Hour: _____

2. A group of college students were given a short course in speed-reading. The instructor was curious if a monetary incentive would influence performance on a reading test taken at the end of the course. Seventy students were offered $15 for obtaining a certain level of performance on the test, and another seventy students were not offered any money. The students that were offered $15 scored an average of 75% on the test. The students that were not offered any money scored an average of 86%.

Independent variable:

Dependent variable:

Experimental group:

Control group:

What should the instructor's conclusion about monetary incentive be?

3. Tom notices that his shower is covered in a strange green slime. His friend Barney tells him that coconut juice will get rid of the green slime. Tom decides to check this out by spraying half of the shower with coconut juice. He does not spray the other half of the shower with anything. After 3 days of the "coconut juice treatment" there is no change in the appearance of the green slime on either side of the shower.

Independent variable:

Dependent variable:

Experimental group:

Control group:

What should Tom's conclusion be?

Name: _____ Hour: _____

Practice: Write a hypothesis for each of the questions and identify the variables, control group, and experimental group.

1. Does cigarette smoking increase the risk of lung cancer?

Hypothesis: If_____, then _____

Independent Variable:

Dependent Variable:

Control Group:

Experimental Group:

2. Does eating breakfast increase performance in school?

Hypothesis: If_____, then _____

Independent Variable:

Dependent Variable:

Control Group:

Experimental Group:

3. Do students who study perform better in school?

Hypothesis: If_____, then _____

Independent Variable:

Dependent Variable:

Control Group:

Experimental Group:

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1.1 Multiple-Choice Questions

1) Which of the following statements about the properties of life is *false*?
A) All organisms have the ability to take in energy and use it.
B) All organisms have the ability to respond to stimuli from the environment.
C) All organisms have the ability to reproduce.
D) All organisms have the ability to maintain a constant internal temperature.

2) Life is organized in a hierarchical fashion. Which of the following sequences correctly lists that hierarchy from least inclusive to most inclusive?
A) ecosystem, population, organ system, cell, community, molecule, organ, organism, organelle, tissue
B) cell, molecule, organ system, organ, organelle, population, tissue, organism, ecosystem, community
C) organism, organ system, tissue, population, organ, organelle, community, cell, ecosystem, molecule
D) molecule, organelle, cell, tissue, organ, organ system, organism, population, community, ecosystem

3) What is the difference between a tissue and an organ system?
A) The tissue level of organization is more inclusive than the organ system level.
B) Tissues are not composed of cells; organ systems are composed of cells.
C) A tissue cannot exist unless it is a component of an organ system, whereas an organ system can exist independently of tissues.
D) An organ system includes tissues.

4) The tree in your backyard is home to two cardinals, a colony of ants, a wasp's nest, two squirrels, and millions of bacteria. Together, all of these organisms represent
A) a species.
B) a community.
C) a population.
D) an ecosystem.

5) If you eat a hamburger, you are mainly eating ground-up beef muscle. What levels of organization are represented in this ground-up muscle?
A) organism, population, and community
B) organ, organ system, and organism
C) organelle, cell, and tissue
D) tissue, organ, and organ system

6) Which of the following statements regarding a common cellular activity is *false*?
A) Cells respond to the environment.
B) Cells develop and maintain complex organization.
C) Cells regulate their internal environment.
D) New cells are derived from cellular components like organelles.

7) Your instructor asks you to look into your microscope to see a prokaryotic cell. You will be looking for a cell that
A) has a nucleus.
B) has a membrane.
C) makes up most of the tissues of your body.
D) is much larger than most cells in your body.

8) Which of the following statements about ecosystems is *false*?
A) Bacteria and fungi recycle energy within an ecosystem.
B) Plants and other photosynthetic organisms are producers in ecosystems.
C) Chemical nutrients cycle within an ecosystem.
D) In the process of energy conversions within an ecosystem, some energy is converted to heat.

9) The ultimate source of energy flowing into nearly all ecosystems is
A) wind.
B) sunlight.
C) electricity.
D) radioactivity.

10) In an ecosystem, energy
A) cycles along with chemical nutrients.
B) typically flows from consumers to producers to decomposers.
C) typically flows from producers through a series of consumers.
D) comes ultimately from bacteria.

11) Which of the following statements about genetics is *true*?
A) Genes are proteins that produce DNA.
B) DNA is made up of six different kinds of nucleotides.
C) Differences among organisms reflect different nucleotide sequences in their DNA.
D) Each DNA molecule is a single strand of nucleotides.

12) Organisms that are prokaryotes are in the domains
A) Bacteria and Archaea.
B) Plantae and Animalia.
C) Eukarya and Archaea.
D) Fungi and Bacteria.

13) Which of the following statements about the domain Bacteria is *true*?
A) Archaea belong to this domain.
B) All bacteria have a membrane-bound nucleus.
C) All bacteria are multicellular organisms.
D) All bacteria lack a nucleus.

14) Members of the kingdom Animalia
A) can obtain their food either by absorption or by photosynthesis.
B) are composed of cells that lack a cell membrane.
C) can obtain their food by eating other organisms.
D) make their own food through photosynthesis.

15) Kingdom Fungi includes species
A) such as mushrooms and plants.
B) that obtain food by ingestion.
C) that use photosynthesis to obtain food.
D) that obtain food by decomposing dead organisms and absorbing the nutrients.

16) Which of the following is a kingdom within the domain Eukarya?
A) Viruses
B) Fungi
C) Archaea
D) Bacteria

17) All organisms belonging to the kingdom Plantae
A) are photosynthetic.
B) obtain food by decomposing the remains of dead organisms and absorbing the nutrients.
C) are unicellular and lack a nucleus.
D) are multicellular and lack a nucleus.

18) The teeth of grain-eating animals (such as horses) are usually broad and ridged. This makes the teeth suitable for grinding and chewing. Meat-eating animals (such as lions) have pointed teeth that are good for puncturing and ripping flesh. This illustrates
A) a result of natural selection only.
B) the connection between form and function only.
C) a food web.
D) a result of natural selection as well as the connection between form and function.

19) Which of the following statements is *not* consistent with Darwin's theory of natural selection?
A) Individuals in a population exhibit variations, some of which are passed from parents to offspring.
B) Individual organisms exhibit genetic change during their life spans to better fit their environment.
C) Factors in the environment result in some organisms having better reproductive success than others.
D) Natural selection can lead to the appearance of new species.

20) An antibiotic kills 99.9% of a bacterial population. You would expect the next generation of bacteria
A) to be just as susceptible to that antibiotic as was the previous generation.
B) to be more resistant to that antibiotic.
C) to die out due to the drastic decrease in population size.
D) to be more contagious than the prior generation.

21) Which of the following statements about evolution is *true*?
A) Individuals evolve within the span of their own lifetimes.
B) Organisms evolve structures in response to needs.
C) Evolution is deliberate and purposeful.
D) Evolution can result in adaptations.

22) Consider the following statement: "If all vertebrates have backbones, and turtles are vertebrates, then turtles have backbones." This statement is an example of
A) a hypothesis.
B) rationalization.
C) deductive reasoning.
D) inductive reasoning.

23) A hypothesis is
A) the same as a theory.
B) a proposed explanation for a set of observations.
C) an explanatory idea that is broad in scope and supported by a large body of evidence.
D) a widely accepted idea about a phenomenon.

24) You notice that over the past month, many students on campus have started wearing a new style of school sweatshirt. You think to yourself that perhaps the bookstore has recently started selling this new sweatshirt style. This prediction is an example of
A) an experimental question.
B) a type of observation.
C) a hypothesis.
D) an experiment.

25) A theory is
A) an idea that has been proven.
B) a concept in the early stages that still needs to be tested.
C) a description of a belief that invokes the supernatural.
D) an explanation of an idea that is broad in scope and supported by a large body of evidence.

26) To be scientifically valid, a hypothesis must be
A) part of a theory.
B) controlled.
C) reasonable.
D) testable and falsifiable.

27) The role of a control in an experiment is to
A) provide a basis of comparison to the experimental group.
B) prove that a hypothesis is correct.
C) ensure repeatability.
D) counteract the negative effect of the experiment.

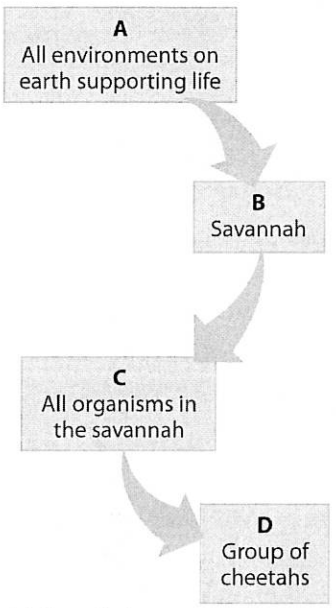
28) A scientist performs a controlled experiment. This means that
A) the experiment is repeated many times to ensure that the results are accurate.
B) the experiment proceeds at a slow pace to guarantee that the scientist can carefully observe all reactions and process all experimental data.
C) two experiments are conducted, one differing from the other by only a single variable.
D) one experiment is performed, but the scientist controls the variables.

29) Which of the following best represents an example of technology?
A) figuring out what mountain gorillas eat
B) sequencing the human genome
C) developing a test for genetic diseases
D) identifying the cause of a new contagious disease

30) Which of the following is *not* an example of evolution that has resulted from human activity?
A) Many strains of bacteria are now resistant to some commonly used antibiotics.
B) Like certain other crops, domesticated strawberries are larger than wild strawberries.
C) Because of hunting, species such as bears and wolves are in danger of extinction.
D) Some insect species are now resistant to pesticides.

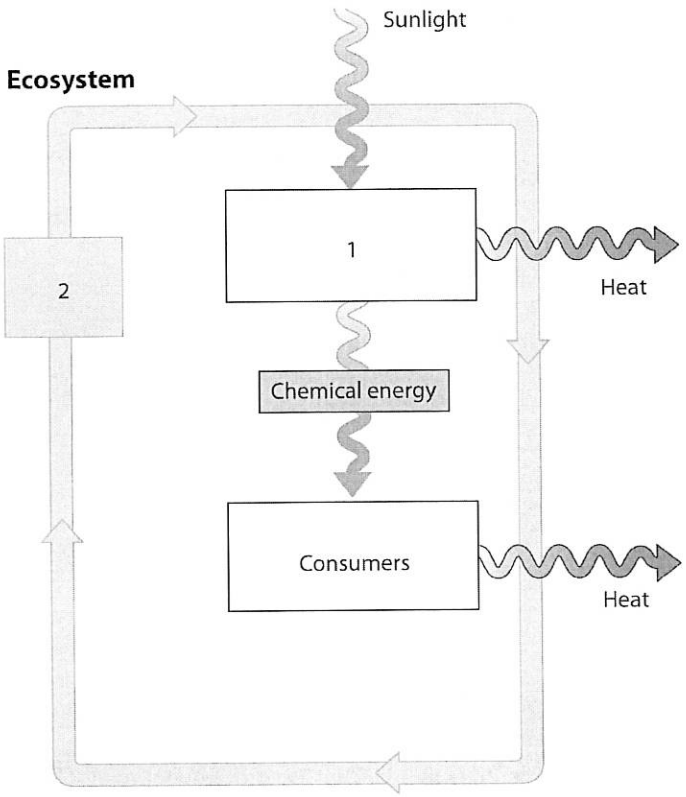
1.2 Art Questions

1) Which level in the hierarchy shown is a community?



A) level A
B) level B
C) level C
D) level D

2) Which of the following organisms belongs to the group represented in Box 1?



A) giraffe
B) tree
C) decomposing bacteria
D) leopard

1.3 Scenario Questions

After reading the paragraph, answer the question(s) that follow.

The National Institutes of Health (NIH) set up a study to determine whether large doses of vitamin C would shorten the length of time it takes to recover from a cold. Three thousand volunteers were split into two groups. For two weeks, members of Group A took 3,000 mg of vitamin C daily. Group B received 3,000 mg of a placebo. At the end of the two-week period, the researchers inserted live cold viruses directly into the noses of all the volunteers. The volunteers in both Group A and B continued to take their daily pills. All the volunteers got colds, and there was no significant difference in the length of time the colds lasted.

1) Which was the experimental group?
A) Group A only
B) Group B only
C) all 3,000 volunteers
D) the researchers that inserted the cold virus

2) To have confidence that the results of the experiment were valid, you'd also want to know
A) whether any volunteers had colds at the start of the experiment.
B) whether the volunteers exercised daily.
C) whether the volunteers all worked for the same company.
D) what the volunteers ate during the experiment.

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1)
Answer: D
Topic: 1.1
Skill: Knowledge/Comprehension

2)
Answer: D
Topic: 1.2
Skill: Knowledge/Comprehension

3)
Answer: D
Topic: 1.2
Skill: Knowledge/Comprehension

4)
Answer: B
Topic: 1.2
Skill: Application/Analysis

5)
Answer: C
Topic: 1.2
Skill: Application/Analysis

6)
Answer: D
Topic: 1.3
Skill: Knowledge/Comprehension

7)
Answer: B
Topic: 1.3
Skill: Application/Analysis

8)
Answer: A
Topic: 1.4
Skill: Knowledge/Comprehension

9)
Answer: B
Topic: 1.4
Skill: Knowledge/Comprehension

10)
Answer: C
Topic: 1.4
Skill: Knowledge/Comprehension

11)
Answer: C
Topic: 1.5
Skill: Knowledge/Comprehension

12)
Answer: A
Topic: 1.6
Skill: Knowledge/Comprehension

13)
Answer: D
Topic: 1.6
Skill: Knowledge/Comprehension

14)
Answer: C
Topic: 1.6
Skill: Knowledge/Comprehension

15)
Answer: D
Topic: 1.6
Skill: Knowledge/Comprehension

16)
Answer: B
Topic: 1.6
Skill: Knowledge/Comprehension

17)
Answer: A
Topic: 1.6
Skill: Knowledge/Comprehension

18)
Answer: D
Topic: 1.7
Skill: Application/Analysis

19)
Answer: B
Topic: 1.7
Skill: Knowledge/Comprehension

20)
Answer: B
Topic: 1.7
Skill: Application/Analysis

21)
Answer: D
Topic: 1.7
Skill: Knowledge/Comprehension

22)
Answer: C
Topic: 1.8
Skill: Knowledge/Comprehension

23)
Answer: B
Topic: 1.8
Skill: Knowledge/Comprehension

24)
Answer: C
Topic: 1.8
Skill: Knowledge/Comprehension

25)
Answer: D
Topic: 1.8
Skill: Knowledge/Comprehension

26)
Answer: D
Topic: 1.9
Skill: Knowledge/Comprehension

27)
Answer: A
Topic: 1.9
Skill: Knowledge/Comprehension

28)
Answer: C
Topic: 1.9
Skill: Knowledge/Comprehension

29)
Answer: C
Topic: 1.10
Skill: Knowledge/Comprehension

30)
Answer: C
Topic: 1.11
Skill: Knowledge/Comprehension

1.2 Art Questions

Answer: C
Topic: 1.2
Skill: Knowledge/Comprehension

2)
Answer: B
Topic: 1.4
Skill: Application/Analysis

1.3 Scenario Questions

1)
Answer: A
Topic: 1.9
Skill: Knowledge/Comprehension

2)
Answer: A
Topic: 1.9
Skill: Application/Analysis

CHAPTER 2

The Chemical Basis of Life

Chapter Objectives

Opening Essay

Explain why an understanding of chemistry and the properties of water are important aspects of biology.

Elements, Atoms, and Compounds

2.1 Define matter, an element, a compound, and a trace element.
2.2 Explain how and why iodine, fluoride, and iron are added to the human diet.
2.3 Distinguish between the size, location, and properties of protons, electrons, and neutrons.
2.3 Define the atomic number and mass number of an atom.
2.3 Define an isotope and explain what makes some isotopes radioactive.
2.4 Describe the uses and dangers of radioactive isotopes.

Chemical Bonds

2.5 Explain how the electron configuration of an atom influences its chemical behavior.
2.6–2.8 Distinguish between covalent bonds, nonpolar polar covalent bonds, polar covalent bonds, hydrogen bonds, and ionic bonds, noting their relative strengths and how and where they form.
2.9 Explain the significance of chemical reactions. Identify the reactants and products of photosynthesis.

Water's Life-Supporting Properties

2.10–2.13 Describe the special properties of water that make it vital to living systems. Explain how these properties are related to hydrogen bonding.
2.10 Define and distinguish between cohesion, adhesion, and surface tension.
2.11 Define and distinguish between heat and temperature. Explain how sweating helps to cool your body.
2.12 Explain why ice floats.
2.13 Define a solute, a solvent, and a solution.
2.14 Explain how acids and bases directly or indirectly affect the hydrogen ion concentration of a solution.
2.14 Explain the basis of the pH scale.
2.14 Explain how buffers function.
2.15 Describe the causes and consequences of acid precipitation and ocean acidification.
2.16 Explain why the search for extraterrestrial life centers on the search for water.

Lecture Outline

I. Introduction

A. Chemicals are the stuff that make up
  1. our bodies,
  2. the bodies of other organisms, and
  3. the physical environment.

B. Life's chemistry is tied to water.
  1. Life first evolved in water.
  2. All living organisms require water.
  3. The chemical reactions of your body occur in cells consisting of 70–95% water.

II. Elements, Atoms, and Compounds

A. 2.1 Organisms are composed of elements, in combinations called compounds
  1. Living organisms are composed of **matter**, which is anything that occupies space and has mass (weight).
  2. Matter is composed of chemical elements.
    a. An **element** is a substance that cannot be broken down to other substances.
    b. There are 92 elements in nature—only a few exist in a pure state.
  3. A **compound** is a substance consisting of two or more different elements in a fixed ratio.
  4. Compounds are more common than pure elements.
  5. Sodium chloride, table salt, is a common compound of equal parts of sodium (Na) and chlorine (Cl).
  6. About 25 elements are essential to life.
  7. Four elements make up about 96% of the weight of most living organisms. These are
    a. oxygen,
    b. carbon,
    c. hydrogen, and
    d. nitrogen.
  8. **Trace elements** are essential but are only needed in minute quantities.

B. 2.2 CONNECTION: Trace elements are common additives to food and water
  1. Some trace elements are required to prevent disease.
    a. Without iron, your body cannot transport oxygen.
    b. An iodine deficiency prevents production of thyroid hormones, resulting in goiter.
  2. Fluoride is added to municipal water and dental products to help reduce tooth decay.
  3. Several chemicals are added to food to
    a. help preserve it,
    b. make it more nutritious, and/or
    c. make it look better.
  4. Check out the "Nutrition Facts" label on foods and drinks you purchase.

C. 2.3 Atoms consist of protons, neutrons, and electrons
  1. Each element consists of one kind of atom.
  2. An **atom** is the smallest unit of matter that still retains the properties of an element.
  3. Three subatomic particles in atoms are relevant to our discussion of the properties of elements.
    a. **Protons** are positively charged.
    b. **Electrons** are negatively charged.

c. **Neutrons** are electrically neutral.

4. Neutrons and protons are packed into an atom's **nucleus**.
5. Electrons orbit the nucleus.
6. The negative charge of electrons and the positive charge of protons keep electrons near the nucleus.
7. The number of protons is the atom's **atomic number**.
8. An atom's **mass number** is the sum of the number of protons and neutrons in the nucleus.
9. The **atomic mass** is approximately equal to its mass number.
10. Although all atoms of an element have the same atomic number, some differ in mass number.
11. Different **isotopes** of an element have
    a. the same number of protons,
    b. but different numbers of neutrons.
12. Different isotopes of an element behave identically in chemical reactions.
13. In **radioactive isotopes**, the nucleus decays spontaneously, giving off particles and energy.

D. 2.4 CONNECTION: Radioactive isotopes can help or harm us

1. Living cells cannot distinguish between isotopes of the same element.
    a. Therefore, radioactive compounds in metabolic processes can act as tracers.
    b. This radioactivity can be detected by instruments.
    c. Using these instruments, the fate of radioactive tracers can be monitored in living organisms.
2. Radioactive tracers are frequently used in medical diagnosis.
3. Sophisticated imaging instruments are used to detect them.
    a. An imaging instrument that uses positron-emission tomography (PET) detects the location of injected radioactive materials.
    b. PET is useful for diagnosing heart disorders, cancer, and in brain research.
4. In addition to benefits, there are also dangers associated with using radioactive substances.
    a. Uncontrolled exposure can cause damage to some molecules in a living cell, especially DNA.
    b. Chemical bonds are broken by the emitted energy, which causes abnormal bonds to form.

III. Chemical Bonds

A. 2.5 The distribution of electrons determines an atom's chemical properties

1. Of the three subatomic particles—protons, neutrons, and electrons—only electrons are directly involved in chemical activity.
2. Electrons occur in energy levels called **electron shells**.
    a. Information about the distribution of electrons is found in the periodic table of the elements.
3. An atom may have one, two, or three electron shells surrounding the nucleus.
    a. The number of electrons in the outermost shell determines the chemical properties of the atom.
    b. Atoms whose outer shells are not full tend to interact with other atoms, participating in chemical reactions.

4. Atoms with incomplete outer shells tend to react so that both atoms end up with completed outer shells.
5. These atoms may react with each other by sharing, donating, or receiving electrons.
6. These interactions usually result in atoms staying close together, held by attractions called **chemical bonds**.

B. 2.6 Covalent bonds join atoms into molecules through electron sharing

1. The strongest kind of chemical bond is a **covalent bond** in which two atoms share one or more outer-shell electrons.
2. Two or more atoms held together by covalent bonds form a **molecule**.
3. A covalent bond connects two hydrogen atoms in a molecule of the gas H_2.
4. There are four alternative ways to represent common molecules.
5. Atoms in a covalently bonded molecule continually compete for shared electrons.
   a. The attraction (pull) for shared electrons is called **electronegativity**.
   b. More electronegative atoms pull harder.
6. In molecules of only one element, the pull toward each atom is equal, because each atom has the same electronegativity.
7. The bonds formed are called **nonpolar covalent bonds**.
8. Water has atoms with different electronegativities.
   a. Oxygen attracts the shared electrons more strongly than hydrogen.
   b. So, the shared electrons spend more time near oxygen.
   c. The oxygen atom has a slightly negative charge and the hydrogen atoms have a slightly positive charge.
   d. The result is a **polar covalent bond**.
   e. Because of these polar covalent bonds, water is a **polar molecule**.

C. 2.7 Ionic bonds are attractions between ions of opposite charge

   a. An **ion** is an atom or molecule with an electrical charge resulting from gain or loss of electrons.
   b. When an electron is lost, a positive charge results.
   c. When an electron is gained, a negative charge results.

1. Two ions with opposite charges attract each other.
   a. When the attraction holds the ions together, it is called an **ionic bond**.
   b. **Salt** is a synonym for an ionic compound.

D. 2.8 Hydrogen bonds are weak bonds important in the chemistry of life

1. Most large molecules are held in their three-dimensional functional shape by weak bonds.
2. Hydrogen, as part of a polar covalent bond, has a partial positive charge.
3. The charged regions on molecules are electrically attracted to oppositely charged regions on neighboring molecules.
4. Because the positively charged region is always a hydrogen atom, the bond is called a **hydrogen bond**.

E. 2.9 Chemical reactions make and break chemical bonds

1. Remember that the structure of atoms and molecules determines the way they behave.
   a. Remember that atoms combine to form molecules.
   b. Hydrogen and oxygen can react to form water:

$$2H_2 + O_2 \rightarrow 2H_2O$$

2. The formation of water from hydrogen and oxygen is an example of a **chemical reaction**.

3. The **reactants** (H_2 and O_2) are converted to H_2O, the **product**.
4. Chemical reactions do not create or destroy matter.
5. Chemical reactions only rearrange matter.
6. Photosynthesis is a chemical reaction that is essential to life on Earth.
   a. Carbon dioxide (from the air) reacts with water.
   b. Sunlight powers the conversion to produce the products glucose and oxygen.

IV. Water's Life-Supporting Properties

A. 2.10 Hydrogen bonds make liquid water cohesive

1. The tendency of molecules of the same kind to stick together is **cohesion**.
   a. Cohesion is much stronger for water than other liquids.
   b. Most plants depend upon cohesion to help transport water and nutrients from their roots to their leaves.
2. The tendency of two kinds of molecules to stick together is **adhesion**.
3. Cohesion is related to **surface tension**—a measure of how difficult it is to break the surface of a liquid.
   a. Hydrogen bonds give water high surface tension, making it behave as if it were coated with an invisible film.
   b. Water striders stand on water without breaking the water surface.

B. 2.11 Water's hydrogen bonds moderate temperature

1. Because of hydrogen bonding, water has a greater ability to resist temperature change than other liquids.
   a. **Heat** is the energy associated with movement of atoms and molecules in matter.
   b. **Temperature** measures the intensity of heat.
2. Heat is released when hydrogen bonds form.
3. Heat must be absorbed to break hydrogen bonds.
4. When a substance evaporates, the surface of the liquid that remains behind cools down, in the process of **evaporative cooling**.
5. This cooling occurs because the molecules with the greatest energy leave the surface.

C. 2.12 Ice is less dense than liquid water

1. Water can exist as a gas, liquid, or solid.
2. Water is less dense as a solid than a liquid because of hydrogen bonding.
3. When water freezes, each molecule forms a stable hydrogen bond with its neighbors.
   a. As ice crystals form, the molecules are less densely packed than in liquid water.
   b. Because ice is less dense than water, it floats.

D. 2.13 Water is the solvent of life

1. A **solution** is a liquid consisting of a uniform mixture of two or more substances.
   a. The dissolving agent is the **solvent**.
   b. The substance that is dissolved is the **solute**.
   c. An **aqueous solution** is one in which water is the solvent.
2. Water's versatility as a solvent results from the polarity of its molecules.
3. Polar or charged solutes dissolve when water molecules surround them, forming aqueous solutions.
4. Table salt is an example of a solute that will go into solution in water.

E. 2.14 The chemistry of life is sensitive to acidic and basic conditions

1. In aqueous solutions, a small percentage of water molecules break apart into ions.
   a. Some are hydrogen ions (H^+).
   b. Some are hydroxide ions (OH^-).

c. Both types are very reactive.

2. A compound that releases H^+ to a solution is an **acid**.
3. A compound that accepts H^+ is a **base**.
4. The **pH scale** describes how acidic or basic a solution is.
   a. The pH scale ranges from 0 to 14, with zero the most acidic and 14 the most basic.
   b. Each pH unit represents a tenfold change in the concentration of H^+.
5. A **buffer** is a substance that minimizes changes in pH. Buffers
   a. accept H+ when it is in excess and
   b. donate H^+ when it is depleted.

F. 2.15 CONNECTION: Acid precipitation and ocean acidification threaten the environment

1. When we burn fossil fuels (coal, oil, and gas), air-polluting compounds and CO_2 are released into the atmosphere.
   a. Sulfur and nitrous oxides react with water in the air to form acids.
   b. These acids fall to Earth as **acid precipitation**, which is rain, snow, or fog with a pH lower than 5.2.
   c. CO_2 dissolving in seawater lowers ocean pH in a process known as **ocean acidification**.

G. 2.16 EVOLUTION CONNECTION: The search for extraterrestrial life centers on the search for water

1. The emergent properties of water support life on Earth.
2. When astrobiologists search for signs of extraterrestrial life on distant planets, they look for evidence of water.
3. The National Aeronautics and Space Administration (NASA) have found evidence that water was once abundant on Mars.

Key Terms

acid
acid precipitation
adhesion
aqueous solution
atom
atomic mass
atomic number
base
buffer
chemical bond
chemical reaction
cohesion
compound
covalent bond
electron
electron shell
electronegativity
element
evaporative cooling
heat
hydrogen bond
ion
ionic bond
isotope
mass number
matter
molecule
neutron
nonpolar covalent bond
nucleus
ocean acidification
pH scale
polar covalent bond
polar molecule
product
proton
radioactive isotope
reactant
salt
solute
solution
solvent
surface tension
temperature
trace element

Chapter 2: Reading Guide

2.1 Organisms are composed of elements, in combination called compounds

Living organisms and everything around them are composed of _____.

What are the 3 physical states of matter:

Define the following and give an example of each one:

- Element
- Compound
- Trace element

How many elements are essential for life?

Which 4 make up 96% of the weight of the human body:

2.2 Trace elements are common additives to food and water

What is the function of iron in your body?

Where do we get iron from and why add it to our food?

What other trace elements are important for the human body?

2.3 Atoms consist of protons, neutrons, and electrons

Define the following:

Atom-

Proton-

Electron-

Neutron-

Atomic number is amount of _____.

If an element has 6 protons, what is its atomic number?

What element is this?

Usually an atom has a net electrical charge of _____. This is because:

What is the mass number and atomic mass?

How do these two differ?

What are isotopes?

Give an example of an isotope.

What do we use radioactive isotopes for?

2.5 The distribution of electrons determines an atom's chemical properties

The farther an electron is from the postiviely charged nucleus, the _____ its energy.

Define electron shells:

Each orbitial can hold a max of ____ electrons.

The first electron shell of an atom only has _____ orbital, thus can only hold ____ electrons.

The rest of the electron shells have _____ orbitals and can hold ____ electrons.

The outermost shell is called the _____.

What is the importance of this outermost shell?

Draw the electron shells, showing the correct number of electrons for oxygen.

2.6 Covalent bonds join atoms into molecules through electron sharing

Define covalent bond:

What do two or more atoms held together by a covalent bond form?

Give an example:

How many covalent bonds can an atom form?

Explain the difference between nonpolar covalent bonds and polar covalent bonds. Give an example for each one.

2.7 Ionic bonds are attractions between ions of opposite charge

Define the following:

Ion-

Ionic bond-

2.8 Hydrogen bonds are weak bonds important in the chemistry of life

What are the strongest chemical bonds?

Why do we need hydrogen bonds? How are the helpful to humans?

Define hydrogen bond:

Draw the 5 water molecules represented in Figure 2.8 on page 25. Label the hydrogen bond.

2.9 Chemical rxns make and break chemical bonds

Give an example of a chemical reaction. Label the reactants and products.

Water's Life-Supporting Properties

Describe each of the 4 life supporting properties water gives us:

Cohesive

Moderate temperature

Ice is less dense than liquid water

Solvent of life

Define the following:

Cohesion-

Adhesion-

Surface tension-

Evaporative cooling-

Solution-

Solvent-

Solute-

Acid-

Base-

Buffer-

A solution with a pH of 3 is _____. A solution with a pH of 7 is _____. A solution with a pH of 12 is _____.

Each pH unit represents a:

AP Biology 012 – Life Requires Free Energy
Video Review Sheet

www.bozemanscience.com/012-life-requires-free-energy

1. Introduction:
    a. Where do we get a constant supply of free energy?

    b. What do plants do with it?

    c. How do we utilize free energy?

    d. What is "neat" about glycolysis?

    e. What are the three major things we GET from free energy?

    f. What is homeostasis?

    g. What can we do with extra free energy?

    h. What happens when we get disruptions?

2. Life requires:

3. To maintain order we require a constant

4. What is the first law of thermodynamics?

5. Eventually all energy ends up as

6. What is the second law of thermodynamics?

7. What is entropy?

8. How can evolution occur if things are going to greater disorder?

9. What is glycolysis? Why does it cost ATP?

10. How is it that different types of sugars can use glycolysis though they all don't contain glucose?

11. What is the relationship between metabolism and size? Why do mice have such a high metabolism?

12. Organization requires

13. What is released when you break down ATP to ADP?

14. Growth isn't just about getting bigger but also

15. We use extra energy to do:

16. We can store

17. What happens if we have a decrease in free energy – as people?

18. Describe what happened at Easter Island.

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 depends 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 and that form the basis for our modern understanding of biology. You will learn how the subatomic particles—protons, neutrons, and electrons—are organized into atoms and atoms are combined by covalent or ionic bonds into molecules. 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* reflects the amount of matter in an object, whereas *weight* reflects gravity's pull on that mass.) The basic forms of matter are **elements,** 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. A compound usually has characteristics quite different from its constituent elements, an example of the emergence of novel properties in higher levels of organization.

Essential 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.

Symbol	Element
Ca	
P	
K	
S	
Na	
Cl	
Mg	

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

An **atom** is the smallest unit of an element retaining the physical and chemical properties of that 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** orbit rapidly about the nucleus.

Protons and neutrons have a similar mass of about 1.7×10^{-24} g or 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 its atom. Unless indicated otherwise, 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 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, or **radioactive**; their nuclei spontaneously decay, giving off particles and energy.

Radioactive isotopes are important tools in biological research and medicine. Chemical processes can be located and monitored within an organism using radioactive tracers and PET (positron-emission tomography). Too great an exposure to radiation from decaying isotopes poses a significant health hazard.

The Energy Levels of Electrons **Energy** is defined as the ability to cause change. **Potential energy** is energy stored in matter as a consequence of the relative position of masses. Matter naturally tends to move toward a more stable lower level of potential energy and requires the input of energy to return to a higher potential energy.

The potential energy of electrons increases as their distance from the positively charged nucleus increases. Electrons can orbit in several different potential energy states, called **energy levels** or **electron shells**, surrounding the nucleus.

INTERACTIVE QUESTION 2.3

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

Electron Configuration and Chemical Properties The chemical behavior of an atom is a function of its electron configuration—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 holds only two electrons; thus $_2$He is inert.) Atoms with incomplete valence shells are chemically reactive because of their unpaired electrons. The *periodic table of the elements* is arranged in order of the sequential addition of electrons to orbitals in the electron shells.

INTERACTIVE QUESTION 2.4

Draw the electron shell diagram for these atoms.

a. $_7$N

b. $_8$O

c. $_{12}$Mg

d. $_6$C

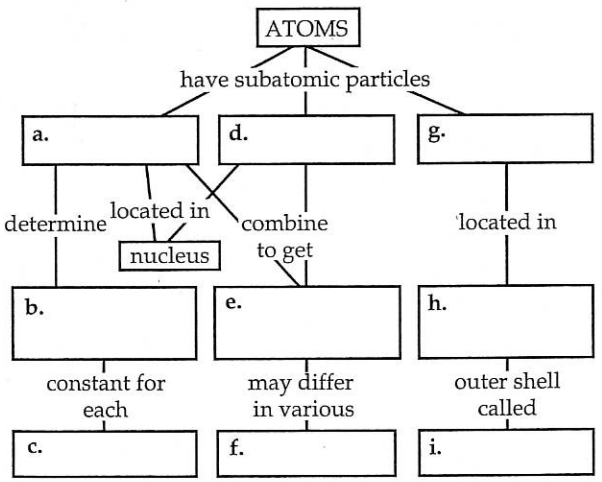
Electron Orbitals An **orbital** is the three-dimensional space or volume within which an electron is most likely to be found. No more than two electrons can occupy the same orbital. The first electron shell can contain two electrons in a single spherical orbital, called the 1s orbital. The second electron shell can hold a maximum of eight electrons in its four orbitals, which are a 2s 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 (d.) 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,** that hold the atoms 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 number and type of atoms and also the bonding within a molecule. The dash indicates a **single covalent bond,** or just a **single bond.** A **molecular formula,** such as O_2, indicates only the kinds and numbers of atoms in a molecule. In an oxygen molecule, two pairs of valence electrons are shared between oxygen atoms, forming a **double covalent bond,** or simply a **double bond.**

The **valence,** or bonding capacity, of an atom equals the number of unpaired electrons in its valence shell. (Even though phosphorus has three unpaired electrons and a valence of three, it has a valence of five in some important biological molecules.)

INTERACTIVE QUESTION 2.7

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

a. hydrogen **c.** nitrogen

b. oxygen **d.** carbon

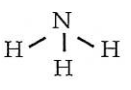
Electronegativity is the attraction of a particular type of atom for shared electrons. If the atoms in a molecule have similar electronegativities, the electrons remain equally shared between the two nuclei, and the covalent bond is said to be a **nonpolar covalent bold.** If one element is more electronegative,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

INTERACTIVE QUESTION 2.8

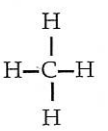
Explain whether the following molecules contain nonpolar or polar covalent bonds. (Hint: N and O both have high electronegativities.)

a. nitrogen molecule $N \equiv N$

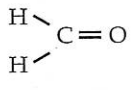
b. ammonia



c. methane



d. formaldehyde



Ionic Bonds If two atoms are very different in their attraction for the shared electrons, the more electronegative atom may completely transfer an electron from another 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. Ammonium (NH_4^+) is a cation; this covalently bonded molecule is missing one electron.

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 molecular formula for this salt be? a. _____ Which atom becomes the cation? b. _____

Weak Chemical Bonds Weak bonds, such as ionic bonds in water, form temporary interactions between molecules and are involved in many biological signals and processes. Weak bonds within large molecules such as proteins help to create the three-dimensional shape and resulting activity of these molecules.

When a hydrogen atom is covalently bonded with an electronegative atom, and thus has a partial positive charge, it can be attracted to another electronegative atom and form 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.

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 should its shape be roughly like a V?

2.4 Chemical reactions make and break chemical bonds

Chemical reactions involve the making or breaking of chemical bonds in the transformation of matter into different forms. 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 coefficients for respiration, the conversion of glucose and oxygen to carbon dioxide and water, so that all atoms are conserved in the chemical reaction.

$$C_6H_{12}O_6 + \_\_ O_2 \longrightarrow \_\_ CO_2 + \_\_ H_2O$$

Most 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:* an attraction between atoms that share one or more pairs of outer-shell electrons)
electro- = electricity (*electronegativity:* the tendency for an atom to pull electrons toward itself)

iso- = equal (*isotope:* an element having the same number of protons and electrons 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 for 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: 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. Explain what is meant by saying that the sharing of electrons between atoms falls on a continuum from nonpolar covalent bonds to ionic bonds.

Test Your Knowledge

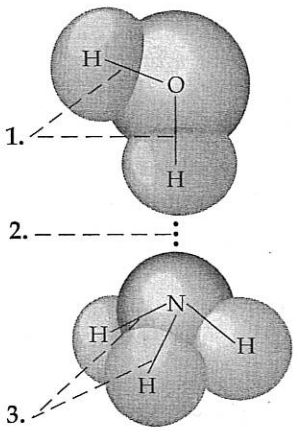
MULTIPLE CHOICE: *Choose the one best answer*

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. 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.
3. 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.
4. Oxygen has eight electrons. You would expect the arrangement of these electrons to be:
   a. eight in the second energy shell, creating an inert element.
   b. two in the first energy shell and six in the second, creating a valence of six.
   c. two in the 1*s* orbital and two each in the three 2*p* orbitals, creating a valence of zero.
   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.
5. A covalent bond between two atoms is likely to be polar if
   a. one of the atoms is much more electronegative than the other.
   b. the two atoms are equally electronegative.
   c. the two atoms are of the same element.
   d. the bond is part of a tetrahedrally shaped molecule.
   e. one atom is an anion.

6. 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.

7. 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.

8. What types of bonds are identified in the following illustration of a water molecule interacting with an ammonia molecule?



   a. Bonds 1 are polar covalent bonds, bond 2 is a hydrogen bond, and bonds 3 are nonpolar covalent bonds.
   b. Bonds 1 and 3 are polar covalent bonds, and bond 2 is a hydrogen bond.
   c. Bonds 1 and 3 are polar covalent bonds, and bond 2 is an ionic bond.
   d. Bonds 1 and 3 are nonpolar covalent bonds, and bond 2 is a hydrogen bond.
   e. Bonds 1 and 3 are polar covalent bonds, and bond 2 is a nonpolar covalent bond.

9. Which of the following weak bonds may form between any closely aligned molecules?
   a. nonpolar covalent
   b. polar covalent
   c. ionic
   d. hydrogen
   e. van der Waals interactions

10. 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.

Use this information to answer questions 11 through 16.

The six elements most common in living organisms are:

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

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

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

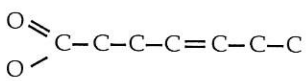
13. A radioactive isotope of carbon has the mass number 14. How many neutrons does this isotope have?
    a. 2
    b. 6
    c. 8
    d. 12
    e. 14

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

15. Based on electron configuration, which of these elements would have chemical behavior most like that of oxygen?
    a. C
    b. H
    c. N
    d. P
    e. S

16. How many of these elements 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

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



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

18. 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

19. What type of bond would you expect potassium (K) to form?
    a. ionic; it would donate one electron and carry a positive charge
    b. ionic; it would donate 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

20. What is the molecular shape of methane (CH_4)?
    a. planar or flat, with the H arranged around the C
    b. pentagonal, or a flat five-sided arrangement
    c. tetrahedral, due to the hybridization of the *s* and three *p* orbits of the C
    d. circular, with the four H attached in a ring around the C
    e. linear, since all the bonds are nonpolar covalent

21. Which of the following is a molecule capable of forming hydrogen bonds?
    a. CH_4
    b. H_2O
    c. NaCl
    d. H_2
    e. a, b, and d can form hydrogen bonds.

22. 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

23. 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.

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

25. What coefficients must be placed in the blanks to balance this chemical reaction?

$$C_5H_{12} + \_\_ O_2 \longrightarrow \_\_ CO_2 + \_\_ H_2O$$

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

Chapter 3

Water and the Fitness of the Environment

Key Concepts

3.1 The polarity of water molecules results in hydrogen bonding

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

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

Framework

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

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

Chapter Review

3.1 The polarity of water molecules results in hydrogen bonding

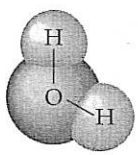
A water molecule consists of two hydrogen atoms each covalently bonded to a more electronegative oxygen atom. This **polar molecule** has a shape like a wide V with a slight positive charge on each hydrogen atom ($\delta+$) and a slight negative charge ($\delta-$) associated with the oxygen. Hydrogen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

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

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

INTERACTIVE QUESTION 3.1

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



Moderation of Temperature In a body of matter, **heat** is a measure of the total quantity of **kinetic energy,** the energy associated with the movement of atoms and molecules. **Temperature** measures the average kinetic energy of the molecules in a substance.

Temperature is measured using a **Celsius scale.** Water at sea level freezes at 0°C and boils at 100°C. A **calorie (cal)** is the amount of heat energy it takes to raise 1 g of water 1°C. A **kilocalorie (kcal)** is 1,000 calories, the amount of heat required to raise 1 kg of water 1°C. A **joule (J)** equals 0.239 cal; a calorie is 4.184 J.

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

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

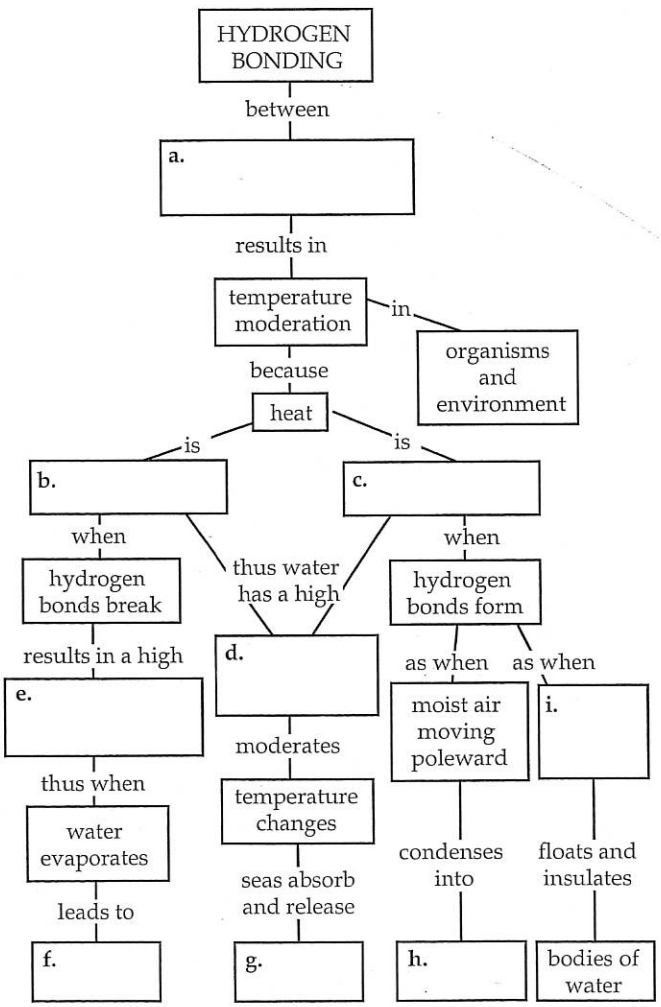
As a substance vaporizes, the liquid left behind loses the kinetic energy of the escaping molecules and cools down. **Evaporative cooling** helps to protect terrestrial organisms from overheating and contributes to the stability of temperatures in lakes and ponds.

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

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

INTERACTIVE QUESTION 3.2

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



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

INTERACTIVE QUESTION 3.3

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

a. olive oil

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** (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 a 0.5 *M* solution of lactic acid? (^{12}C, ^{1}H, ^{16}O)

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

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

A water molecule can dissociate into a **hydrogen ion**, H^+ (which binds to another water molecule to form a hydronium ion, H_3O^+) and a **hydroxide ion**, OH^-. Although reversible and statistically rare, this dissociation into the highly reactive hydrogen and hydroxide ions has important biological consequences. In pure water at 25°C, the concentrations of H^+ and OH^- ions are the same; both are equal to 10^{-7} *M*.

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

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

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

INTERACTIVE QUESTION 3.5

Complete the following table to review your understanding of pH.

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

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

INTERACTIVE QUESTION 3.6

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

In which direction will this reaction proceed

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

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

b. when the pH rises above normal level?

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

Word Roots

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

Structure Your Knowledge

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

Property	Explanation of Property	Example of Benefit to Life
a.	Hydrogen bonds hold 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.
Ice floats	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 water molecule is capable of forming
   a. one hydrogen bond.
   b. three hydrogen bonds.
   c. four hydrogen bonds.
   d. two covalent bonds and two hydrogen bonds.
   e. two covalent bonds and four hydrogen bonds.
2. The polarity of water molecules
   a. promotes the formation of hydrogen bonds.
   b. helps water to dissolve nonpolar solutes.
   c. lowers the heat of vaporization and leads to evaporative cooling.
   d. creates a crystalline structure in liquid water.
   e. does all of the above.
3. What accounts for the movement of water up the vessels of a tall tree?
   a. cohesion
   b. hydrogen bonding
   c. adhesion
   d. hydrophilic vessel walls
   e. all of the above
4. Climates tend to be moderate near large bodies of water because
   a. a large amount of solar heat is absorbed during the gradual rise in temperature of the water.
   b. water releases heat to the environment as it cools.
   c. the high specific heat of water helps to moderate air temperatures.
   d. a great deal of heat is absorbed and released by the breaking and forming of hydrogen bonds.
   e. of all of the above.

5. Temperature is a measure of
   a. specific heat.
   b. average kinetic energy of molecules.
   c. total kinetic energy of molecules.
   d. Celsius degrees.
   e. joules.

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

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

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

9. Some archaea are able to live in lakes with pH 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.

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

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

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

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

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

15. How many molecules of glucose would be in the 1 liter solution made in question 14?
    a. 0.1
    b. 6
    c. 60
    d. 6×10^{23}
    e. 6×10^{22}

16. Why is water such an excellent solvent?
    a. As a polar molecule, it can surround and dissolve ionic and polar molecules.
    b. It forms ionic bonds with ions, hydrogen bonds with polar molecules, and hydrophobic interactions with nonpolar molecules.
    c. It forms hydrogen bonds with itself.
    d. It has a high specific heat and a high heat of vaporization.
    e. It is wet and has a great deal of surface tension.

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

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

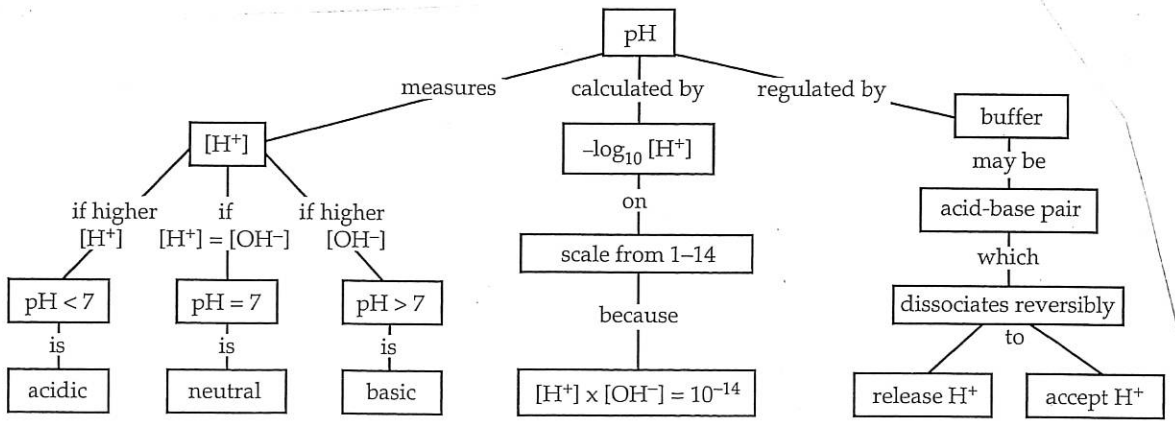
19. A hydration shell is most likely to form around
    a. an ion.
    b. a fat.
    c. a sugar.
    d. both a and c.
    e. both b and c.

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

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

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

2. See concept map below.



pH practice worksheet

1. What gives rise to cohesiveness of water molecules?
2. A water strider can walk across the surface of a small pond because?
3. Which type of bond must be broken for water to vaporize?
4. At what temperature is water at its densest?
5. Why does ice float in liquid water?
6. What is the difference behind hydrophobic and hydrophilic substances?
7. What is the pH of a solution with a hydroxyl ion [OH-] concentration of 10^{-12} M?
8. What is the pH of a solution with a hydrogen ion [H+] concentration of 10^{-8} M?
9. Which of the following solutions has the greatest concentration of [OH-]?

    A. Lemon juice at pH 2
    B. Vinegar pH 3
    C. Tomato juice pH 4
    D. Urine pH 6
    E. Seawater pH 8

10. If the pH of a solution is increased from pH 5 to pH 7, it means that the
11. One liter of a solution pH 9 has how many more hydroxyl [OH-] than one liter of a solution of pH 4?
12. How do buffers work?

Campbell's Biology: Concepts and Connections, 7e **(Reece et al.)**
Chapter 2 The Chemical Basis of Life

2.1 Multiple-Choice Questions

1) The four most common elements in living organisms are
A) C, H, O, Fe.
B) C, H, O, Na.
C) C, H, O, N.
D) C, N, O, Na.

2) Which of the following is a trace element in the human body?
A) nitrogen
B) zinc
C) oxygen
D) hydrogen

3) Which of the following statements regarding matter is *false*?
A) All life is composed of matter.
B) All matter has mass.
C) All matter is composed of elements.
D) All matter exists in the form of compounds.

4) Which of the following statements best describes a compound?
A) A compound is a pure element.
B) A compound contains two or more different elements in a fixed ratio.
C) A compound is exemplified by sodium.
D) A compound is a solution.

5) In the equation $2\ H_2 + O_2 \rightarrow 2\ H_2O$,
A) H_2, O_2, and H_2O are all compounds.
B) H_2, O_2, and H_2O are all elements.
C) only H_2O is a compound.
D) only H_2 and O_2 are compounds.

6) Which of the following trace elements needed by humans is commonly added to table salt?
A) iodine
B) iron
C) magnesium
D) fluoride

7) In some areas, fluoride is added during the municipal water treatment process in order to help
A) prevent goiter
B) prevent the growth of bacteria
C) prevent the development of mental retardation
D) reduce tooth decay

8) Which of the following particles is found in the nucleus of an atom?
A) protons and neutrons
B) protons and electrons
C) only protons
D) only electrons

9) Electrons move about the nucleus of an atom in the same way that
A) insects fly around a bright lamp at night.
B) cars are parked along the sides of a street.
C) boats cross a lake.
D) birds migrate to a new winter home.

10) What is the atomic mass of an atom that has 6 protons, 6 neutrons, and 6 electrons?
A) 6
B) 8
C) 12
D) 18

11) An uncharged atom of boron has an atomic number of 5 and an atomic mass of 11. How many electrons does boron have?
A) 11
B) 15
C) 5
D) 2

12) Which of the following is another term used for atomic mass?
A) darwin
B) mendel
C) dalton
D) calvin

13) The sodium atom contains 11 electrons, 11 protons, and 12 neutrons. What is the mass number of sodium?
A) 11
B) 22
C) 23
D) 34

14) Which of the following best describes the atomic number of an atom?
A) the number of protons in the atom
B) the number of electrons in the atom
C) the number of neutrons in the atom
D) the number of protons, electrons, and neutrons in the atom

15) Typically, nitrogen atoms are composed of electrons, protons, and neutrons. An isotope of nitrogen could
A) be positively charged.
B) be negatively charged.
C) have more protons than the usual nitrogen atom.
D) have more neutrons than the usual nitrogen atom.

16) A radioactive isotope is an isotope that
A) is stable.
B) decays.
C) has more protons than the common variant of the element.
D) has the same atomic mass, but a different atomic number than the common variant of the element.

17) If you found a fossilized dinosaur bone, what method could be used to determine the age of the fossil?
A) electrophoresis
B) DNA fingerprinting
C) isotope analysis
D) radial immunodiffusion

18) Which of the following statements about radioactive isotopes is *true*?
A) The nuclei of radioactive isotopes are unusually stable, but the atoms tend to lose electrons.
B) When given a choice between radioactive and nonradioactive isotopes of the same atom, living cells are more likely to incorporate the radioactive isotopes into their structures.
C) The energy emitted by radioactive isotopes can break chemical bonds and cause molecular damage in cells.
D) Radioactive elements are natural and therefore not harmful.

19) Radioactive isotopes
A) are frequently added to foods as nutritional supplements.
B) can be used in conjunction with PET scans to diagnose diseases.
C) do not occur naturally.
D) are never incorporated into organic compounds.

20) When full, the innermost electron shell of argon contains _____ electrons, and the outermost shell contains _____ electrons.
A) 2 . . . 2
B) 2 . . . 8
C) 4 . . . 8
D) 8 . . . 8

21) What happens to an atom if the electrons in the outer shell are altered?
A) The atom becomes radioactive.
B) The atom will disintegrate.
C) The properties of the atom will change.
D) The atom's characteristics change and it becomes a different element.

22) A(n) _____ forms when two atoms share electrons.
A) ion
B) covalent bond
C) ionic bond
D) hydrogen bond

23) A hydrogen atom has one electron. How many covalent bonds can hydrogen form?
A) one covalent bond
B) two covalent bonds
C) four covalent bonds
D) no covalent bonds

24) Table salt is formed when
A) chlorine gives an electron to sodium.
B) a hydrogen bond forms between sodium and chlorine.
C) sodium and chlorine share electrons to form a bond.
D) sodium donates its single outer electron to chlorine.

25) The body uses atoms in different ways to accomplish different tasks. For example, one portion of the body's calcium supply strengthens bones, whereas another portion combines with proteins to stimulate blood clotting after tissue injury. Which of the statements that follow provides the most logical chemical explanation of calcium's ability to perform such different functions?
A) The bone contains calcium salts, which are less reactive than the calcium ions found in the blood.
B) The calcium in blood is a more reactive form of the atom and therefore has fewer protons than the calcium in bone.
C) There are many different isotopes of calcium, and the most reactive isotope is found in the bone.
D) The calcium in blood has a lighter atomic mass than the calcium in bone and is in a more reactive form.

26) Medicines are often administered in pill form. In many cases, the active ingredient of the pill (the drug) is joined to another substance by _____. This forms a(n) _____, which is stable in the dry environment of a pill bottle but dissociates under the wet conditions of the digestive system to release the drug to the body.
A) ionic bonds . . . salt
B) hydrogen bonds . . . base
C) ionic bonds . . . acid
D) covalent bonds . . . salt

27) What is the fundamental difference between covalent and ionic bonding?
A) In a covalent bond, the partners share a pair of electrons; in an ionic bond, one partner accepts electrons from the other.
B) In covalent bonding, both partners end up with filled outer electron shells; in ionic bonding, one partner does and the other does not.
C) Covalent bonding involves only the outermost electron shell; ionic bonding also involves the next electron shell inside the outermost shell.
D) Covalent bonds form between atoms of the same element; ionic bonds form between atoms of different elements.

28) Which of the following statements regarding the oxygen atom of a water molecule is *true*?
A) Oxygen is more positively charged than the hydrogen atoms.
B) Oxygen attracts electrons less strongly than the hydrogen atoms.
C) Oxygen is more electronegative than the hydrogen atoms.
D) Oxygen is attracted to the negatively charged atoms of other molecules.

29) In a water molecule, hydrogen and oxygen are held together by a(n) _____ bond.
A) double covalent
B) nonpolar covalent
C) hydrogen
D) polar covalent

30) A water molecule (H□O□H) is held together by
A) a single covalent bond.
B) a double covalent bond.
C) two polar covalent bonds.
D) hydrogen bonds.

31) The hydrogen atoms of a water molecule are bonded to the oxygen atom by _____ bonds, whereas neighboring water molecules are held together by _____ bonds.
A) hydrogen . . . polar covalent
B) polar covalent . . . hydrogen
C) ionic . . . covalent
D) polar covalent . . . ionic

32) _____ are weak bonds that are not strong enough to hold atoms together to form molecules but are strong enough to form bonds within and around large molecules.
A) Ionic bonds
B) Covalent bonds
C) Polar covalent bonds
D) Hydrogen bonds

33) Water molecules stick to other water molecules because
A) water molecules are neutral, and neutral molecules are attracted to each other.
B) hydrogen bonds form between the hydrogen atoms of one water molecule and the oxygen atoms of other water molecules.
C) covalent bonds form between the hydrogen atoms of one water molecule and the oxygen atoms of other water molecules.
D) the oxygen atoms of adjacent water molecules are attracted to one another.

34) Which of the following statements regarding chemical reactions is *false*?
A) Chemical reactions involve the making and breaking of chemical bonds.
B) Some chemical reactions create electrons; others destroy them.
C) The reactants contain the same number of atoms as the products.
D) Although the atoms of a reaction's reactants and products are identical to each other, their molecular formulae differ.

35) In the equation $2\ H_2 + O_2 \rightarrow 2\ H_2O$, the H_2 molecules are _____ and the H_2O molecules are _____.
A) reactants . . . products
B) products . . . reactants
C) created . . . destroyed
D) used . . . stored

36) Photosynthesis requires many steps to make glucose. As a result of the synthesis process,
A) all the carbons from the six carbon dioxide atoms are found in glucose.
B) more atoms are present at the beginning than at the end.
C) more carbon dioxide is released from the plant than is absorbed.
D) water is synthesized by the plant from H_2 and O_2.

37) The tendency of water molecules to stick together is referred to as
A) adhesion.
B) polarity.
C) cohesion.
D) transpiration.

38) Water's surface tension and heat storage capacity is accounted for by its
A) orbitals.
B) hydrogen bonds.
C) mass.
D) size.

39) The temperature of evaporation is much higher for water than for alcohol. Without knowing more about the chemistry of alcohol, which of the following is the most logical chemical explanation for this phenomenon?
A) Ionic bonds form between alcohol molecules. These are the weakest type of bond and are easier to break than the hydrogen bonds between water molecules.
B) Alcohol has a higher surface tension than water. This means that alcohol molecules can easily break away from other alcohol molecules and evaporate at a lower temperature.
C) Alcohol molecules are more cohesive than water molecules. This means that as alcohol molecules evaporate, they pull other alcohol molecules into the air along with them.
D) Fewer hydrogen bonds form between alcohol molecules. As a result, less heat is needed for alcohol molecules to break away from solution and enter the air.

40) As ice melts,
A) hydrogen bonds are broken.
B) water molecules become less tightly packed.
C) the water becomes less dense.
D) heat is released.

41) Which of the following statements about water is *false*?
A) Ice is more dense than liquid water.
B) Water naturally exists in all three physical states on Earth.
C) Floating ice on a pond insulates the liquid water below, slowing its rate of freezing.
D) If ice sank, the oceans would eventually freeze solid.

42) You've made a hot drink by dissolving a teaspoon of instant coffee and a teaspoon of sugar in a cup of hot water. Which of the following statements is *true*?
A) You've just prepared an aqueous solution.
B) The water is the solute portion of the drink.
C) The instant coffee and sugar are solvents.
D) The instant coffee and sugar dissolve because they have no charged regions to repel the partial positive and partial negative regions of the water molecules.

43) Which of the following is dependent on the ability of water molecules to form hydrogen bonds with other molecules besides water?
A) the evaporative cooling of skin surfaces
B) the milder temperatures of coastal regions compared to inland areas
C) the ability of certain insects to walk on the surface of water
D) the universality of water as a solvent

44) Clot formation in our blood can lead to a heart attack or stroke. What was altered in the proteins that made the clot?
A) The proteins became more polar.
B) The blood was saturated with proteins.
C) The proteins were no longer soluble in the blood.
D) The proteins became more soluble in the blood.

45) A pharmaceutical company hires a chemist to analyze the purity of the water being used in its drug preparations. If the water is pure, the chemist would expect to find
A) only molecules of H_2O.
B) H_2O molecules and H^+ ions.
C) H_2O molecules, H^+ ions, and OH^- ions.
D) only H^+ ions and OH^- ions.

46) A solution with a pH of 7 is
A) strongly acidic.
B) weakly acidic.
C) neutral.
D) weakly basic.

47) Compared to a solution of pH 3, a solution of pH 1 is
A) 100 times more acidic.
B) 10 times more acidic.
C) 10 times more basic.
D) 100 times more basic.

48) Which of the following statements about pH is *true*?
A) The pH scale is a measure of oxygen ion concentration.
B) A single unit change on the pH scale is equivalent to a 1% change in hydrogen ion concentration.
C) An increase in hydrogen ion concentration means a decrease in pH scale units.

49) Household ammonia has a pH of 12; household bleach has a pH of 13. Which of the following statements about them is *true*?
A) Both of these substances are strong acids.
B) The ammonia has 10 times as many OH^- ions as the bleach.
C) The ammonia has 10 times as many H^+ ions as the bleach.
D) A solution that could buffer the bleach and ammonia would remove excess OH^- ions.

50) A buffer
A) is an acid that is used to offset overly basic conditions in the body.
B) is a base that is used to offset overly acidic conditions in the body.
C) donates H^+ ions when conditions become too basic and accepts H^+ ions when conditions become too acidic.
D) donates OH^- ions when conditions become too basic and accepts OH^- ions when conditions become too acidic.

51) A diabetic, who does not utilize insulin properly, will metabolize fats instead of glucose. A condition called diabetic ketoacidosis is a common result of excessive fat metabolism, causing blood pH values of 7.1 or less (normal range = 7.35—7.45). What has happened to the blood pH and why?
A) The pH is above normal (basic) because the ketones are too basic.
B) The pH is below normal (acidic) because the buffering capacity was exceeded.
C) The pH is not affected because the blood buffers can absorb the excess H^+.
D) The pH is below normal because buffers can donate OH^+.
Answer: B
Topic: 2.14
Skill: Application/Analysis

52) Which of the following statements about acid precipitation is *false*?
A) Acid precipitation is defined as having a pH below 5.6.
B) Acid precipitation damages natural wilderness areas.
C) Acid precipitation is primarily the result of burning fossil fuels.
D) Acid precipitation has little or no effect on soil chemistry.

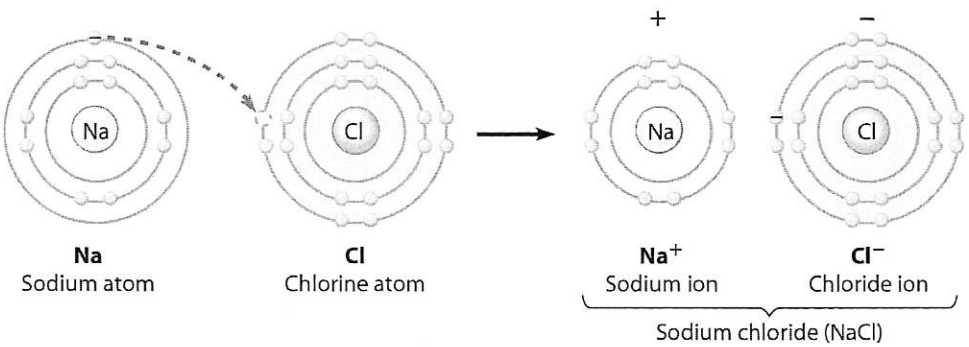
53) The emission of _____ and _____ are primarily responsible for acid precipitation.
A) carbon dioxide . . . methane
B) nitrogen oxides . . . sulfur oxides
C) halones . . . CFCs
D) carbon dioxide . . . ozone

54) Which of the following would be considered an effective way to decrease the production of acid precipitation?
A) Drive more full-size SUVs.
B) Build more coal-generated electricity power plants.
C) Discourage the use of alternative energy resources such as solar, wind, and geothermal energy.
D) Whenever possible, walk or ride a bicycle instead of driving a car.

55) Which of the following hypotheses would be supported if liquid water were found on Mars and contained evidence of bacteria-like organisms?
A) Life must evolve in the presence of oxygen.
B) The chemical evolution of life is possible.
C) Life on Earth must have originated on Mars.
D) Life is guided by intelligent design.

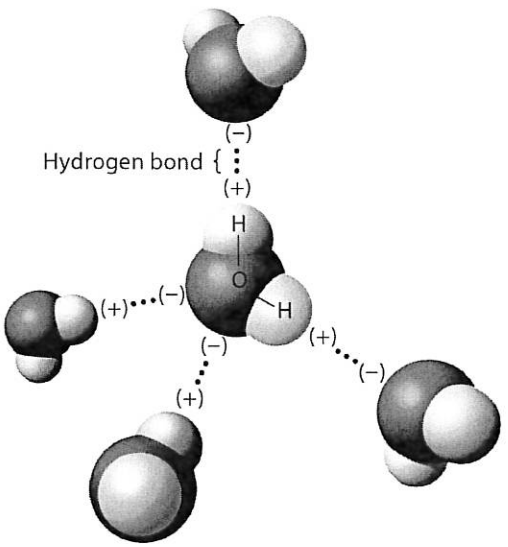
2.2 Art Questions

1) What change is occurring in this figure?



A) Chlorine is losing an electron.
B) Sodium is becoming negatively charged.
C) Sodium is filling its third electron shell.
D) Chlorine is filling its third electron shell.

2) The hydrogen bonds shown in this figure are each



A) between two hydrogen atoms.
B) between an oxygen and a hydrogen atom of the same water molecule.
C) between an oxygen and a hydrogen atom of different water molecules.
D) between two atoms with the same charge.

2.3 Scenario Questions

After reading the paragraph, answer the question(s) that follow.

You've been experiencing acid indigestion lately, and you'd like a quick fix for the problem. You do a little research on the Internet and discover that your problem is caused by excess stomach acid. In the pharmacy aisles, however, you're having a little trouble deciding what to purchase to address the problem. At the pharmacy counter, the clerk recommends that you purchase Pepcid-AC® or Alka-Seltzer® tablets.

1) If you could check the pH of the recommended tablets, you would expect it to be
A) higher than 7.
B) lower than 7.
C) exactly 7.
D) pH neutral.

2) If you were able to chemically analyze your stomach fluids 30 minutes after taking two tablets, you would find
A) more hydrogen ions.
B) fewer hydrogen ions.
C) the same number of hydrogen ions.
D) that the pH in your stomach has decreased.

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Chapter 2 The Chemical Basis of Life

2.1 Multiple-Choice Questions

1)
Answer: C
Topic: 2.1
Skill: Knowledge/Comprehension

2)
Answer: B
Topic: 2.1
Skill: Knowledge/Comprehension

3)
Answer: D
Topic: 2.1
Skill: Knowledge/Comprehension

4)
Answer: B
Topic: 2.1
Skill: Knowledge/Comprehension

5)
Answer: C
Topic: 2.1
Skill: Application/Analysis

6)
Answer: A
Topic: 2.2
Skill: Knowledge/Comprehension

7)
Answer: D
Topic: 2.2
Skill: Knowledge/Comprehension

8)
Answer: A
Topic: 2.3
Skill: Knowledge/Comprehension

9)
Answer: A
Topic: 2.3
Skill: Application/Analysis

10)
Answer: C
Topic: 2.3
Skill: Knowledge/Comprehension

11)
Answer: C
Topic: 2.3
Skill: Application/Analysis

12)
Answer: C
Topic: 2.3
Skill: Knowledge/Comprehension

13)
Answer: C
Topic: 2.3
Skill: Application/Analysis

14)
Answer: A
Topic: 2.3
Skill: Knowledge/Comprehension

15)
Answer: D
Topic: 2.3
Skill: Knowledge/Comprehension

16)
Answer: B
Topic: 2.3
Skill: Knowledge/Comprehension

17)
Answer: C
Topic: 2.3
Skill: Application/Analysis

18)
Answer: C
Topic: 2.4
Skill: Knowledge/Comprehension

19)
Answer: B
Topic: 2.4
Skill: Knowledge/Comprehension

20)
Answer: B
Topic: 2.5
Skill: Knowledge/Comprehension

21)
Answer: C
Topic: 2.5
Skill: Knowledge/Comprehension

22)
Answer: B
Topic: 2.6
Skill: Knowledge/Comprehension

23)
Answer: A
Topic: 2.6
Skill: Application/Analysis

24)
Answer: D
Topic: 2.7
Skill: Knowledge/Comprehension

25)
Answer: A
Topic: 2.7
Skill: Synthesis/Evaluation

26)
Answer: A
Topic: 2.7
Skill: Application/Analysis

27)
Answer: A
Topic: 2.6, 2.7
Skill: Knowledge/Comprehension

28)
Answer: C
Topic: 2.8
Skill: Knowledge/Comprehension

29)
Answer: D
Topic: 2.8
Skill: Knowledge/Comprehension

30)
Answer: C
Topic: 2.8
Skill: Knowledge/Comprehension

31)
Answer: B
Topic: 2.8
Skill: Knowledge/Comprehension

32)
Answer: D
Topic: 2.8
Skill: Knowledge/Comprehension

33)
Answer: B
Topic: 2.8
Skill: Knowledge/Comprehension

34)
Answer: B
Topic: 2.9
Skill: Knowledge/Comprehension

35)
Answer: A
Topic: 2.9
Skill: Knowledge/Comprehension

36)
Answer: A
Topic: 2.9
Skill: Knowledge/Comprehension

37)
Answer: C
Topic: 2.10
Skill: Knowledge/Comprehension

38)
Answer: B
Topic: 2.10, 2.11
Skill: Knowledge/Comprehension

39)
Answer: D
Topic: 2.11
Skill: Application/Analysis

40)
Answer: A
Topic: 2.12
Skill: Knowledge/Comprehension

41)
Answer: A
Topic: 2.12
Skill: Knowledge/Comprehension

42)
Answer: A
Topic: 2.13
Skill: Application/Analysis

43)
Answer: D
Topic: 2.10, 2.11, 2.13
Skill: Application/Analysis

44)
Answer: C
Topic: 2.13
Skill: Knowledge/Comprehension

45)
Answer: C
Topic: 2.14
Skill: Knowledge/Comprehension

46)
Answer: C
Topic: 2.14
Skill: Knowledge/Comprehension

47)
Answer: A
Topic: 2.14
Skill: Knowledge/Comprehension

48)
Answer: C
Topic: 2.14
Skill: Knowledge/Comprehension

49)
Answer: C
Topic: 2.14
Skill: Knowledge/Comprehension

50)
Answer: C
Topic: 2.14
Skill: Knowledge/Comprehension

51)
Answer: B
Topic: 2.14
Skill: Application/Analysis

52)
Answer: D
Topic: 2.15
Skill: Knowledge/Comprehension

53)
Answer: B
Topic: 2.15
Skill: Knowledge/Comprehension

54)
Answer: D
Topic: 2.15
Skill: Synthesis/Evaluation

55)
Answer: B
Topic: 2.16
Skill: Application/Analysis

2.2 Art Questions

1)
Answer: D
Topic: 2.7
Skill: Knowledge/Comprehension

2)
Answer: C
Topic: 2.8
Skill: Application/Analysis

2.3 Scenario Questions

1)
Answer: A
Topic: 2.14
Skill: Application/Analysis

2)
Answer: B
Topic: 2.14
Skill: Application/Analysis