

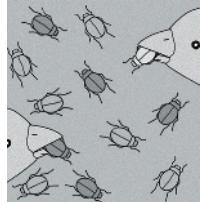
APPENDIX A Answers

Chapter 1

Figure Questions

Figure 1.4 Dividing the length of the prokaryotic cell by the length of the scale bar, the length of the prokaryotic cell is about 1.4 scale bars. Each scale bar represents 1 μm , so the prokaryotic cell is about 1.4 μm long. Dividing the diameter of the eukaryotic cell by the length of the scale bar, the diameter of the eukaryotic cell is about 8.2 scale bars, which is 8.2 μm . **Figure 1.10** The response to insulin is glucose uptake by cells and glucose storage in liver cells. The initial stimulus is a high glucose level, which is reduced when glucose is taken up by cells.

Figure 1.18



5 Environmental change resulting in survival of organisms with different traits

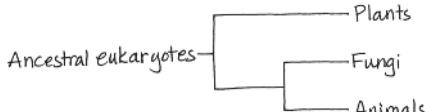
Concept Check 1.1

1. Examples: A molecule consists of *atoms* bonded together. Each organelle has an orderly arrangement of *molecules*. Photosynthetic plant cells contain *organelles* called chloroplasts. A tissue consists of a group of similar *cells*. Organs such as the heart are constructed from several *tissues*. A complex multicellular organism, such as a plant, has several types of *organs*, such as leaves and roots. A population is a set of *organisms* of the same species. A community consists of *populations* of the various species inhabiting a specific area. An ecosystem consists of a biological *community* along with the nonliving factors important to life, such as air, soil, and water. The biosphere is made up of all of Earth's *ecosystems*. **2.** (a) New properties emerge at successive levels of biological organization: Structure and function are correlated. (b) Life's processes involve the expression and transmission of genetic information. (c) Life requires the transfer and transformation of energy and matter. **3.** Sample answers: *Organization (Emergent properties)*: The ability of a human heart to pump blood requires an intact heart; it is not a capability of any of the heart's tissues or cells working alone. *Organization (Structure and function)*: The strong, sharp teeth of a wolf are well suited to grasping and dismembering its prey. *Information*: Human eye color is determined by the combination of genes inherited from the two parents. *Energy and Matter*: A plant, such as a grass, absorbs energy from the sun and transforms it into molecules that act as stored fuel. Animals can eat parts of the plant and use the food for energy to carry out their activities. *Interactions (Molecules)*: When your stomach is full, it signals your brain to decrease your appetite. *Interactions (Ecosystems)*: A mouse eats food, such as nuts or grasses, and deposits some waste products (such as feces and urine). Construction of a nest rearranges the environment and can hasten degradation of some of its components. The mouse may also act as food for a predator.

Concept Check 1.2

1. The naturally occurring heritable variation in a population is “edited” by natural selection because individuals with traits better suited to the environment survive and reproduce more successfully than others, and these traits are passed on to the next generation more often. Over time, better-suited individuals persist and their percentage in the population increases, while less well-suited individuals become less prevalent—a type of population editing. **2.** Here is one possible explanation: The ancestor species of the green warbler finch lived on an island where insects were a plentiful food source. Among individuals in the ancestor population, there was likely variation in beak shape and size. Individuals with slender, sharp beaks were likely more successful at picking up insects for food. Being well-nourished, they gave rise to more offspring than birds with thick, short beaks. Their many offspring inherited slender, sharp beaks (because of genetic information being passed from generation to generation, although Darwin didn't know this). In each generation, the offspring birds with the beaks of a shape best at picking up insects would eat more and have more offspring. Therefore, the green warbler finch of today has a slender beak that is very well matched (adapted) to its food source, insects.

3.



Concept Check 1.3

1. Mouse coat color matches the environment for both beach and inland populations. **2.** Inductive reasoning derives generalizations from specific cases; deductive reasoning predicts specific outcomes from general premises. **3.** Compared to a hypothesis, a scientific theory is usually more general and substantiated by a much greater amount of evidence. Natural selection is an explanatory idea that applies to all kinds of organisms and is supported by vast amounts of evidence of various kinds. **4.** Based on the mouse coloration in Figure 1.25, you might expect that the mice that live on the sandy soil would be lighter in color and those that live on the lava rock would be much darker. And in fact, that is what researchers have found. You would predict that each color of mouse would be less preyed upon in its native habitat than it would be in the other habitat. (Research results also support this prediction.) You could repeat the Hoekstra experiment with colored models, painted to resemble these two types of mouse. Or you could try transplanting some of each population to its non-native habitat and counting how many you can recapture over the next few days, then comparing the four samples as was done in Hoekstra's experiment. (The painted models are easier to recapture, of course!) In the live mouse transplantation experiment, you would have to do controls to eliminate the variable represented by the transplanted mice being in a new, unknown territory. You could control for the transplantation process by transplanting some dark mice from one area of lava rock to one far distant, and some light mice from one area of sandy soil to a distant area.

Concept Check 1.4

1. Science aims to understand natural phenomena and the underlying mechanisms that affect them, while technology involves application of scientific discoveries for a particular purpose or to solve a specific problem. **2.** Natural selection could be operating. Malaria is present in sub-Saharan Africa, so there might be an advantage to people with the sickle-cell disease form of the gene that makes them more able to survive and pass on their genes to offspring. Among those of African descent living in the United States, where malaria is absent, there would be no advantage, so they would be selected against more strongly, resulting in fewer individuals with the sickle-cell disease form of the gene.

Summary of Key Concepts Questions

1.1 Finger movements rely on the coordination of the many structural components of the hand (muscles, nerves, bones, etc.), each of which is composed of elements from lower levels of biological *organization* (cells, molecules). The development of the hand relies on the genetic *information* encoded in chromosomes found in cells throughout the body. To power the finger movements that result in a text message, muscle and nerve cells require chemical *energy* that they transform in powering muscle contraction or in propagating nerve impulses. Texting is in essence communication, an *interaction* that conveys information between organisms, in this case of the same species. **1.2** Ancestors of the beach mouse may have exhibited variations in their coat color. Because of the prevalence of visual predators, the better-camouflaged (lighter) mice in the beach habitat may have survived longer and been able to produce more offspring. Over time, a higher and higher proportion of individuals in the population would have had the adaptation of lighter fur that acted to camouflage the mouse in the beach habitat. **1.3** Gathering and interpreting data are core activities in the scientific process, and they are affected by, and affect in turn, three other arenas of the scientific process: exploration and discovery, community analysis and feedback, and societal benefits and outcomes. **1.4** Different approaches taken by scientists studying natural phenomena at different levels complement each other, so more is learned about each problem being studied. A diversity of backgrounds among scientists may lead to fruitful ideas in the same way that important innovations have often arisen where a mix of cultures coexist, due to multiple different viewpoints.

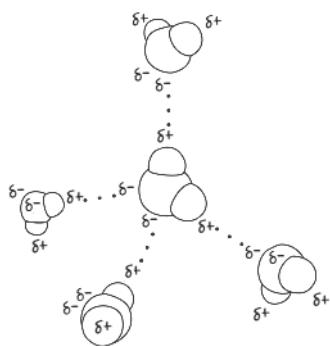
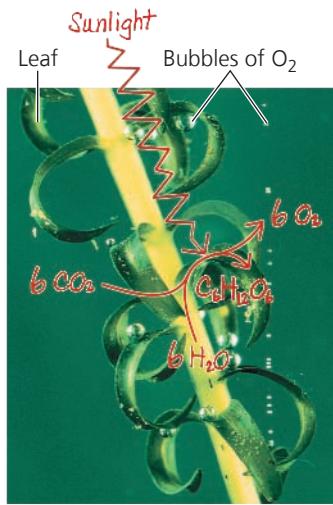
Test Your Understanding

1. B 2. C 3. C 4. B 5. C 6. A 7. D 8. Your figure should show the following: (1) for the biosphere, the Earth with an arrow coming out of a tropical ocean; (2) for the ecosystem, a distant view of a coral reef; (3) for the community, a collection of reef animals and algae, with corals, fishes, some seaweed, and any other organisms you can think of; (4) for the population, a group of fish of the same species; (5) for the organism, one fish from your population; (6) for the organ, the fish's stomach; (7) for a tissue, a group of similar cells from the stomach; (8) for a cell, one cell from the tissue, showing its nucleus and a few other organelles; (9) for an organelle, the nucleus, where most of the cell's DNA is located; and (10) for a molecule, a DNA double helix. Your sketches can be very rough!

Chapter 2

Figure Questions

Figure 2.7 Atomic number = 12; 12 protons, 12 electrons; three electron shells; 2 valence electrons

Figure 2.14 One possible answer:**Figure 2.17****Concept Check 2.1**

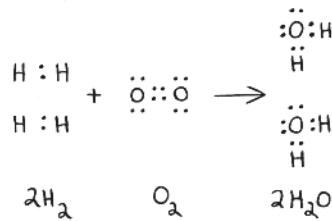
1. Table salt (sodium chloride) is made up of sodium and chlorine. We are able to eat the compound, showing that it has different properties from those of a metal (sodium) and a poisonous gas (chlorine). **2.** Yes. An organism requires trace elements, though only in small amounts. **3.** A person with an iron deficiency will probably show fatigue and other effects of a low oxygen level in the blood. (The condition is called anemia and can also result from too few red blood cells or abnormal hemoglobin.) **4.** Variant ancestral plants that could tolerate elevated levels of the elements in serpentine soils could grow and reproduce there. (Plants that were well adapted to nonserpentine soils would not be expected to survive in serpentine areas.) The offspring of the variants would also vary, with those most capable of thriving under serpentine conditions growing best and reproducing most. Over many generations, this probably led to the serpentine-adapted species we see today.

Concept Check 2.2

1. 7 2. ^{15}N 3. 9 electrons; two electron shells; 1s, 2s, 2p (three orbitals); 1 electron is needed to fill the valence shell. **4.** The elements in a row all have the same number of electron shells. All the elements in a column have the same number of electrons in their valence shells.

Concept Check 2.3

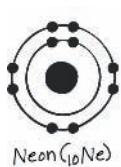
1. In this structure, each carbon atom has only three covalent bonds instead of the required four. **2.** The attraction between oppositely charged ions, forming ionic bonds. **3.** If you could synthesize molecules that mimic these shapes, you might be able to treat diseases or conditions caused by the inability of affected individuals to synthesize such molecules—or to block the function of such molecules if overproduction is the cause of the disorder.

Concept Check 2.4**1.**

2. At equilibrium, the forward and reverse reactions occur at the same rate. **3.** $\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{Energy}$. Glucose and oxygen react to form carbon dioxide and water, releasing energy. We breathe in oxygen because we need it for this reaction to occur, and we breathe out carbon dioxide because it is a by-product of this reaction. (This reaction is called cellular respiration, and you will learn more about it in Chapter 9.)

Summary of Key Concepts Questions

2.1 A compound is made up of two or more elements combined in a fixed ratio, while an element is a substance that cannot be broken down to other substances. **2.2**

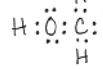


Both neon and argon have completed valence shells, containing 8 electrons. They do not have unpaired electrons that could participate in chemical bonds. **2.3** Electrons are shared equally between the two atoms in a nonpolar covalent bond. In a polar covalent bond, the electrons are drawn closer to the more electronegative atom. In the formation of ions, an electron is completely transferred from one atom to a much more electronegative atom. **2.4** The concentration of

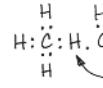
products would increase as the added reactants were converted to products. Eventually, an equilibrium would again be reached in which the forward and reverse reactions were proceeding at the same rate and the relative concentrations of reactants and products returned to where they were before the addition of more reactants.

Test Your Understanding

1.D 2.A 3.B 4.A 5.D 6.B 7.C 8.D

9. a.

This structure makes sense because all valence shells are complete, and all bonds have the correct number of electrons.

b.

This structure doesn't make sense because H has only 1 electron to share, so it cannot form bonds with 2 atoms.

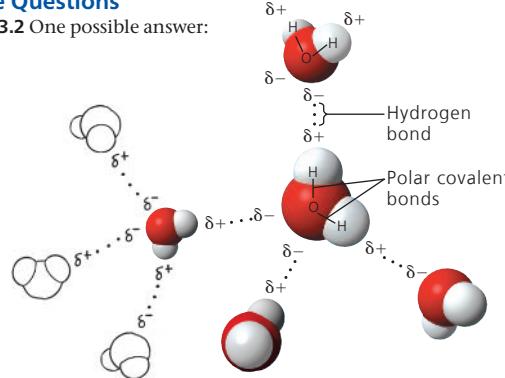
Chapter 3**Figure Questions****Figure 3.2** One possible answer:

Figure 3.8 Heating the solution would cause the water to evaporate faster than it is evaporating at room temperature. At a certain point, there wouldn't be enough water molecules to dissolve the salt ions. The salt would start coming out of solution and re-forming crystals. Eventually, all the water would evaporate, leaving behind a pile of salt like the original pile. **Figure 3.12** Adding excess CO_2 to the oceans ultimately reduces the rate at which calcification (by organisms) can occur.

Concept Check 3.1

1. Electronegativity is the attraction of an atom for the electrons of a covalent bond. Because oxygen is more electronegative than hydrogen, the oxygen atom in H_2O pulls electrons toward itself, resulting in two partial negative charges on the oxygen atom and a partial positive charge on each hydrogen atom. Atoms in neighboring water molecules with opposite partial charges are attracted to each other, forming a hydrogen bond. **2.** Due to its two polar covalent bonds, a water molecule has regions of partial negative charge on the O atom that allow it to form hydrogen bonds with hydrogen atoms on neighboring water molecules, and regions of partial positive charge on the H atoms that allow them to form hydrogen bonds with oxygen atoms on neighboring water molecules. **3.** The hydrogen atoms of one molecule, with their partial positive charges, would repel the hydrogen atoms of the adjacent molecule. **4.** The covalent bonds of water molecules would not be polar, so no regions of the molecule would carry partial charges and water molecules would not form hydrogen bonds with each other.

Concept Check 3.2

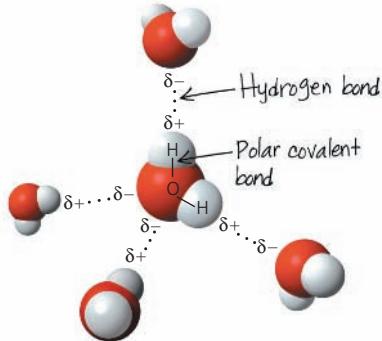
1. Hydrogen bonds hold neighboring water molecules together. This cohesion helps chains of water molecules move upward against gravity in water-conducting cells as water evaporates from the leaves. Adhesion between water molecules and the walls of the water-conducting cells also helps counter gravity. **2.** High humidity hampers cooling by suppressing the evaporation of sweat. **3.** As water freezes, it expands because water molecules move farther apart in forming ice crystals. When there is water in a crevice of a boulder, expansion due to freezing may crack the boulder. **4.** The hydrophobic substance repels water, perhaps helping to keep the ends of the legs from becoming coated with water and breaking through the surface. If the legs were coated with a hydrophilic substance, water would be drawn up them, possibly making it more difficult for the water strider to walk on water.

Concept Check 3.3

1. 10^5 , or 100,000 **2.** $[\text{H}^+] = 0.01 \text{ M} = 10^{-2} \text{ M}$, so $\text{pH} = 2$. **3.** $\text{CH}_3\text{COOH} \rightarrow \text{CH}_3\text{COO}^- + \text{H}^+$. CH_3COOH is the acid (the H^+ donor), and CH_3COO^- is the base (the H^+ acceptor). **4.** The pH of the water should decrease from 7 to about 2 (as mentioned in the text); the pH of the acetic acid solution will decrease only a small amount, because as a weak acid, it acts (like carbonic acid) as a buffer. The reaction shown for question 3 will shift to the left, with CH_3COO^- accepting the influx of H^+ and becoming CH_3COOH molecules.

Summary of Key Concepts Questions

3.1

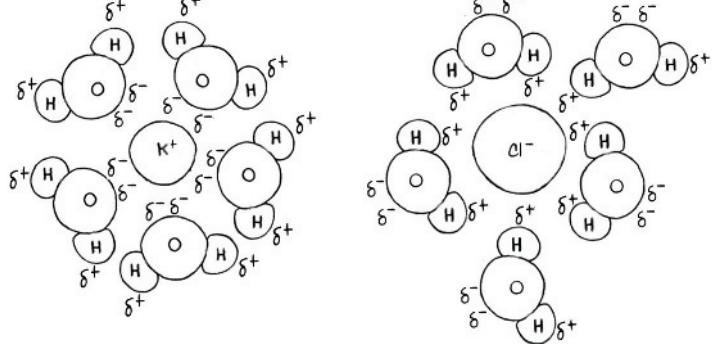


No. A covalent bond is a strong bond in which electrons are shared between two atoms. A hydrogen bond is a weak bond, which does not involve electron sharing, but is simply an attraction between two partial charges on neighboring atoms. **3.2** Ions dissolve in water when polar water molecules form a hydration shell around them, with partially charged regions of water molecules being attracted to ions of the opposite charge. Polar molecules dissolve as water molecules form hydrogen bonds with them and surround them. Solutions are homogeneous mixtures of solute and solvent. **3.3** The concentration of hydrogen ions (H^+) would be 10^{-11} , and the pH of the solution would be 11.

Test Your Understanding

1. C 2. D 3. C 4. A 5. D

6.



7. Due to intermolecular hydrogen bonds, water has a high specific heat (the amount of heat required to increase the temperature of water by 1°C). When water is heated, much of the heat is absorbed in breaking hydrogen bonds before the water molecules increase their motion and the temperature increases. Conversely, when water is cooled, many H bonds are formed, which releases a significant amount of heat. This release of heat can provide some protection against freezing of the plants' leaves, thus protecting the cells from damage. **8.** Both global warming and ocean acidification are caused by increasing levels of carbon dioxide in the atmosphere, the result of burning fossil fuels.

Chapter 4

Figure Questions

Figure 4.2 Because the concentration of the reactants influences the equilibrium (as discussed in Concept 2.4), there might have been more HCN relative to CH_2O since there would have been a higher concentration of the reactant gas containing nitrogen.

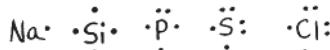
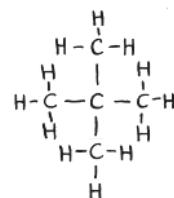
Figure 4.4

Figure 4.6 The tails of fats contain only carbon-hydrogen bonds, which are relatively nonpolar. Because the tails occupy the bulk of a fat molecule, they make the molecule as a whole nonpolar and therefore incapable of forming hydrogen bonds with water.

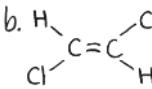
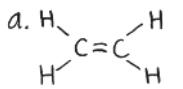
Figure 4.7

Concept Check 4.1

1. The sparks provided energy needed for the inorganic molecules in the atmosphere to react with each other. (You'll learn more about energy and chemical reactions in Chapter 8.)

Concept Check 4.2

1.

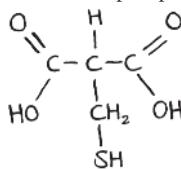


2. The forms of C_4H_{10} in (b) are structural isomers, as are the butenes (forms of C_4H_8) in (c). **3.** Both consist largely of hydrocarbon chains, which provide fuel—gasoline for engines and fats for plant embryos and animals. Reactions of both types of molecules release energy. **4.** No. There is not enough diversity in propane's atoms. It can't form structural isomers because there is only one way for three carbons to attach to each other (in a line). There are no double bonds, so *cis-trans* isomers are not possible. Each carbon has at least two hydrogens attached to it, so the molecule is symmetrical and cannot have enantiomers.

Concept Check 4.3

1. An amino acid has both an amino group ($-\text{NH}_2$), which makes it an amine, and a carboxyl group ($-\text{COOH}$), which makes it a carboxylic acid. **2.** The ATP molecule loses a phosphate, becoming ADP.

3.



A chemical group that can act as a base has been replaced with a group that can act as an acid, increasing the acidic properties of the molecule. The shape of the molecule would also change, likely changing the molecules with which it can interact. The original cysteine molecule has an asymmetric carbon in the center. After replacement of the amino group with a carboxyl group, this carbon is no longer asymmetric.

Summary of Key Concepts Questions

4.1 Miller showed that organic molecules could form under the physical and chemical conditions estimated to have been present on early Earth. This abiotic synthesis of organic molecules would have been a first step in the origin of life.

4.2 Acetone and propanal are structural isomers. Acetic acid and glycine have no asymmetric carbons, whereas glycerol phosphate has one. Therefore, glycerol phosphate can exist as forms that are enantiomers, but acetic acid and glycine cannot. **4.3** The methyl group is nonpolar and not reactive. The other six groups are called functional groups because they can participate in chemical reactions. Also, all except the sulphydryl group are hydrophilic, increasing the solubility of organic compounds in water.

Test Your Understanding

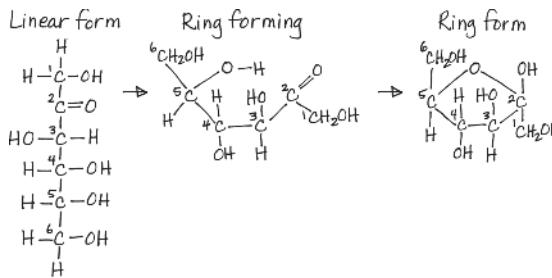
1. B 2. B 3. C 4. C 5. A 6. B 7. A

8. The molecule on the right; the middle carbon is asymmetric.

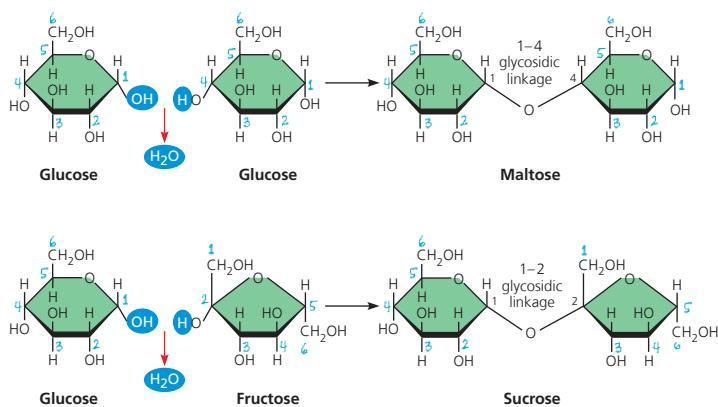
9. $\cdot\ddot{\text{Si}}\cdot$ Silicon has 4 valence electrons, the same number as carbon. Therefore, silicon would be able to form long chains, including branches, that could act as skeletons for large molecules. It would clearly do this much better than neon (with no valence electrons) or aluminum (with 3 valence electrons).

Chapter 5

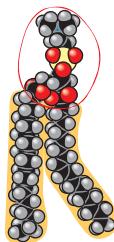
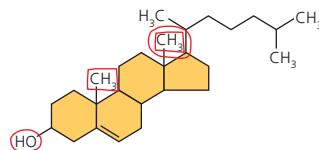
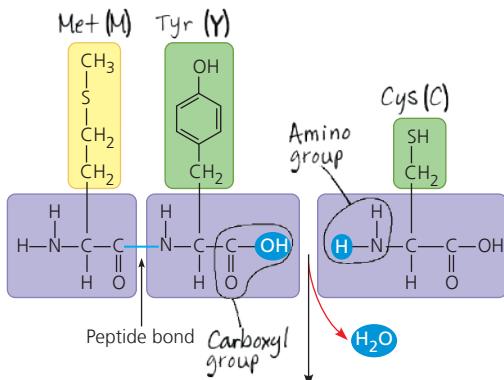
Figure Questions

Figure 5.3 Glucose and fructose are structural isomers.**Figure 5.4**

Four carbons are in the fructose ring, and two are not. (The latter two carbons are attached to carbons 2 and 5, which are in the ring.) The fructose ring differs from the glucose ring, which has five carbons in the ring and one that is not. (Note that the orientation of this fructose molecule is flipped horizontally relative to that of the one in Figure 5.5b; also, note that the oxygen on carbon 2 lost its proton and that the oxygen on carbon 2, which used to be the carbonyl oxygen, gained a proton.)

Figure 5.5

(a) In maltose, the linkage is called a 1-4 glycosidic linkage because the number 1 carbon in the left monosaccharide (glucose) is linked to the number 4 carbon in the right monosaccharide (also glucose). (b) In sucrose, the linkage is called a 1-2 glycosidic linkage because the number 1 carbon in the left monosaccharide (glucose) is linked to the number 2 carbon in the right monosaccharide (fructose). (Note that the fructose molecule is oriented differently from glucose in Figures 5.4 and 5.5b, where carbon 2 is on the right. In fructose in Figure 5.5b and here, carbon 2 of fructose is on the left.)

Figure 5.11**Figure 5.12****Figure 5.15****Figure 5.16** (1) The polypeptide backbone is most easily followed in the ribbon model.

(2)

(3) The point of this diagram is to show that a pancreas cell secretes insulin proteins, so the shape is not important to the process being illustrated. **Figure 5.17** We can see that their complementary shapes allow the two proteins to fit together quite precisely. **Figure 5.19** The R group on glutamic acid is acidic and hydrophilic, whereas that on valine is nonpolar and hydrophobic. Therefore, it is unlikely that valine and glutamic acid participate in the same intramolecular interactions. A change in these interactions could (and does) cause a disruption of molecular structure. **Figure 5.26** Using a genomics approach allows us to use gene sequences to identify species and to learn about evolutionary relationships among any two species. This is because all species are related by their evolutionary history, and the evidence is in the DNA sequences. Proteomics—looking at proteins that are expressed—allows us to learn about how organisms or cells are functioning at a given time or in an association with another species.

Concept Check 5.1

- The four main classes are proteins, carbohydrates, lipids, and nucleic acids. Lipids are not polymers.
- Nine, with one water molecule required to hydrolyze each connection between adjacent monomers
- The amino acids in the fish protein must be released in hydrolysis reactions and incorporated into other proteins in dehydration reactions.

Concept Check 5.2

- $C_3H_6O_3$
- $C_{12}H_{22}O_{11}$
- The antibiotic treatment is likely to have killed the cellulose-digesting prokaryotes in the cow's gut. The absence of these prokaryotes would hamper the cow's ability to obtain energy from food and could lead to weight loss and possibly death. Thus, prokaryotic species are reintroduced, in appropriate combinations, in the gut culture given to treated cows.

Concept Check 5.3

- Both have a glycerol molecule attached to fatty acids. The glycerol of a fat has three fatty acids attached, whereas the glycerol of a phospholipid is attached to two fatty acids and one phosphate group.
- Human sex hormones are steroids, a type of compound that is hydrophobic and thus classified as a lipid.
- The oil droplet membrane could consist of a single layer of phospholipids rather than a bilayer, because an arrangement in which the hydrophobic tails of the membrane phospholipids were in contact with the hydrocarbon regions of the oil molecules would be more stable.

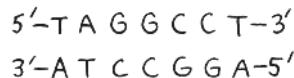
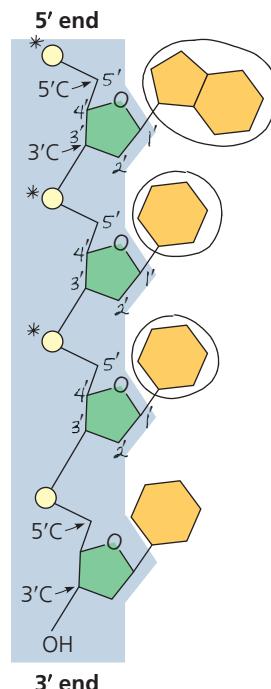
Concept Check 5.4

- Secondary structure involves hydrogen bonds between atoms of the polypeptide backbone. Tertiary structure involves interactions between atoms of the side chains of the amino acid subunits.
- The two ring forms of glucose are called α and β , depending on how the glycosidic bond dictates the position of a hydroxyl group.
- Proteins have α helices and β pleated sheets, two types of repeating structures found in polypeptides due to interactions between the repeating constituents of the chain (not the side chains).
- The hemoglobin molecule is made up of two types of polypeptides: It contains two molecules each of α -globin and β -globin.
- During formation of a polypeptide by polymerization of amino acids, the amino group of one amino acid reacts with the carboxyl group of the next, forming a peptide bond. Therefore, in a polypeptide, there is only one amino group on the N-terminus and one carboxyl group on the C-terminus, along with any carboxyl groups or amino groups located in the amino acid side chains (R groups).
- These are all nonpolar, hydrophobic amino acids, so you would expect this region to be located in the interior of the folded polypeptide, where it would not contact the aqueous environment inside the cell.

Concept Check 5.5

1.

2.

**Concept Check 5.6**

- The DNA of an organism encodes all of its proteins, and proteins are the molecules that carry out the work of cells, whether an organism is unicellular or multicellular. By knowing the DNA sequence of an organism, scientists would be able to catalog the protein sequences as well.
- Ultimately, the DNA sequence carries the information necessary to make the proteins that determine the traits of a particular species. Because the traits of the two species are similar, you would expect the proteins to be similar as well, and therefore the gene sequences should also have a high degree of similarity.

Summary of Key Concepts Questions

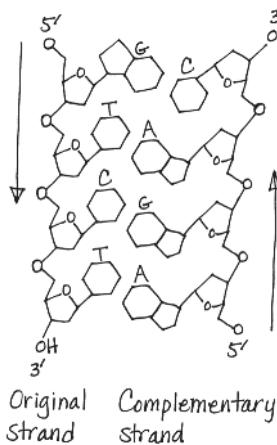
5.1 The polymers of large carbohydrates (polysaccharides), proteins, and nucleic acids are built from three different types of monomers (monosaccharides, amino acids, and nucleotides, respectively). **5.2** Both starch and cellulose are polymers of glucose, but the glucose monomers are in the α configuration in starch and the β configuration in cellulose. The glycosidic linkages thus have different geometries, giving the polymers different shapes and thus different properties. Starch is an energy-storage compound in plants; cellulose is a structural component of plant cell walls. Humans can hydrolyze starch to provide energy but cannot hydrolyze cellulose. Cellulose aids in the passage of food through the digestive tract. **5.3** Lipids are not polymers because they do not exist as a chain of linked monomers. They are not considered macromolecules because they do not reach the giant size of many polysaccharides, proteins, and nucleic acids. **5.4** A polypeptide, which may consist of hundreds of amino acids in a specific sequence (primary structure), has regions of coils and pleats (secondary structure), which are then folded into irregular contortions (tertiary structure) and may be noncovalently associated with other polypeptides (quaternary structure). The linear order of amino acids, with the varying properties of their side chains (R groups), determines what secondary and tertiary structures will form to produce a protein. The resulting unique three-dimensional shapes of proteins are key to their specific and diverse functions. **5.5** The complementary base pairing of the two strands of DNA makes possible the precise replication of DNA every time a cell divides, ensuring that genetic information is faithfully transmitted. In some types of RNA, complementary base pairing enables RNA molecules to assume specific three-dimensional shapes that facilitate diverse functions. **5.6** You would expect the human gene sequence to be most similar to that of the mouse (another mammal), then to that of the fish (another vertebrate), and least similar to that of the fruit fly (an invertebrate).

Test Your Understanding

1. D 2. A 3. B 4. A 5. B 6. B 7. C
8.

	Monomers or Components	Polymer or larger molecule	Type of linkage
Carbohydrates	Monosaccharides	Polysaccharides	Glycosidic linkages
Fats	Fatty acids	Triacylglycerols	Ester linkages
Proteins	Amino acids	Polypeptides	Peptide bonds
Nucleic acids	Nucleotides	Polynucleotides	Phosphodiester linkages

9.



Chapter 6

Figure Questions

Figure 6.3 The cilia in the lower portion of the TEM were oriented lengthwise in the plane of the slice, while those in the upper portion of the TEM were oriented perpendicular to the plane of the slice. Therefore, the cilia in the lower portion were cut in longitudinal section, and the cilia in the upper portion were cut in cross section. **Figure 6.4** You would use the pellet from the final fraction, which is rich in ribosomes. These are the sites of protein translation.

Figure 6.6 The dark bands in the TEM correspond to the hydrophilic heads of the phospholipids, while the light band corresponds to the hydrophobic fatty acid tails of the phospholipids. **Figure 6.9** The DNA in a chromosome dictates synthesis of a messenger RNA (mRNA) molecule, which then moves out to the cytoplasm. There, the information is used for the production, on ribosomes, of proteins that carry out cellular functions. **Figure 6.10** Any of the bound

ribosomes (attached to the endoplasmic reticulum) could be circled, because any could be making a protein that will be secreted. **Table 6.1** Three dimers

Figure 6.22 Each centriole has nine sets of 3 microtubules, so the entire centrosome (two centrioles) has 54 microtubules. Each microtubule consists of a helical array of tubulin dimers (as shown in Table 6.1).

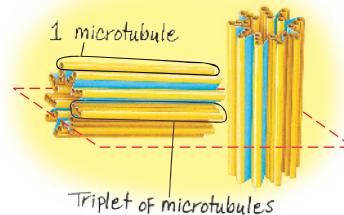


Figure 6.24 The two central microtubules terminate above the basal body, so they aren't present at the level of the cross section through the basal body, indicated by the lower red rectangle shown in the EM on the left.

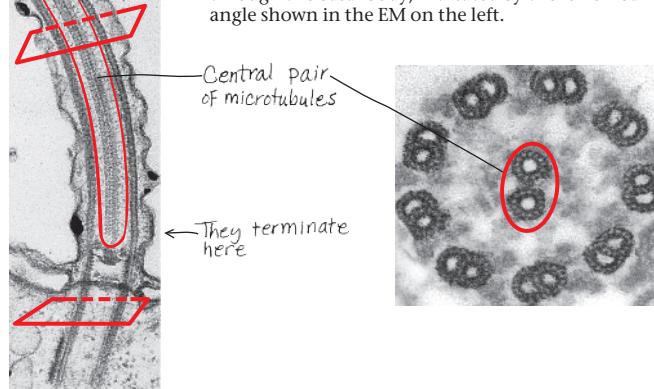


Figure 6.32 (1) nuclear pore, ribosome, proton pump, cyt c. (2) As shown in the figure, the enzyme RNA polymerase moves along the DNA, transcribing the genetic information into an mRNA molecule. Given that RNA polymerase is somewhat larger than a nucleosome, the enzyme would not be able to fit between the histone proteins of the nucleosome and the DNA itself. Thus, the group of histone proteins must be separated from or moved along the DNA somehow in order for the RNA polymerase enzyme to access the DNA. (3) A mitochondrion.

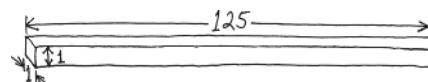
Concept Check 6.1

1. Stains used for light microscopy are colored molecules that bind to cell components, affecting the light passing through, while stains used for electron microscopy involve heavy metals that affect the beams of electrons.
2. (a) Light microscope, (b) scanning electron microscope.

Concept Check 6.2

1. See Figure 6.8.

2.



This cell would have the same volume as the cells in columns 2 and 3 in Figure 6.7 but proportionally more surface area than that in column 2 and less than that in column 3. Thus, the surface-to-volume ratio should be greater than 1.2 but less than 6. To obtain the surface area, you would add the area of the six sides (the top, bottom, sides, and ends): $125 + 125 + 125 + 125 + 1 + 1 = 502$. The surface-to-volume ratio equals 502 divided by a volume of 125, or roughly 4.0.

Concept Check 6.3

1. Ribosomes in the cytoplasm translate the genetic message, carried from the DNA in the nucleus by mRNA, into a polypeptide chain. 2. Nucleoli consist of DNA and the ribosomal RNAs (rRNAs) made according to its genes in the DNA, as well as proteins imported from the cytoplasm. Together, the rRNAs and proteins are assembled into large and small ribosomal subunits. (These are exported through nuclear pores to the cytoplasm, where they will participate in polypeptide synthesis.) 3. Each chromosome consists of one long DNA molecule attached to numerous protein molecules, a combination called chromatin. As a cell begins division, each chromosome becomes "condensed" as its diffuse mass of chromatin coils up.

Concept Check 6.4

1. The primary distinction between rough and smooth ER is the presence of bound ribosomes on the rough ER. Both types of ER make phospholipids, but membrane proteins and secretory proteins are all produced by the ribosomes on the rough ER. The smooth ER also functions in detoxification, carbohydrate metabolism, and storage of calcium ions. 2. Transport vesicles move membranes and the substances they enclose between other components of the

endomembrane system. **3.** The mRNA is synthesized in the nucleus and then passes out through a nuclear pore to the cytoplasm, where it is translated on a bound ribosome, attached to the rough ER. The protein is synthesized into the lumen of the ER and may be modified there. A transport vesicle carries the protein to the Golgi apparatus. After further modification in the Golgi, another transport vesicle carries it back to the ER, where it will perform its cellular function.

Concept Check 6.5

1. Both organelles are involved in energy transformation, mitochondria in cellular respiration and chloroplasts in photosynthesis. They both have multiple membranes that separate their interiors into compartments. In both organelles, the innermost membranes—cristae, or infoldings of the inner membrane, in mitochondria and the thylakoid membranes in chloroplasts—have large surface areas with embedded enzymes that carry out their main functions. **2.** Yes. Plant cells are able to make their own sugar by photosynthesis, but mitochondria in plant cells (which are, of course, eukaryotic) are the organelles that are able to generate ATP molecules to be used for energy generation from sugars, a function required in all cells. **3.** Mitochondria and chloroplasts are not derived from the ER, nor are they connected physically or via transport vesicles to organelles of the endomembrane system. Mitochondria and chloroplasts are structurally quite different from vesicles derived from the ER, which are bounded by a single membrane.

Concept Check 6.6

1. Dynein arms, powered by ATP, move neighboring doublets of microtubules relative to each other. Because they are anchored within the flagellum or cilium and with respect to one another, the doublets bend instead of sliding past each other. Synchronized bending of the nine microtubule doublets brings about bending of both cilia and flagella. **2.** Such individuals have defects in the microtubule-based movement of cilia and flagella. Thus, the sperm can't move because of malfunctioning or nonexistent flagella, and the airways are compromised because cilia that line the trachea malfunction or don't exist, and so mucus cannot be cleared from the lungs.

Concept Check 6.7

1. The most obvious difference is the presence of direct cytoplasmic connections between cells of plants (plasmodesmata) and animals (gap junctions). These connections result in the cytoplasm being continuous between adjacent cells. **2.** The cell would not be able to function properly and would probably soon die, as the cell wall or ECM must be permeable to allow the exchange of matter between the cell and its external environment. Molecules involved in energy production and use must be allowed entry, as well as those that provide information about the cell's environment. Other molecules, such as products synthesized by the cell for export and the by-products of cellular respiration, must be allowed to exit. **3.** The parts of the protein that face aqueous regions would be expected to have polar or charged (hydrophilic) amino acids, while the parts that go through the membrane would be expected to have nonpolar (hydrophobic) amino acids. You would predict polar or charged amino acids at each end (tail), in the region of the cytoplasmic loop, and in the regions of the two extracellular loops. You would predict nonpolar amino acids in the four regions that go through the membrane between the tails and loops.

Concept Check 6.8

1. *Colpidium colpoda* moves around in freshwater using cilia, projections from the plasma membrane that enclose microtubules in a “9 + 2” arrangement. The interactions between motor proteins and microtubules cause the cilia to bend synchronously, propelling the cell through the water. This is powered by ATP, obtained via breaking down sugars from food in a process that occurs in mitochondria. *C. colpoda* obtains bacteria as their food source, maybe via the same process (involving filopodia) the macrophage uses in Figure 6.31. This process uses actin filaments and other elements of the cytoskeleton to ingest the bacteria. Once ingested, the bacteria are broken down by enzymes in lysosomes. The proteins involved in all of these processes are encoded by genes on DNA in the nucleus of the *C. colpoda*.

Summary of Key Concepts Questions

6.1 Both light and electron microscopy allow cells to be studied visually, thus helping us understand internal cellular structure and the arrangement of cell components. Cell fractionation techniques separate out different groups of cell components, which can then be analyzed biochemically to determine their function. Performing microscopy on the same cell fraction helps to correlate the biochemical function of the cell with the cell component responsible.

6.2 The separation of different functions in different organelles has several advantages. Reactants and enzymes can be concentrated in one area instead of spread throughout the cell. Reactions that require specific conditions, such as a lower pH, can be compartmentalized. And enzymes for specific reactions are often embedded in the membranes that enclose or partition an organelle.

6.3 The nucleus contains the genetic material of the cell in the form of DNA, which specifies messenger RNA, which in turn provides instructions for the synthesis of proteins (including the proteins that make up part of the ribosomes). DNA also codes for ribosomal RNAs, which are combined with proteins in the nucleolus into the subunits of ribosomes. Within the cytoplasm, ribosomes join with mRNA to build polypeptides, using the genetic information in the mRNA. **6.4** Transport vesicles move proteins and membranes synthesized by the rough ER to the Golgi for further processing and then to the plasma membrane, lysosomes, or other locations in the cell, including back to the ER.

6.5 According to the endosymbiont theory, mitochondria originated from an

oxygen-using prokaryotic cell that was engulfed by a cell that was ancestral to eukaryotic cells. Over time, the host and endosymbiont evolved into a single unicellular organism containing a mitochondrion. Chloroplasts originated when at least one of these eukaryotic cells containing mitochondria engulfed and then retained a photosynthetic prokaryote, which eventually evolved into a chloroplast. **6.6** Inside the cell, motor proteins interact with components of the cytoskeleton to move cellular parts. Motor proteins “walk” vesicles along microtubules. The movement of cytoplasm within a cell involves interactions of the motor protein myosin and microfilaments (actin filaments). Whole cells can be moved by the rapid bending of flagella or cilia, which is caused by the motor protein-powered sliding of microtubules within these structures. Cell movement can also occur when pseudopodia form at one end of a cell (caused by actin polymerization into a filamentous network), followed by contraction of the cell toward that end; this amoeboid movement is powered by interactions of microfilaments with myosin. Interactions of motor proteins and microfilaments in muscle cells causes muscle contraction that can propel whole organisms (for example, by walking or swimming). **6.7** A plant cell wall is primarily composed of microfibrils of cellulose embedded in other polysaccharides and proteins. The ECM of animal cells is primarily composed of collagen and other protein fibers, such as fibronectin and other glycoproteins. These fibers are embedded in a network of carbohydrate-rich proteoglycans. A plant cell wall provides structural support for the cell and, collectively, for the plant body. In addition to giving support, the ECM of an animal cell allows for communication of environmental changes into the cell. **6.8** The nucleus houses the chromosomes; each is made up of proteins and a single DNA molecule. The genes that exist along the DNA carry the genetic information necessary to make the proteins involved in ingesting a bacterial cell, such as the actin of microfilaments that form pseudopodia (filopodia), the proteins in the mitochondria responsible for providing the necessary ATP, and the enzymes present in the lysosomes that will digest the bacterial cell.

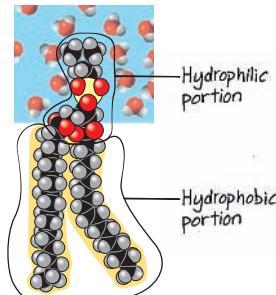
Test Your Understanding

1. B 2. C 3. B 4. A 5. D 6. See Figure 6.8.

Chapter 7

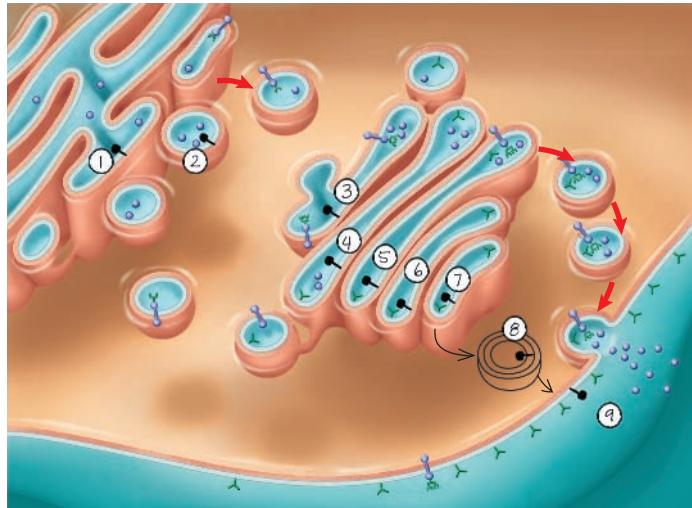
Figure Questions

Figure 7.2



The hydrophilic portion is in contact with an aqueous environment (cytosol or extracellular fluid), and the hydrophobic portion is in contact with the hydrophobic portions of other phospholipids in the interior of the bilayer. **Figure 7.4** You couldn't rule out movement of proteins within membranes of the same species. You might propose that the membrane lipids and proteins from one species weren't able to mingle with those from the other species because of some incompatibility. **Figure 7.7** A transmembrane protein like the dimer in (f) might change its shape upon binding to a particular extracellular matrix (ECM) molecule. The new shape might enable the interior portion of the protein to bind to a second, cytoplasmic protein that would relay the message to the inside of the cell, as shown in (c). **Figure 7.8** The shape of a protein on the HIV surface is likely to be complementary to the shape of the receptor (CD4) and also to that of the co-receptor (CCR5). A molecule with a shape similar to that of the HIV surface protein could bind CCR5, blocking HIV binding. (Another answer would be a molecule that bound to CCR5 and changed the shape of CCR5 so it could no longer bind HIV; in fact, this is how maraviroc works.)

Figure 7.9



The protein would contact the extracellular fluid. (Because one end of the protein is in the ER membrane, no part of the protein extends into the cytoplasm.) The part of the protein not in the membrane extends into the ER lumen. Once the vesicle fuses with the plasma membrane, the “inside” of the ER membrane, facing the lumen, will become the “outside” of the plasma membrane, facing the extracellular fluid. **Figure 7.12** The orange dye would be evenly distributed throughout the solution on both sides of the membrane. The solution levels would not be affected because the orange dye can diffuse through the membrane and equalize its concentration. Thus, no additional osmosis would take place in either direction. In this experiment, the membrane is meant to represent the plasma membrane of a cell. **Figure 7.13** The cells take up water and become turgid, causing the stalk to lose its limpness and become crisp. **Figure 7.16** The sodium ion concentration ($[Na^+]$) is low inside the cell and high outside, while potassium ion concentration ($[K^+]$) is low outside the cell and high inside. Three Na^+ ions are moved out of the cell and two K^+ ions into the cell for each cycle. **Figure 7.17** The diamond solutes are moving into the cell (downward), and the round solutes are moving out of the cell (upward); each is moving against its concentration gradient. **Figure 7.21** (a) In the micrograph of the algal cell, the diameter of the algal cell is about 2.3 times longer than the scale bar, which represents 5 μm , so the diameter of the algal cell is about 11.5 μm . (b) In the micrograph of the coated vesicle, the diameter of the coated vesicle is about 1.2 times longer than the scale bar, which represents 0.25 μm , so the diameter of the coated vesicle is about 0.3 μm . (c) Therefore, the food vacuole around the algal cell will be about $40 \times$ larger than the coated vesicle.

Concept Check 7.1

- They are on the inside of the transport vesicle membrane.
- The grasses living in the cooler region would be expected to have more unsaturated fatty acids in their membranes because those fatty acids remain fluid at lower temperatures. The grasses living immediately adjacent to the hot springs would be expected to have more saturated fatty acids, which would allow the fatty acids to “stack” more closely, making the membranes less fluid and therefore helping them to stay intact at higher temperatures. (In plants, cholesterol is generally not used to moderate the effects of temperature on membrane fluidity because it is found at vastly lower levels in membranes of plant cells than in those of animal cells.)

Concept Check 7.2

- O_2 and CO_2 are both small, nonpolar molecules that can easily pass through the hydrophobic interior of a membrane.
- Water is a polar molecule, so it cannot pass very rapidly through the hydrophobic region in the middle of a phospholipid bilayer.
- The hydronium ion is charged, while glycerol is not. Charge is probably more significant than size as a basis for exclusion by the aquaporin channel.

Concept Check 7.3

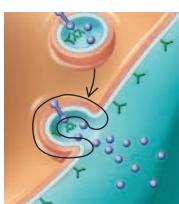
- CO_2 is a nonpolar molecule that can diffuse through the plasma membrane. As long as it diffuses away so that the concentration remains low outside the cell, it will continue to exit the cell in this way. (This is the opposite of the case for O_2 , described in this section of the text.)
- Paramecium*'s contractile vacuole will become less active. The vacuole pumps out excess water that accumulates in the cell; this accumulation occurs only in a hypotonic environment.

Concept Check 7.4

- These pumps use ATP. To establish a voltage, ions have to be pumped against their gradients, which requires energy.
- Each ion is being transported against its electrochemical gradient. If either ion were transported down its electrochemical gradient, this would be considered cotransport.
- The internal environment of a lysosome is acidic, so it has a higher concentration of H^+ than does the cytoplasm. Therefore, you might expect the membrane of the lysosome to have a proton pump such as that shown in Figure 7.18 to pump H^+ into the lysosome.

Concept Check 7.5

- Exocytosis. When a transport vesicle fuses with the plasma membrane, the vesicle membrane becomes part of the plasma membrane.
- The glycoprotein is synthesized in the ER lumen, moves through the Golgi apparatus, and then travels in a vesicle to the plasma membrane, where it undergoes exocytosis and becomes part of the ECM.



Summary of Key Concepts Questions

- 7.1** Plasma membranes define the cell by separating the cellular components from the external environment. This allows conditions inside cells to be controlled by membrane proteins, which regulate entry and exit of molecules and even cell function (see Figure 7.7). The processes of life can be carried out inside the controlled environment of the cell, so membranes are crucial. In eukaryotes, membranes also function to subdivide the cytoplasm into different compartments where distinct processes can occur, even under differing conditions such as low or high pH.
- 7.2** Aquaporins are channel proteins that greatly increase the permeability of a membrane to water molecules, which are polar and therefore do not readily diffuse through the hydrophobic interior of the membrane.
- 7.3** There

will be a net diffusion of water out of a cell into a hypertonic solution. The free water concentration is higher inside the cell than in the solution (where not as many water molecules are free, because many are clustered around the numerous solute particles).

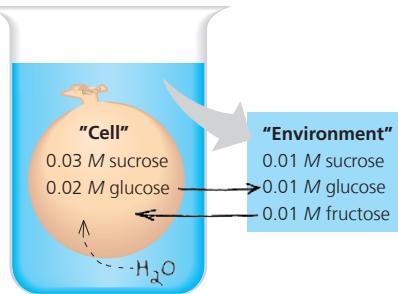
7.4 One of the solutes moved by the cotransporter is actively transported against its concentration gradient. The energy for this transport comes from the concentration gradient of the other solute, which was established by an electrogenic pump that used energy to transport the other solute across the membrane. Because energy is required overall to drive this process (because ATP is used to establish the concentration gradient), it is considered active transport.

7.5 In receptor-mediated endocytosis, specific molecules bind to receptors on the plasma membrane in a region where a coated pit develops. The cell can acquire bulk quantities of those specific molecules when the coated pit forms a vesicle and carries the bound molecules into the cell.

Test Your Understanding

- B
- C
- A
- C
- B

- (a)



- (b) The solution outside is hypotonic. It has less sucrose, which is a nonpenetrating solute.
- (c) See answer for (a).
- (d) The artificial cell will become more turgid.
- (e) Eventually, the two solutions will have the same solute concentrations. Even though sucrose can't move through the membrane, water flow (osmosis) will lead to isotonic conditions.

Chapter 8

Figure Questions

Figure 8.5 With a proton pump (Figure 7.18), the energy stored in ATP is used to pump protons across the membrane and build up a higher (nonrandom) concentration outside of the cell, so this process results in higher free energy. When solute molecules (analogous to hydrogen ions) are uniformly distributed, similar to the random distribution in the bottom of (b), the system has less free energy than it does in the top of (b). The system in the bottom can do no work. Because the concentration gradient created by a proton pump (Figure 7.18) represents higher free energy, this system has the potential to do work once there is a higher concentration of protons on one side of the membrane (as you will see in Figure 9.15).

Figure 8.10 Glutamic acid (Glu) has a carboxyl group at the end of its R group. Glutamine (Gln) has exactly the same structure as glutamic acid, except that there is an amino group in place of the $-O^-$ on the R group. (This O atom on the R group leaves during the synthesis reaction.) Thus, in this figure, Gln is drawn as a Glu with an attached NH_2 .

Figure 8.13

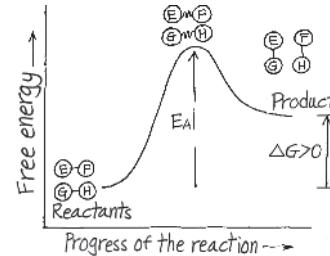
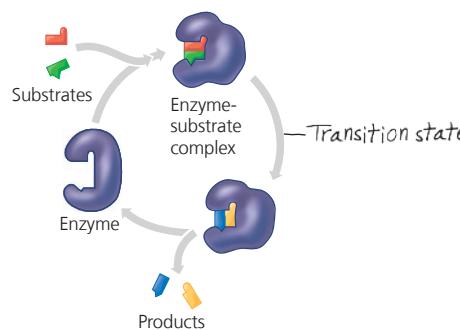


Figure 8.16



Concept Check 8.1

- The second law is the trend toward randomization, or increasing entropy. When the concentrations of a substance on both sides of a membrane are equal, the distribution is more random than when they are unequal. Diffusion of a substance to a region where it is initially less concentrated increases entropy,

making it an energetically favorable (spontaneous) process as described by the second law. This explains the process seen in Figure 7.11. **2.** The apple has potential energy in its position hanging on the tree, and the sugars and other nutrients it contains have chemical energy. The apple has kinetic energy as it falls from the tree to the ground. Finally, when the apple is digested and its molecules broken down, some of the chemical energy is used to do work, and the rest is lost as thermal energy. **3.** The sugar crystals become less ordered (entropy increases) as they dissolve and become randomly spread out in the water. Over time, the water evaporates, and the crystals form again because the water volume is insufficient to keep them in solution. While the reappearance of sugar crystals may represent a “spontaneous” increase in order (decrease in entropy), it is balanced by the decrease in order (increase in entropy) of the water molecules, which changed from a relatively compact arrangement as liquid water to a much more dispersed and disordered form as water vapor.

Concept Check 8.2

1. Cellular respiration is a spontaneous and exergonic process. The energy released from glucose is used to do work in the cell or is lost as heat. **2.** Catabolism breaks down organic molecules, releasing their chemical energy and resulting in smaller products with more entropy, as when moving from the top to the bottom of Figure 8.5c. Anabolism consumes energy to synthesize larger molecules from simpler ones, as when moving from the bottom to the top of part (c). **3.** The reaction is exergonic because it releases energy—in this case, in the form of light. (This is a nonbiological version of the bioluminescence seen in Figure 8.1.)

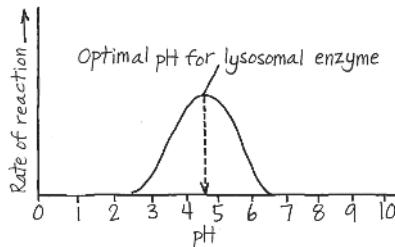
Concept Check 8.3

1. ATP usually transfers energy to an endergonic process by phosphorylating (adding a phosphate group to) another molecule. (Exergonic processes, in turn, phosphorylate ADP to regenerate ATP.) **2.** A set of coupled reactions can transform the first combination into the second. Since this is an exergonic process overall, ΔG is negative and the first combination must have more free energy (see Figure 8.10). **3.** Active transport: The solute is being transported against its concentration gradient, which requires energy, provided by ATP hydrolysis.

Concept Check 8.4

1. A spontaneous reaction is a reaction that is exergonic. However, if it has a high activation energy that is rarely attained, the rate of the reaction may be low. **2.** O_2 is required as a substrate to react with the gas. There is O_2 in the lab air, which is why the Bunsen burner has a flame above the gas delivery opening, but there is no O_2 in the rubber tubing or the gas supply. **3.** In the presence of malonate, increase the concentration of the normal substrate (succinate) and see whether the rate of reaction increases. If it does, malonate is a competitive inhibitor.

4.



Concept Check 8.5

1. The activator binds in such a way that it stabilizes the active form of an enzyme, whereas the inhibitor stabilizes the inactive form. **2.** A catabolic pathway breaks down organic molecules, generating energy that is stored in ATP molecules. In feedback inhibition of such a pathway, ATP (one product) would act as an allosteric inhibitor of an enzyme catalyzing an early step in the catabolic process. When ATP is plentiful, the pathway would be turned off and no more would be made.

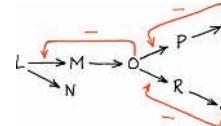
Summary of Key Concepts Questions

8.1 The process of “ordering” a cell’s structure is accompanied by an increase in the entropy (disorder) of the universe. For example, an animal cell takes in highly ordered organic molecules as the source of matter and energy used to build and maintain its structures. In the same process, however, the cell releases heat and the simple molecules of CO_2 and H_2O to the surroundings. The increase in entropy of the latter process offsets the entropy decrease in the former. **8.2** A spontaneous reaction has a negative ΔG and is exergonic. For a chemical reaction to proceed with a net release of free energy ($-\Delta G$), the enthalpy or total energy of the system must decrease ($-\Delta H$), and/or the entropy or disorder must increase (yielding a more negative term, $-\Delta S$). Spontaneous reactions supply the energy to perform cellular work. **8.3** The free energy released from the hydrolysis of ATP may drive endergonic reactions through the transfer of a phosphate group to a reactant molecule, forming a more reactive phosphorylated intermediate. ATP hydrolysis also powers the mechanical and transport work of a cell, often by powering shape changes in the relevant motor proteins. Cellular respiration, the catabolic breakdown of glucose, provides the energy for the endergonic regeneration of ATP from ADP and P_i . **8.4** Activation energy barriers prevent the complex molecules of the cell, which are rich in free energy, from spontaneously breaking down to less ordered, more stable molecules. Enzymes permit a regulated metabolism by binding to specific substrates and forming enzyme-substrate complexes that selectively lower the E_A for the chemical reactions in a cell. **8.5** A cell tightly regulates its metabolic

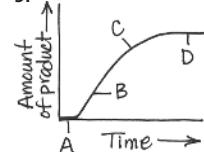
pathways in response to fluctuating needs for energy and materials. The binding of activators or inhibitors to regulatory sites on allosteric enzymes stabilizes either the active or the inactive form of the subunits. For example, the binding of ATP to a catabolic enzyme in a cell with excess ATP would inhibit that pathway. Such types of feedback inhibition preserve chemical resources within a cell. If ATP supplies are depleted, binding of ADP to the regulatory site of catabolic enzymes would activate that pathway, generating more ATP.

Test Your Understanding

1. B 2. C 3. B 4. A 5. C 6. D 7. C



9.



- A. The substrate molecules are entering the pancreatic cells, so no product is made yet.
B. There is sufficient substrate, so the reaction is proceeding at a maximum rate.
C. As the substrate is used up, the rate decreases (the slope is less steep).
D. The line is flat because no new substrate remains and thus no new product appears.

Chapter 9

Figure Questions

Figure 9.2 The C atom is oxidized. The electrons that used to be equally shared with H atoms in methane are now much closer to the O atoms in CO_2 than they are to the C.

Figure 9.3 The reduced form has an extra hydrogen, along with 2 electrons, bound to the carbon shown at the top of the nicotinamide (opposite the N). There are different numbers and positions of double bonds in the two forms: The oxidized form has three double bonds in the ring, while the reduced form has only two. (In organic chemistry you may have learned, or will learn, that three double bonds in a ring are able to “resonate,” or act as a ring of electrons. Having three resonant double bonds is more “oxidized” than having only two double bonds in the ring.) In the oxidized form there is a + charge on the N (because it is sharing 4 electron pairs), whereas in the reduced form it is only sharing 3 electron pairs (having a pair of electrons to itself). **Figure 9.6** Because there is no external source of energy for the reaction, it must be exergonic, and the reactants must be at a higher energy level than the products. **Figure 9.8** The removal would probably stop glycolysis, or at least slow it down, since it would push the equilibrium for step 5 toward DHAP (toward the bottom in this figure). If less (or no) glyceraldehyde 3-phosphate were available, step 6 would slow down (or be unable to occur). **Figure 9.12** The electrons in NADH are in a C–H bond (right side of Figure 9.3). In H_2O , the electrons are in an O–H bond. Because the electronegativities of C and H are similar, the electrons are equally shared in NADH. The electronegativity of O is much higher than that of C or H, so the electrons are much closer to O in H_2O and have “fallen” in potential energy. **Figure 9.14** At first, some ATP could be made, since electron transport could proceed as far as complex III, and a small H^+ gradient could be built up. Soon, however, no more electrons could be passed to complex III because it could not be reoxidized by passing its electrons to complex IV. **Figure 9.15** First, there are 2 NADH from the oxidation of pyruvate plus 6 NADH from the citric acid cycle (CAC); $8\text{NADH} \times 2.5\text{ATP/NADH} = 20\text{ATP}$. Second, there are 2 FADH₂ from the CAC; $2\text{FADH}_2 \times 1.5\text{ATP/FADH}_2 = 3\text{ATP}$. Third, the 2 NADH from glycolysis enter the mitochondrion through one of two types of shuttle. They pass their electrons either to 2 FAD, which become FADH₂ and result in 3 ATP, or to 2 NAD⁺, which become NADH and result in 5 ATP. Thus, $20 + 3 + 3 = 26\text{ATP}$, or $20 + 3 + 5 = 28\text{ATP}$ from all NADH and FADH₂.

Concept Check 9.1

1. Both processes include glycolysis, the citric acid cycle, and oxidative phosphorylation. In aerobic respiration, the final electron acceptor is molecular oxygen (O_2); in anaerobic respiration, the final electron acceptor is a different substance. **2.** $C_6H_6O_5$ would be oxidized and NAD⁺ would be reduced.

Concept Check 9.2

1. NAD⁺ acts as the oxidizing agent in step 6, accepting electrons from glyceraldehyde 3-phosphate (G3P), which thus acts as the reducing agent.

Concept Check 9.3

1. NADH and FADH₂ one ATP is produced during substrate-level phosphorylation in step 5. **2.** The CO_2 that we exhale is produced by pyruvate oxidation and the citric acid cycle. **3.** In both cases, the precursor molecule loses a CO_2 molecule and then donates electrons to an electron carrier in an oxidation step. Also, the product has been activated due to the attachment of a CoA group to its S atom.

Concept Check 9.4

1. Oxidative phosphorylation would eventually stop entirely, resulting in no ATP production by this process. Without oxygen to “pull” electrons down the electron transport chain, H^+ would not be pumped into the mitochondrion’s intermembrane space and chemiosmosis would not occur. **2.** Decreasing the pH means addition of H^+ . This would establish a proton gradient even without the function of the electron transport chain, and we would expect ATP synthase to function and synthesize ATP. (In fact, it was experiments like this that

provided support for chemiosmosis as an energy-coupling mechanism.) **3.** One of the components of the electron transport chain, ubiquinone (Q), must be able to diffuse within the membrane. It could not do so if the membrane components were locked rigidly into place.

Concept Check 9.5

1. A derivative of pyruvate, such as acetaldehyde during alcohol fermentation, or pyruvate itself during lactic acid fermentation; O₂; another electron acceptor at the end of an electron transport chain, such as sulfate (SO₄²⁻) **2.** The cell would need to consume glucose at a rate about 16 times the consumption rate in the aerobic environment (2 ATP are generated by fermentation versus up to 32 ATP by cellular respiration).

Concept Check 9.6

1. The fat is much more reduced; it has many —CH₂— units, and in all these bonds the electrons are equally shared. The electrons present in a carbohydrate molecule are already somewhat oxidized (shared unequally in bonds; there are more C—O and O—H bonds), as quite a few of them are bound to oxygen. Electrons that are equally shared, as in fat, have a higher energy level than electrons that are unequally shared, as in carbohydrates. Thus, fat is a much better fuel than carbohydrate. **2.** When you consume more food than necessary for metabolic processes, your body synthesizes fat as a way of storing energy for later use. **3.** AMP will accumulate, stimulating phosphofructokinase, and thus increasing the rate of glycolysis. Since oxygen is not present, the cell will convert more pyruvate to lactate, providing a supply of ATP. **4.** When O₂ is present, the fatty acid chains containing most of the energy of a fat are oxidized and fed into the citric acid cycle and the electron transport chain. During intense exercise, however, O₂ is scarce in muscle cells, so ATP must be generated by glycolysis alone. A very small part of the fat molecule, the glycerol backbone, can be oxidized via glycolysis, but the amount of energy released by this portion is insignificant compared to that released by the fatty acid chains. (This is why moderate exercise, staying below 70% maximum heart rate, is better for burning fat—because enough O₂ remains available to the muscles.)

Summary of Key Concepts Questions

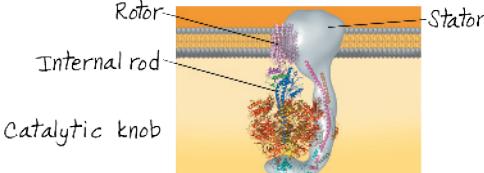
9.1 Most of the ATP produced in cellular respiration comes from oxidative phosphorylation, in which the energy released from redox reactions in an electron transport chain is used to produce ATP. In substrate-level phosphorylation, an enzyme directly transfers a phosphate group to ADP from an intermediate substrate. All ATP production in glycolysis occurs by substrate-level phosphorylation; this form of ATP production also occurs at one step in the citric acid cycle. **9.2** The oxidation of the three-carbon sugar, glyceraldehyde 3-phosphate, yields energy. In this oxidation, electrons and H⁺ are transferred to NAD⁺, forming NADH, and a phosphate group is attached to the oxidized substrate. ATP is then formed by substrate-level phosphorylation when this phosphate group is transferred to ADP. **9.3** The release of six molecules of CO₂ represents the complete oxidation of glucose. During the processing of two pyruvates to acetyl CoA, the fully oxidized carboxyl groups (—COO⁻) are given off as 2 CO₂. The remaining four carbons are released as CO₂ in the citric acid cycle as citrate is oxidized back to oxaloacetate. **9.4** The flow of H⁺ through the ATP synthase complex causes the rotor and attached rod to rotate, exposing catalytic sites in the knob portion that produce ATP from ADP and P_i. ATP synthases are found in the inner mitochondrial membrane, the plasma membrane of prokaryotes, and membranes within chloroplasts. **9.5** Anaerobic respiration yields more ATP. The 2 ATP produced by substrate-level phosphorylation in glycolysis represent the total energy yield of fermentation. NADH passes its “high-energy” electrons to pyruvate or a derivative of pyruvate, recycling NAD⁺ and allowing glycolysis to continue. In anaerobic respiration, the NADH produced during glycolysis, as well as additional molecules of NADH produced when pyruvate is oxidized, are used to generate ATP molecules. An electron transport chain captures the energy of the electrons in NADH via a series of redox reactions; ultimately, the electrons are transferred to an electronegative atom in a molecule other than oxygen. **9.6** The ATP produced by catabolic pathways is used to drive anabolic pathways. Also, many of the intermediates of glycolysis and the citric acid cycle are used in the biosynthesis of a cell’s molecules.

Test Your Understanding

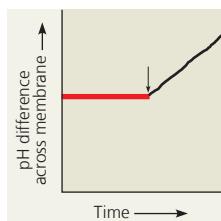
1.C 2.C 3.A 4.B 5.D 6.A 7.B

8. Since the overall process of glycolysis results in net production of ATP, it would make sense for the process to slow down when ATP levels have increased substantially. Thus, we would expect ATP to allosterically inhibit phosphofructokinase. **9.** The proton pump in Figures 7.18 and 7.19 is carrying out active transport, using ATP hydrolysis to pump protons against their concentration gradient. Because ATP is required, this is active transport of protons. The ATP synthase in Figure 9.13 is using the flow of protons down their concentration gradient to power ATP synthesis. Because the protons are moving down their concentration gradient, no energy is required, and this is passive transport.

10.



12.



H⁺ would continue to be pumped across the membrane into the intermembrane space, increasing the difference between the matrix pH and the intermembrane space pH. H⁺ would not be able to flow back through ATP synthase, since the enzyme is inhibited by the poison, so rather than maintaining a constant difference across the membrane, the difference would continue to increase. (Over a longer period of time, the H⁺ concentration in the intermembrane space would be so high that no more H⁺ would be able to be pumped against the gradient.)

This wasn’t asked for in the question, but if your graph levels off at the right end and this is your reasoning, your answer is correct.)

Chapter 10

Figure Questions

Figure 10.11 In the leaf, most of the chlorophyll electrons excited by photon absorption are used to power the reactions of photosynthesis. **Figure 10.15** The person at the top of the photosystem I tower would not turn to his left and throw his electron into the NADPH bucket. Instead, he would throw it onto the top of the ramp at his right, next to the photosystem II tower. The electron would then roll down the ramp, get energized by a photon, and return to him. This cycle would continue as long as light was available. (This is why it’s called cyclic electron flow.) **Figure 10.16** You would (a) decrease the pH outside the mitochondrion (thus increasing the H⁺ concentration) and (b) increase the pH in the chloroplast stroma (thus decreasing the H⁺ concentration). In both cases, this would generate an H⁺ gradient across the membrane that would cause ATP synthase to synthesize ATP. **Figure 10.17** Steps that increase [H⁺] in the thylakoid space or decrease [H⁺] in the stroma contribute to the [H⁺] concentration gradient across the thylakoid membrane. In step 2, water is split in the thylakoid space, releasing 2 H⁺ and increasing [H⁺]. In step 3, as electrons travel down the electron transport chain, 4 H⁺ are pumped into the thylakoid space, increasing [H⁺]. In step 5, NADPH formation uses an H⁺ from the stroma, decreasing [H⁺] in the stroma. **Figure 10.22** The gene encoding hexokinase is part of the DNA of a chromosome in the nucleus. There, the gene is transcribed into mRNA, which is transported to the cytoplasm where it is translated on a free ribosome into a polypeptide. The polypeptide folds into a functional protein with secondary and tertiary structure. Once functional, it carries out the first reaction of glycolysis in the cytoplasm.

Concept Check 10.1

1. Because heterotrophs cannot photosynthesize, they cannot capture the energy of sunlight and produce energy-rich compounds like sugars, as autotrophs can. Sugars are oxidized by cellular respiration, providing energy (in the form of ATP) for cellular processes. Without this ability, heterotrophs depend on autotrophs to provide sugars as the food molecules that fuel their vital processes. **2.** The main product of fossil fuel combustion (for example, by cars) is CO₂. Placing containers of algae near sources of CO₂ emission makes sense because the algae need CO₂ to carry out photosynthesis. The higher the CO₂ concentration, the higher will be the rate of algal photosynthesis. (At the same time, algae would be reducing the CO₂ concentration in those areas, which would otherwise contribute to climate change; see Concept 1.1.)

Concept Check 10.2

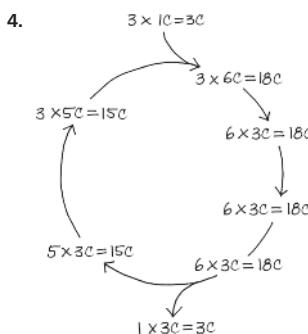
1. CO₂ enters the leaves via stomata, and, being a nonpolar molecule, can cross the leaf cell membrane and the chloroplast membranes to reach the stroma of the chloroplast. **2.** Using ¹⁸O, a heavy isotope of oxygen, as a label, researchers were able to confirm van Niel’s hypothesis that the oxygen atoms in O₂ produced during photosynthesis comes from H₂O, not from CO₂. **3.** The light reactions could *not* keep producing NADPH and ATP without the NADP⁺, ADP, and P_i that the Calvin cycle generates. The two cycles are interdependent.

Concept Check 10.3

1. Green, because green light is mostly transmitted and reflected—not absorbed—by photosynthetic pigments **2.** Water (H₂O) is the initial electron donor; NADP⁺ accepts electrons at the end of the electron transport chain, becoming reduced to NADPH. **3.** In this experiment, the rate of ATP synthesis would slow and eventually stop. Because the added compound would not allow a proton gradient to build up across the membrane, ATP synthase could not catalyze ATP production.

Concept Check 10.4

1. 6, 18, 12 2. The more potential energy and reducing power a molecule stores, the more energy and reducing power are required for the formation of that molecule. Glucose is a valuable energy source because it is highly reduced (has lots of C—H bonds), storing lots of potential energy in its electrons. To reduce CO₂ to glucose, a large amount of energy and a lot of reducing power are required in the form of large numbers of ATP and NADPH molecules, respectively. **3.** Yes, it would inhibit the dark reactions. The light reactions require ADP and NADP⁺, which would not be formed in sufficient quantities from ATP and NADPH if the Calvin cycle stopped.



For every three turns of the Calvin cycle, the total number of carbon atoms remains constant because three carbons enter as part of CO_2 molecules, replacing the three that left as part of a G3P molecule. **5.** In glycolysis, G3P acts as an intermediate. The six-carbon sugar fructose 1,6-bisphosphate is cleaved into two three-carbon sugars, one of which is G3P. The other is an isomer called dihydroxyacetone phosphate (DHAP), which can be converted to G3P by an isomerase. Because G3P is the substrate for the next enzyme, it is constantly removed, and the reaction equilibrium is pulled in the direction of conversion of DHAP to more G3P. In the Calvin cycle, G3P acts as both an intermediate and a product. For every three CO_2 molecules that enter the cycle, six G3P molecules are formed, five of which must remain in the cycle and become rearranged to regenerate three five-carbon RuBP molecules. The one remaining G3P is a product, which can be thought of as the result of “reducing” the three CO_2 molecules that entered the cycle into a three-carbon sugar that can later be used to generate energy.

Concept Check 10.5

1. Photorespiration decreases photosynthetic output by adding O_2 , instead of CO_2 , to the Calvin cycle. As a result, no sugar is generated (no carbon is fixed), and O_2 is used rather than generated. **2.** Without PS II, no O_2 is generated in bundle-sheath cells. This avoids the problem of O_2 competing with CO_2 for binding to rubisco in these cells. **3.** Both problems are caused by a drastic change in Earth’s atmosphere due to burning of fossil fuels. The increase in CO_2 concentration affects ocean chemistry by decreasing pH, thus affecting calcification by marine organisms. On land, CO_2 concentration and air temperature are conditions that plants have become adapted to, and changes in these characteristics have a strong effect on photosynthesis by plants. Thus, alteration of these two fundamental factors could have critical effects on organisms all around the planet, in all different habitats. **4.** You would expect that C_4 and CAM species would replace many of the C_3 species.

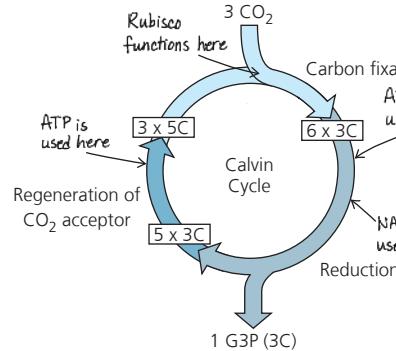
Concept Check 10.6

1. Plants can break down the sugar they make (in the form of glucose) by cellular respiration, producing ATPs for various cellular processes such as endergonic chemical reactions, transport of substances across membranes, and movement of molecules in the cell. ATPs are also used for the movement of chloroplasts during cellular streaming in some plant cells (see Figure 6.26).

Summary of Key Concepts Questions

10.1 Photosynthesizing autotrophs are called producers because they use sunlight as energy to make their own organic molecules (including sugars) from CO_2 and H_2O . Heterotrophs are called consumers because they cannot make their own food and therefore must feed on other organisms, either autotrophs or other heterotrophs. Heterotrophs that consume the remains of dead organisms are called decomposers. Photosynthesis enables almost all organisms to survive because it makes food for photosynthesizing autotrophs, which in turn are food for most heterotrophs. **10.2** CO_2 and H_2O are the products of cellular respiration; they are the reactants in photosynthesis. In respiration, glucose is oxidized to CO_2 and electrons are passed through an electron transfer chain from glucose to O_2 , producing H_2O . In photosynthesis, H_2O is the source of electrons, which are energized by light, temporarily stored in NADPH, and used to reduce CO_2 to carbohydrate. **10.3** The action spectrum of photosynthesis shows that some wavelengths of light that are not absorbed by chlorophyll *a* are still effective at promoting photosynthesis. The light-harvesting complexes of photosystems contain accessory pigments such as chlorophyll *b* and carotenoids, which absorb different wavelengths and pass the energy to chlorophyll *a*, broadening the spectrum of light usable for photosynthesis.

10.4



In the reduction phase of the Calvin cycle, ATP phosphorylates a three-carbon compound, and NADPH then reduces this compound to G3P. ATP is also used in the regeneration phase, when five molecules of G3P are converted to three molecules of the five-carbon compound RubP. Rubisco catalyzes the first step of carbon fixation—the addition of CO_2 to RuBP.

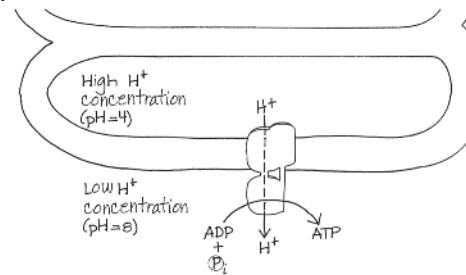
10.5 Both C_4 photosynthesis and CAM photosynthesis involve initial fixation of CO_2 to produce a four-carbon compound (in mesophyll cells in C_4 plants and at night in CAM plants). These compounds are then broken down to release CO_2 (in the bundle-sheath cells in C_4 plants and during the day in CAM plants). ATP is required for recycling the molecule that is used initially to combine with CO_2 . These pathways avoid the photorespiration that consumes ATP

and reduces the photosynthetic output of C_3 plants when they close stomata on hot, dry, bright days. Thus, hot, arid climates would favor C_4 and CAM plants. **10.6** Sucrose made in the leaves of plants is transported through veins to nonphotosynthetic parts of the plant, where some of it is oxidized by cellular respiration, producing ATP for cellular processes. Other sugar molecules enter anabolic pathways, where they are used for synthesis of proteins, lipids, and polysaccharides such as cellulose, the main component of cell walls. Excess sugar is stockpiled as glucose subunits of the polysaccharide starch.

Test Your Understanding

- 1.D 2.B 3.C 4.A 5.A 6.B 7.C

10.



The ATP would end up outside the thylakoid. The thylakoids were able to make ATP in the dark because the researchers set up an artificial proton concentration gradient across the thylakoid membrane; thus, the light reactions were not necessary to establish the H^+ gradient required for ATP synthesis by ATP synthase.

Chapter 11

Figure Questions

Figure 11.6 Epinephrine is a signaling molecule outside the cell; presumably, it binds to a cell-surface receptor protein and thus is part of the signal reception step.

Figure 11.8 This is an example of passive transport. The ion is moving down its concentration gradient, and no energy is required. **Figure 11.9** The aldosterone molecule, a steroid, doesn’t need a receptor protein—it is hydrophobic and can therefore pass directly through the hydrophobic lipid bilayer of the plasma membrane into the cell. (Hydrophilic molecules cannot do this.) **Figure 11.10** The entire phosphorylation cascade wouldn’t operate. Regardless of whether or not the signaling molecule was bound, protein kinase 2 would always be inactive and would not be able to activate the purple-colored protein leading to the cellular response. **Figure 11.11** The signaling molecule (cAMP) would remain in its active form and would continue to signal; the pathway would remain active even in the absence of ligand because the cAMP would persist.

Figure 11.12

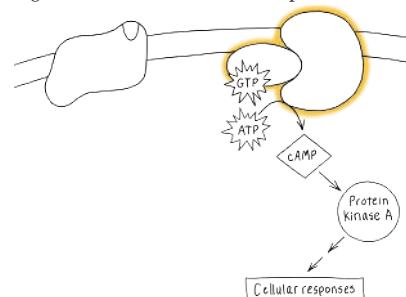


Figure 11.14 The Ca^{2+} pump shown in Figure 11.13 is carrying out active transport of Ca^{2+} ions against their concentration gradient, using ATP for energy. These pumps help maintain a significantly lower $[\text{Ca}^{2+}]$ in the cytoplasm than outside the cell and inside the ER. The Ca^{2+} channel proteins seen in Figure 11.14 are facilitating diffusion of Ca^{2+} down its concentration gradient; here, the Ca^{2+} is moving from inside the ER, where it is more concentrated, to the cytoplasm. Because the ion is moving down its concentration gradient, no energy is required.

Figure 11.16 100,000,000 (one hundred million, or 10^8) glucose molecules are released just from one epinephrine binding to the receptor. The first step results in 100× amplification (one epinephrine activates 100 G proteins); the next step does not amplify the response; the next step is a 100× amplification (10^2 active adenyl cyclase molecules to 10^4 cyclic AMPs); the next step does not amplify; the next two steps are each 10× amplifications, and the final step is a 100× amplification. **Figure 11.17** The signaling pathway shown in Figure 11.14 leads to the splitting of PIP_2 into the second messengers DAG and IP_3 , which produce different responses. (The response elicited by DAG is mentioned but not shown.) The pathway shown for cell B is similar in that it branches and leads to two responses.

Concept Check 11.1

- The two cells of opposite mating type (**a** and **α**) each secrete a unique signaling molecule, which can only be bound by receptors carried on cells of the opposite mating type. Thus, the **a** mating factor cannot bind to another **a** cell and cause it to grow toward the first **a** cell. Only an **α** cell can “receive” the signaling molecule and respond by directed growth. **2.** Glycogen phosphorylase acts in the third stage, the cellular response to epinephrine signaling. **3.** Glucose 1-phosphate would not be generated because the activation of the

enzyme requires an intact cell, with an intact receptor in the membrane and an intact signal transduction pathway. The enzyme cannot be activated directly by interaction with the signaling molecule in the cell-free mixture.

Concept Check 11.2

1. NGF is water-soluble (hydrophilic), so it cannot pass through the lipid membrane to reach intracellular receptors, as steroid hormones can. Therefore, you'd expect the NGF receptor to be in the plasma membrane—which is, in fact, the case. **2.** The cell with the faulty receptor would not be able to respond appropriately to the signaling molecule when it was present. This would most likely have dire consequences for the cell since regulation of the cell's activities by this receptor would not occur appropriately. **3.** Binding of a ligand to a receptor changes the shape of the receptor, altering the ability of the receptor to transmit a signal. Binding of an allosteric regulator to an enzyme changes the shape of the enzyme, either promoting or inhibiting enzyme activity.

Concept Check 11.3

1. A protein kinase is an enzyme that transfers a phosphate group from ATP to a protein, usually activating that protein (often a second type of protein kinase). Many signal transduction pathways include a series of such interactions, in which each phosphorylated protein kinase in turn phosphorylates the next protein kinase in the series. Such phosphorylation cascades carry a signal from outside the cell to the cellular protein(s) that will carry out the response. **2.** Protein phosphatases reverse the effects of the kinases by dephosphorylation, and unless the signaling molecule is at a high enough concentration that it is continuously rebinding the receptor, the kinase molecules will all be returned to their inactive states by phosphatases. **3.** The signal that is being transduced is the *information* that a signaling molecule is bound to the cell-surface receptor. Information is transduced by way of sequential protein-protein interactions that change protein shapes, causing them to function in a way that passes the signal (the information) along. **4.** The IP₃-gated channel would open, allowing calcium ions to flow out of the ER and into the cytoplasm, which would raise the cytosolic Ca²⁺ concentration.

Concept Check 11.4

1. At each step in a cascade of sequential activations, one molecule or ion may activate numerous molecules functioning in the next step. This causes the response to be amplified at each such step and overall results in a large amplification of the original signal. **2.** Scaffolding proteins hold molecular components of signaling pathways in a complex with each other. Different scaffolding proteins would assemble different collections of proteins, facilitating different molecular interactions and leading to different cellular responses in the two cells. **3.** A malfunctioning protein phosphatase would not be able to dephosphorylate a particular receptor or relay protein. As a result, the signaling pathway, once activated, would not be able to be terminated. (In fact, one study found altered protein phosphatases in cells from 25% of colorectal tumors.) **4.** The proteins in the two cells are different, so the cellular response is different. In heart muscle cells, the pathway shown in Figure 11.16 allows glucose to fuel faster muscle contractions and heart rate. In respiratory muscles, the relay proteins must be different, so that the effect is to block muscle contraction. (In fact, the steps are the same through protein kinase A (PKA), but in respiratory muscle cells, PKA phosphorylates a protein that is required for muscle contraction—and in this case, phosphorylation *inactivates* that protein. So muscle contraction cannot occur.)

Concept Check 11.5

1. In formation of the hand or paw in mammals, cells in the regions between the digits are programmed to undergo apoptosis. This serves to shape the digits of the hand or paw so that they are not webbed. (A lack of apoptosis in these regions in water birds results in webbed feet.) **2.** If a receptor protein for a death-signaling molecule were defective such that it was activated even in the absence of the death signal, this would lead to apoptosis when it wouldn't normally occur. Similar defects in any of the proteins in the signaling pathway would have the same effect if the defective proteins activated relay or response proteins in the absence of interaction with the previous protein or second messenger in the pathway. Conversely, if any protein in the pathway were defective in its ability to respond to an interaction with an early protein or other molecule or ion, apoptosis would not occur when it normally should. For example, a receptor protein for a death-signaling ligand might not be able to be activated, even when ligand was bound. This would stop the signal from being transduced into the cell.

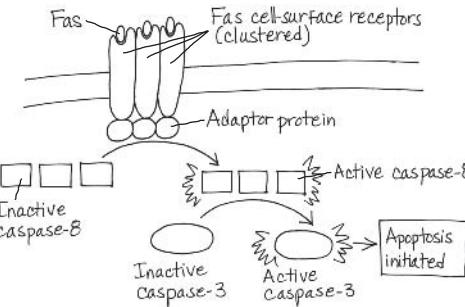
Summary of Key Concepts Questions

11.1 A cell is able to respond to a hormone only if it has a receptor protein on the cell surface or inside the cell that can bind to the hormone. The response to a hormone depends on the specific signal transduction pathway within the cell, which will lead to the specific cellular response. The response can vary for different types of cells. **11.2** Both GPCRs and RTKs have an extracellular binding site for a signaling molecule (ligand) and one or more α -helical regions of the polypeptide that spans the membrane. A GPCR functions singly, while RTKs tend to dimerize or form larger groups of RTKs. GPCRs usually trigger a single transduction pathway, whereas the multiple activated tyrosines on an RTK dimer may trigger several different transduction pathways at the same time. **11.3** A protein kinase is an enzyme that adds a phosphate group to another protein. Protein kinases are often part of a phosphorylation cascade that transduces a signal. A second messenger is a small, nonprotein molecule or ion that rapidly diffuses and relays a signal throughout a cell. Both protein kinases and second messengers can operate in the same pathway. For example, the second messenger cAMP often activates protein kinase A, which then phosphorylates other proteins. **11.4** In G protein-coupled pathways, the GTPase portion of a G protein converts GTP to

GDP, inactivating the G protein. Protein phosphatases remove phosphate groups from activated proteins, thus stopping a phosphorylation cascade of protein kinases. Phosphodiesterase converts cAMP to AMP, thus reducing the effect of cAMP in a signal transduction pathway. **11.5** The basic mechanism of controlled cell suicide evolved early in eukaryotic evolution, and the genetic basis for these pathways has been conserved during animal evolution. Such a mechanism is essential to the development and maintenance of all animals.

Test Your Understanding

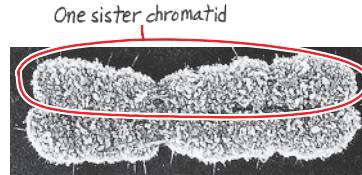
- 1.D 2.A 3.B 4.A 5.C 6.C 7.C 8.** This is one possible drawing of the pathway. (Similar drawings would also be correct.)



Chapter 12

Figure Questions

Figure 12.4



Circling the other chromatid instead would also be correct. **Figure 12.5** The chromosome has four arms. The single (duplicated) chromosome in **2** becomes two (unduplicated) chromosomes in **3**. The duplicated chromosome in step 2 is considered one single chromosome.

Figure 12.7 12; 2; 2; 1

Figure 12.8

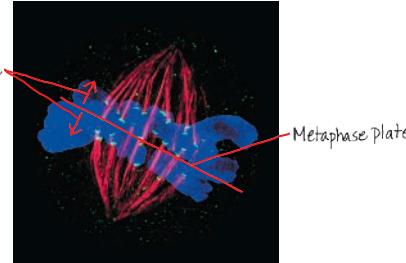


Figure 12.9 The mark would have moved toward the pole closer to it. The lengths of fluorescent microtubules between that pole and the mark would have decreased, while the lengths between the chromosomes and the mark would have remained the same. **Figure 12.14** In both cases, the G₁ nucleus would have remained in G₁ until the time it normally would have entered the S phase. Chromosome condensation and spindle formation would not have occurred until the S and G₂ phases had been completed. **Figure 12.16** Passing the G₂ checkpoint in the diagram corresponds to the beginning of the "Time" axis of the graph, and entry into the mitotic phase (yellow background on the diagram) corresponds to the peaks of MPF activity and cyclin concentration on the graph (see the yellow M banner over the peaks). During G₁ and S phase in the diagram, Cdk is present without cyclin, so on the graph both cyclin concentration and MPF activity are low. The curved purple gradient arrow in the diagram shows increasing cyclin concentration, seen on the graph during the end of S phase and throughout G₂ phase. Then the cell cycle begins again. **Figure 12.17** The cell would divide under conditions where it was inappropriate to do so. If the daughter cells and their descendants also ignored either of the checkpoints and divided, there would soon be an abnormal mass of cells. (This type of inappropriate cell division can contribute to the development of cancer.) **Figure 12.18** The cells in the vessel with PDGF would not be able to respond to the growth factor signal and thus would not divide. The culture would resemble that without the added PDGF.

Concept Check 12.1

- 1.1; 1; 2 2. 39; 39; 78**

Concept Check 12.2

1. 6 chromosomes; they are duplicated; 12 chromatids **2.** Following mitosis, cytokinesis results in two genetically identical daughter cells in both plant cells and animal cells. However, the mechanism of dividing the cytoplasm is different in animals and plants. In an animal cell, cytokinesis occurs by cleavage, which divides the parent cell in two with a contractile ring of actin filaments. In a plant cell, a cell plate forms in the middle of the cell and grows until its membrane fuses with the plasma membrane of the parent cell. A new cell wall grows inside the cell plate, thus eventually between the two new cells. **3.** From the end of S phase in interphase through the end of metaphase in mitosis. **4.** During eukaryotic cell division, tubulin is involved in spindle formation and chromosome movement, while actin functions during cytokinesis. In bacterial binary fission, it's the opposite: Actin-like molecules are thought to move the daughter bacterial chromosomes to opposite ends of the cell, and tubulin-like molecules are thought to act in daughter cell separation. **5.** A kinetochore connects the spindle (a motor; note that it has motor proteins) to a chromosome (the cargo it will move). **6.** Microtubules made up of tubulin in the cell provide "rails" along which vesicles and other organelles can travel, based on interactions of motor proteins with tubulin in the microtubules. In muscle cells, actin in microfilaments interacts with myosin filaments to cause muscle contraction.

Concept Check 12.3

1. The nucleus on the right was originally in the G₁ phase; therefore, it had not yet duplicated its chromosomes. The nucleus on the left was in the M phase, so it had already duplicated its chromosomes. **2.** A sufficient amount of MPF has to exist for a cell to pass the G₂ checkpoint; this occurs through the accumulation of cyclin proteins, which combine with Cdk to form (active) MPF. MPF then phosphorylates other proteins, initiating mitosis. **3.** The intracellular receptor (for example, an estrogen receptor), once activated, would be able to act as a transcription factor in the nucleus, turning on genes that may cause the cell to pass a checkpoint and divide. The RTK receptor, when activated by a ligand, would form a dimer, and each subunit of the dimer would phosphorylate the other. This would lead to a series of signal transduction steps, ultimately turning on genes in the nucleus. As in the case of the estrogen receptor, the genes would code for proteins necessary to cause the cell to pass a checkpoint and divide.

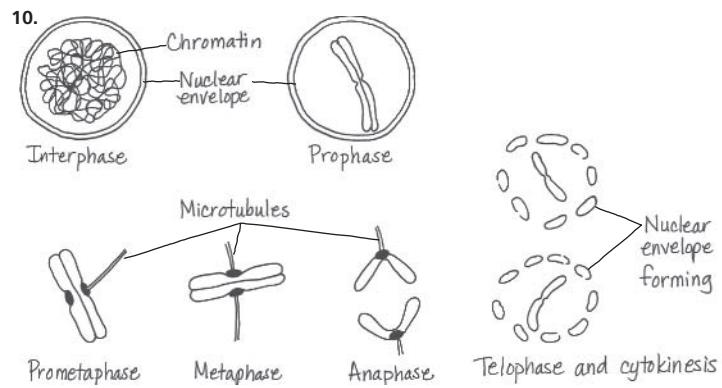
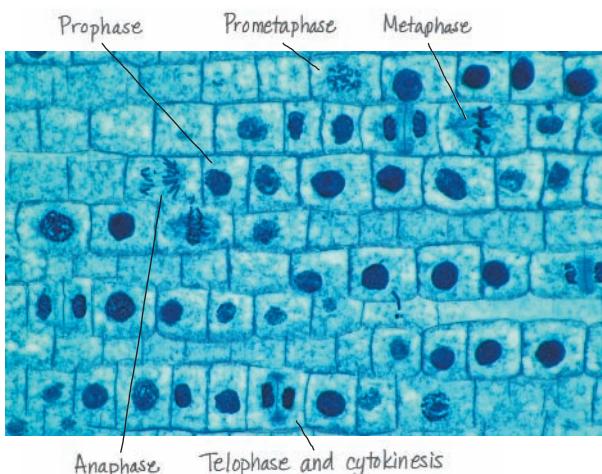
Summary of Key Concepts Questions

12.1 The DNA of a eukaryotic cell is packaged into structures called *chromosomes*. Each chromosome is a long molecule of DNA, which carries hundreds to thousands of genes, with associated proteins that maintain chromosome structure and help control gene activity. This DNA-protein complex is called *chromatin*. The chromatin of each chromosome is long and thin when the cell is not dividing. Prior to cell division, each chromosome is duplicated, and the resulting sister *chromatids* are attached to each other by proteins at the centromeres and, for many species, all along their lengths (a phenomenon called sister chromatid cohesion). **12.2** A chromosome exists as a single DNA molecule in G₁ of interphase and in anaphase and telophase of mitosis. During S phase, DNA replication produces two sister chromatids per chromosome, which persist during G₂ of interphase and through prophase, prometaphase, and metaphase of mitosis.

12.3 Checkpoints allow cellular surveillance mechanisms to determine whether the cell is prepared to go to the next stage. Internal and external signals move a cell past these checkpoints. The G₁ checkpoint determines whether a cell will proceed forward in the cell cycle or switch into the G₀ phase. The signals to pass this checkpoint often are external, such as growth factors. Passing the G₂ checkpoint requires sufficient numbers of active MPF complexes, which in turn orchestrate several mitotic events. MPF also initiates degradation of its cyclin component, terminating the M phase. The M phase will not begin again until sufficient cyclin is produced during the next S and G₂ phases. The signal to pass the M phase checkpoint is not activated until all chromosomes are attached to kinetochore fibers and are aligned at the metaphase plate. Only then will sister chromatid separation occur.

Test Your Understanding

1.B **2.A** **3.C** **4.C** **5.A** **6.B** **7.A** **8.D** **9.** See Figure 12.7 for a description of major events. Only one cell is indicated for each stage, but other correct answers are also present in this micrograph.

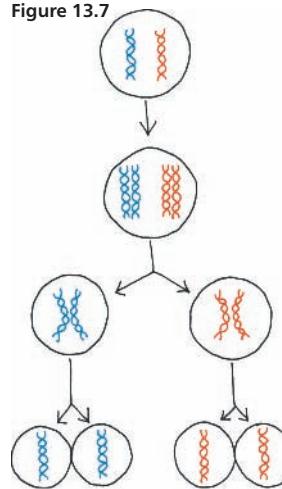


Chapter 13

Figure Questions

Figure 13.3 The chromosomes in a karyotype are photographed at their most condensed, at metaphase, which occurs during M phase of the cell cycle. At this point, the chromosomes have already been duplicated during S phase, so each chromosome exists as two sister chromatids. **Figure 13.4** Two sets of chromosomes are present. Three pairs of homologous chromosomes are present. One long chromosome would be red (maternal), and one would be blue (paternal); one medium chromosome would be red, and one would be blue; one short chromosome would be red, and one would be blue. **Figure 13.6** In (a), haploid cells do not undergo mitosis. In (b), haploid spores undergo mitosis to form the gametophyte, and haploid cells of the gametophyte undergo mitosis to form gametes. In (c), haploid cells undergo mitosis to form either a multicellular haploid organism or a new unicellular haploid organism, and these haploid cells undergo mitosis to form gametes.

Figure 13.7



(A short strand of DNA is shown here for simplicity, but each chromosome or chromatid contains a very long coiled and folded DNA molecule.) **Figure 13.8** If a cell with six chromosomes undergoes two rounds of mitosis, each of the four resulting cells will have six chromosomes, while the four cells resulting from meiosis in Figure 13.8 each have three chromosomes. In mitosis, DNA replication (and thus chromosome duplication) precedes each prophase, ensuring that daughter cells have the same number of chromosomes as the parent cell. In contrast, in meiosis, DNA replication occurs only before prophase I (not before prophase II). Thus, in two rounds of mitosis, the chromosomes duplicate twice and divide twice, while in meiosis, the chromosomes duplicate once and divide twice.

Figure 13.9

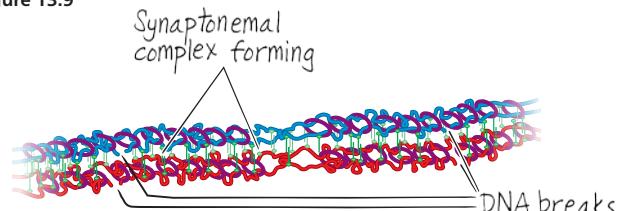


Figure 13.10 Yes. Each of the six chromosomes (three per cell) shown in telophase I has one nonrecombinant chromatid and one recombinant chromatid. Therefore, eight (2 possibilities for the first chromosome \times 2 for the second \times 2 for the third) possible sets of chromosomes can be generated for the cell on the left and eight for the cell on the right.

Concept Check 13.1

- Parents pass genes to their offspring; by dictating the production of messenger RNAs (mRNAs), the genes program cells to make specific enzymes and other proteins, whose cumulative action produces an individual's inherited traits.
- Such organisms reproduce by mitosis, which generates offspring whose genomes are exact copies of the parent's genome (in the absence of mutation).
- She should clone (generate a clone of) it. Crossbreeding it with another plant would generate offspring that have additional variation, which she no longer desires now that she has obtained her ideal orchid.

Concept Check 13.2

- Each of the six chromosomes is duplicated, so each contains two DNA molecules (double helices), so there are 12 DNA molecules in the cell. The haploid

number, n , is 3. One set is always haploid. **2.** There are 23 pairs of chromosomes and two sets. **3.** A human diploid cell would have 23 “pairs of shoes.” A haploid cell would have 23 “shoes,” one of each pair. **4.** This organism has the life cycle shown in Figure 13.6c, since the zygote doesn’t undergo mitosis but immediately undergoes meiosis. Therefore, it must be a fungus or a protist, perhaps an alga.

Concept Check 13.3

1. The chromosomes are similar in that each is composed of two sister chromatids, and the individual chromosomes are positioned similarly at the metaphase plate. The chromosomes differ in that in a mitotically dividing cell, sister chromatids of each chromosome are genetically identical, but in a meiotically dividing cell, sister chromatids are genetically distinct because of crossing over in meiosis I. Moreover, the chromosomes in metaphase of mitosis can be a diploid set or a haploid set, but the chromosomes in metaphase of meiosis II always consist of a haploid set. **2.** If crossing over did not occur, the two homologs would not be associated in any way. This is because each sister chromatid would be either all maternal or all paternal DNA, and the single DNA molecule would therefore not have been joined to the DNA of a nonsister chromatid, holding the complex together. The lack of association of homologs could easily result in the incorrect arrangement of homologs during metaphase I (both might go toward the same pole, for instance) and ultimately in formation of gametes with an abnormal number of chromosomes.

Concept Check 13.4

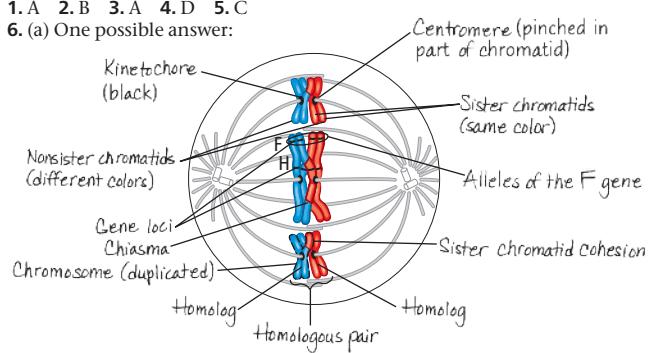
1. Mutations in a gene lead to the different versions (alleles) of that gene. **2.** Without crossing over, independent assortment of chromosomes during meiosis I theoretically can generate 2^n possible haploid gametes, and random fertilization can produce $2^n \times 2^m$ possible diploid zygotes. Because the haploid number (n) of grasshoppers is 23 and that of fruit flies is 4, two grasshoppers would be expected to produce a greater variety of zygotes than would two fruit flies. **3.** If the segments of the maternal and paternal chromatids that undergo crossing over are genetically identical and thus have the same two alleles for every gene, then the recombinant chromosomes will be genetically equivalent to the parental chromosomes. Crossing over contributes to genetic variation only when it involves the rearrangement of different alleles.

Summary of Key Concepts Questions

13.1 Genes program specific traits, and offspring inherit their genes from each parent, accounting for similarities in their appearance to one or the other parent. Humans reproduce sexually, which ensures new combinations of genes (and thus traits) in the offspring. Consequently, the offspring are not clones of their parents (which would be the case if humans reproduced asexually). **13.2** Animals and plants both reproduce sexually, alternating meiosis with fertilization. Both have haploid gametes that unite to form a diploid zygote, which then goes on to divide mitotically, forming a diploid multicellular organism. In animals, haploid cells become gametes and don’t undergo mitosis, while in plants, the haploid cells resulting from meiosis undergo mitosis to form a haploid multicellular organism, the gametophyte. This organism then goes on to generate haploid gametes. (In plants such as trees, the gametophyte is quite reduced in size and not obvious to the casual observer.) **13.3** At the end of meiosis I, the two members of a homologous pair end up in different cells, so they cannot pair up and undergo crossing over during prophase II. **13.4** First, during independent assortment in metaphase I, each pair of homologous chromosomes lines up independently of each other pair at the metaphase plate, so a daughter cell of meiosis I randomly inherits either a maternal or a paternal chromosome of each pair. Second, due to crossing over, each chromosome is not exclusively maternal or paternal, but includes regions at the ends of the chromatid from a nonsister chromatid (a chromatid of the other homolog). (The nonsister segment can also be in an internal region of the chromatid if a second crossover occurs beyond the first one before the end of the chromatid.) This provides much additional diversity in the form of new combinations of alleles. Third, random fertilization ensures even more variation since any sperm of a large number containing many possible genetic combinations can fertilize any egg of a similarly large number of possible combinations.

Test Your Understanding

1. A 2. B 3. A 4. D 5. C
6. (a) One possible answer:



(b) A haploid set is made up of one long, one medium, and one short chromosome, no matter what combination of colors. For example, one red long, one blue medium, and one red short chromosome make up a haploid set. (In

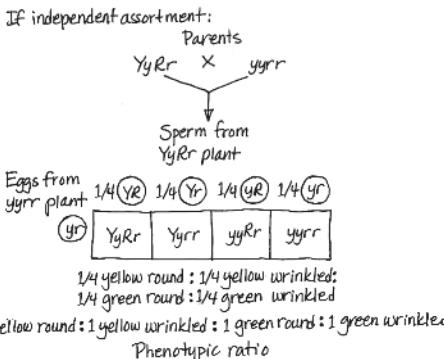
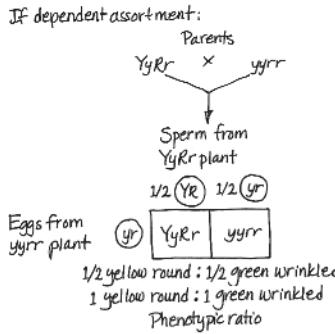
cases where crossovers have occurred, a haploid set of one color may include segments of chromatids of the other color.) All red and blue chromosomes together make up a diploid set. (c) Metaphase I **7.** This cell must be undergoing meiosis because the two homologs of a homologous pair are associated with each other at the metaphase plate; this does not occur in mitosis. Also, chiasmata are clearly present, meaning that crossing over has occurred, another process unique to meiosis.

Chapter 14

Figure Questions

Figure 14.3 All offspring would have purple flowers. (The ratio of purple to white flowers would be 1 purple: 0 white.) The P generation plants are true-breeding, so mating two purple-flowered plants produces the same result as self-pollination: All the offspring have the same trait. If Mendel had stopped after the F₁ generation, he could have concluded that the white factor had disappeared entirely and would not ever reappear.

Figure 14.8



Yes, this cross would also have allowed Mendel to make different predictions for the two hypotheses, thereby allowing him to distinguish the correct one.

Figure 14.10 Your classmate would probably point out that the F₁ generation hybrids show an intermediate phenotype between those of the homozygous parents, which supports the blending hypothesis. You could respond that crossing the F₁ hybrids results in the reappearance of the white phenotype, rather than identical pink offspring, which fails to support the idea of traits blending during inheritance. The blending hypothesis predicts that the white trait would have been lost after the F₁ generation. **Figure 14.11** Both the I^A and I^B alleles are dominant to the i allele because the i allele results in no attached carbohydrate. The I^A and I^B alleles are codominant; both are expressed in the phenotype of $I^A I^B$ heterozygotes, who have type AB blood. **Figure 14.12** In this cross, the final “3” and “1” of a standard cross are lumped together as a single phenotype. This occurs because in dogs that are ee , no pigment is deposited, thus the three dogs that have a B in their genotype (normally black) can no longer be distinguished from the dog that is bb (normally brown). **Figure 14.16** In the Punnett square, two of the three individuals with normal coloration are carriers, so the probability is $\frac{2}{3}$. (Note that you must take into account everything you know when you calculate probability: You know she is not aa , so there are only three possible genotypes to consider.)

Concept Check 14.1

1. According to the law of independent assortment, 25 plants ($\frac{1}{16}$ of the offspring) are predicted to be $aatt$, or recessive for both characters. The actual result is likely to differ slightly from

Parents: $AaTt \times AaTt$

Sperm from $AaTt$ plant

Eggs from $AaTt$ plant: $\frac{1}{4} AT, \frac{1}{4} At, \frac{1}{4} aT, \frac{1}{4} at$

AT	At	aT	at
$AATT$	$AATt$	$AaTT$	$AaTt$
$AATt$	$AAtt$	$AaTt$	$Aatt$
$AaTT$	$AaTt$	$aaTT$	$aaTt$
$AaTt$	$Aatt$	$aaTt$	$aatt$

this value. **2.** The plant could make eight different gametes (YRI , YRi , YrI , yRI , yRi , yrI , and ysi). To fit all the possible gametes in a self-pollination, a Punnett square would need 8 rows and 8 columns. It would have spaces for the 64 possible unions of gametes in the offspring. **3.** Self-pollination is sexual reproduction because meiosis is involved in forming gametes, which unite during fertilization. As a result, the offspring in self-pollination are genetically different from the parent. (As mentioned in the footnote near the beginning of Concept 14.1, we have simplified the explanation in referring to the single pea plant as a parent. Technically, the gametophytes in the flower are the two “parents.”)

Concept Check 14.2

1. $\frac{1}{2}$ homozygous dominant (AA), 0 homozygous recessive (aa), and $\frac{1}{2}$ heterozygous (Aa) **2.** $\frac{1}{4} BBDD$; $\frac{1}{4} BbDD$; $\frac{1}{4} BBdd$; $\frac{1}{4} Bbdd$ **3.** The genotypes that fulfill this condition are $ppyyII$, $ppyyii$, $ppYYii$, $ppYyii$, $PpyyII$, and $Ppyyii$. Use the multiplication rule to find the probability of getting each genotype, and then use the addition rule to find the overall probability of meeting the conditions of this problem:

$$\begin{aligned} pp yy II & \frac{1}{2} (\text{probability of } pp) \times \frac{1}{4} (yy) \times \frac{1}{4} (II) = \frac{1}{32} \\ pp yy Ii & \frac{1}{2} (pp) \times \frac{1}{4} (yy) \times \frac{1}{2} (Ii) = \frac{1}{16} = \frac{1}{32} \\ pp YY ii & \frac{1}{2} (pp) \times \frac{1}{4} (YY) \times \frac{1}{4} (ii) = \frac{1}{16} = \frac{1}{32} \\ pp Yy ii & \frac{1}{2} (pp) \times \frac{1}{4} (yy) \times \frac{1}{4} (ii) = \frac{1}{16} = \frac{1}{32} \\ pp yy ii & \frac{1}{2} (pp) \times \frac{1}{4} (yy) \times \frac{1}{4} (ii) = \frac{1}{16} = \frac{1}{32} \end{aligned}$$

$$\text{Fraction predicted to be homozygous recessive for at least two of the three characters} = \frac{1}{32} = \frac{1}{4}$$

Concept Check 14.3

1. Incomplete dominance describes the relationship between two alleles of a single gene, whereas epistasis relates to the genetic relationship between two genes (and the respective alleles of each). **2.** Half of the children would be expected to have type A blood and half type B blood. **3.** The black and white alleles are incompletely dominant, with heterozygotes being gray in color. A cross between a gray rooster and a black hen should yield approximately equal numbers of gray and black offspring.

Concept Check 14.4

1. $\frac{1}{6}$ (Since cystic fibrosis is caused by a recessive allele, Lucia and Jared’s siblings who have CF must be homozygous recessive. Therefore, each parent must be a carrier of the recessive allele. Since neither Lucia nor Jared has CF and are thus not cc (using C/c as the alleles for the CF gene), this means they each have a $\frac{2}{3}$ chance of being a carrier. If they are both carriers, there is a $\frac{1}{4}$ chance that they will have a child with CF; $\frac{2}{3} \times \frac{2}{3} \times \frac{1}{4} = \frac{1}{9}$); virtually 0 (Both Lucia and Jared would have to be carriers to produce a child with the disease, unless a very rare mutation (change) occurred in the DNA of cells making eggs or sperm in a noncarrier that resulted in the CF allele.) **2.** In normal hemoglobin, the sixth amino acid is glutamic acid (Glu), which is acidic (has a negative charge on its side chain). In sickle-cell hemoglobin, Glu is replaced by valine (Val), which is a nonpolar amino acid, very different from Glu. The primary structure of a protein (its amino acid sequence) ultimately determines the shape of the protein and thus its function. The substitution of Val for Glu enables the hemoglobin molecules to interact with each other and form long fibers, leading to the protein’s deficient function and the deformation of the red blood cell. **3.** Juanita’s genotype is Dd . Because the allele for polydactyly (D) is dominant to the allele for five digits per appendage (d), the trait is expressed in people with either the DD or Dd genotype. But because Juanita’s father does not have polydactyly, his genotype must be dd , which means that Juanita inherited a d allele from him. Therefore, Juanita, who does have the trait, must be heterozygous. **4.** In the monohybrid cross involving flower color, the ratio is 3.15 purple : 1 white, while in the human family in the pedigree, the ratio in the third generation is 1 taster of PTC : 1 nontaster of PTC. The difference is due to the small sample size (two offspring) in the human family. If the second-generation couple in this pedigree were able to have 929 offspring as in the pea plant cross, the ratio would likely be closer to 3:1. (Note that none of the pea plant crosses in Table 14.1 yielded exactly a 3:1 ratio.)

Summary of Key Concepts Questions

14.1 Alternative versions of genes, called alleles, are passed from parent to offspring during sexual reproduction. In a cross between purple- and white-flowered homozygous parents, the F_1 offspring are all heterozygous, each inheriting a purple allele from one parent and a white allele from the other. Because the purple allele is dominant, it determines the phenotype of the F_1 offspring to be purple, and the expression of the recessive white allele is masked. Only in the F_2 generation is it possible for some of the offspring to be homozygous recessive, which causes the white trait to be expressed.

14.2

Sperm	
$\frac{1}{2} Y$	$\frac{1}{2} y$
Eggs	
$\frac{1}{2} Y$	YY Yy
$\frac{1}{2} y$	Yy yy
	$\frac{3}{4}$ yellow $\frac{1}{4}$ green

Sperm	
$\frac{1}{2} R$	$\frac{1}{2} r$
Eggs	
$\frac{1}{2} R$	RR Rr
$\frac{1}{2} r$	Rr rr
	$\frac{3}{4}$ round $\frac{1}{4}$ wrinkled

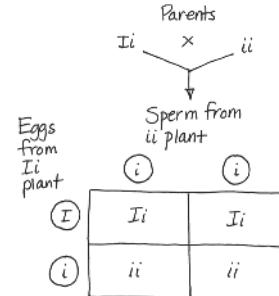
$$\begin{aligned} \frac{3}{4} \text{ yellow} \times \frac{3}{4} \text{ round} &= \frac{9}{16} \text{ yellow round} \\ \frac{3}{4} \text{ yellow} \times \frac{1}{4} \text{ wrinkled} &= \frac{3}{16} \text{ yellow wrinkled} \\ \frac{1}{4} \text{ green} \times \frac{3}{4} \text{ round} &= \frac{3}{16} \text{ green round} \\ \frac{1}{4} \text{ green} \times \frac{1}{4} \text{ wrinkled} &= \frac{1}{16} \text{ green wrinkled} \\ &= 9 \text{ yellow round} : 3 \text{ yellow wrinkled} : 3 \text{ green round} : 1 \text{ green wrinkled} \end{aligned}$$

14.3 The ABO blood group is an example of multiple alleles because this single gene has more than two alleles (I^A , I^B , and i). Two of the alleles, I^A and I^B , exhibit codominance since both carbohydrates (A and B) are present when these two alleles exist together in a genotype. I^A and I^B each exhibit complete dominance over the i allele. This situation is not an example of incomplete dominance because each allele affects the phenotype in a distinguishable way, so the result is not intermediate between the two phenotypes. Because this situation involves a single gene, it is not an example of epistasis or polygenic inheritance. **14.4** The chance of the fourth child having cystic fibrosis is $\frac{1}{4}$, as it was for each of the other children, because each birth is an independent event. We already know both parents are carriers, so whether their first three children are carriers or not has no bearing on the probability that their next child will have the disease. The parents’ genotypes provide the only relevant information.

Test Your Understanding

1. A cross of $Ii \times ii$ would yield offspring with a genotypic ratio of $1 Ii : 1 ii$ (2:2 is an equivalent answer) and a phenotypic ratio of 1 inflated : 1 constricted (2:2 is equivalent).

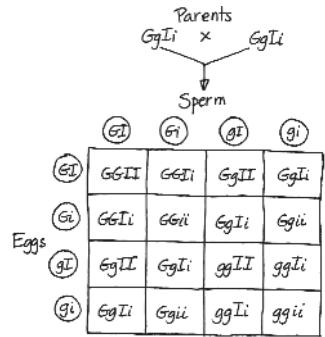
2. Man I^A ; woman I^B ; child ii . Genotypes for future children are predicted to be $\frac{1}{4} I^A I^B$, $\frac{1}{4} I^A i$, $\frac{1}{4} I^B i$, $\frac{1}{4} ii$. **3.** $\frac{1}{2}$



Genotypic ratio $1 Ii : 1 ii$
(2:2 is equivalent)

Phenotypic ratio 1 inflated : 1 constricted
(2:2 is equivalent)

4. The green pod trait is dominant, so the green pod allele is G and the yellow pod allele is g ; the inflated pod trait is dominant, so the inflated pod allele is I and the constricted pod allele is i . The cross described is $GgII \times GgII$.



green inflated : 3 green constricted :
3 yellow inflated : 1 yellow constricted

- 5.** (a) $\frac{1}{64}$; (b) $\frac{1}{64}$; (c) $\frac{1}{8}$; (d) $\frac{1}{32}$ **6.** (a) $\frac{3}{4} \times \frac{3}{4} \times \frac{3}{4} = \frac{27}{64}$; (b) $1 - \frac{27}{64} = \frac{37}{64}$; (c) $\frac{1}{4} \times \frac{1}{4} \times \frac{1}{4} = \frac{1}{64}$; (d) $1 - \frac{1}{64} = \frac{63}{64}$ **7.** (a) $\frac{1}{256}$; (b) $\frac{1}{16}$; (c) $\frac{1}{256}$; (d) $\frac{1}{64}$; (e) $\frac{1}{128}$ **8.** (a) 1; (b) $\frac{1}{32}$; (c) $\frac{1}{8}$; (d) $\frac{1}{2}$ **9.** $\frac{1}{9}$

10. Matings of the original mutant cat with true-breeding noncurl cats will produce both curl and noncurl F_1 offspring if the curl allele is dominant, but only noncurl offspring if the curl allele is recessive. Whether the curl trait is dominant or recessive, you would obtain some true-breeding offspring homozygous for the curl allele from matings between the F_1 cats resulting from the original curl × noncurl crosses. If dominant, you wouldn’t be able to tell true-breeding, homozygous offspring from heterozygotes without further crosses. You know that cats are true-breeding when curl × curl matings produce only curl offspring. As it turns out, the allele that causes curled ears is dominant. **11.** 25%, or $\frac{1}{4}$, will be cross-eyed; all (100%) of the cross-eyed offspring will also be white. **12.** The dominant allele I is epistatic to the P/p locus, and thus the genotypic ratio for the F_1 generation will be $9 I-P-$ (colorless) : $3 I-pp$ (colorless) : $3 iP-$ (purple) : $1 iipp$ (red). Overall, the phenotypic ratio is 12 colorless : 3 purple : 1 red. **13.** Recessive.

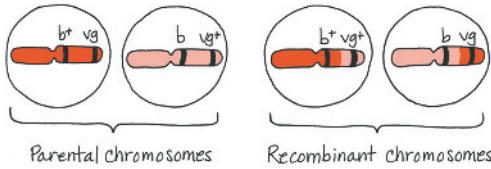
All individuals with alkaptonuria (Ariana, Benito, Elena, and Carlota) are homozygous recessive *aa*. Jorge is *Aa*, since some of his children with Ariana have alkaptonuria. Diego, Carmen, Hector, and Julio are each *Aa*, since they are all unaffected children with one affected parent. Miguel also is *Aa*, since he has an affected child (Carlota) with his heterozygous wife Carmen. Mariposa, Paloma, and Roberto can each have either the *AA* or *Aa* genotype. **14.** $\frac{1}{4}$

Chapter 15

Figure Questions

Figure 15.3 About $\frac{3}{4}$ of the F_2 offspring would have red eyes and about $\frac{1}{4}$ would have white eyes. Since the sex chromosomes are not involved in determining eye color in this hypothetical cross, about half of the white-eyed flies would be female and half would be male; similarly, about half of the red-eyed flies would be female and half would be male. (Note that the autosomes with the eye color alleles would be the same shape in the Punnett square—unlike the X and Y chromosomes—and each offspring would inherit two alleles. The sex of the flies would be determined separately by inheritance of the sex chromosomes. Thus your F_2 Punnett square would have four possible combinations in sperm and two in eggs; it would have eight squares altogether.) **Figure 15.4** The ratio would be 1 yellow round : 1 green round : 1 yellow wrinkled : 1 green wrinkled. (This is similar to a test cross.)

Figure 15.7 All the males would be color-blind, and all the females would be carriers. (Another way to say this is that $\frac{1}{2}$ of the offspring would be color-blind males, and $\frac{1}{2}$ the offspring would be carrier females.) **Figure 15.9** The two largest classes would still be the offspring with the phenotypes of the true-breeding P generation flies, but now they would be gray vestigial and black normal, which is now the “parental type” because those were the specific allele combinations in the P generation (the linked alleles on their chromosomes). **Figure 15.10** The two chromosomes on the left side of the sketch below are like the two chromosomes inherited by the F_1 female, one from each P generation fly. They are passed by the F_1 female intact to the offspring and thus could be called “parental” chromosomes. The other two chromosomes result from crossing over during meiosis in the F_1 female. Because they have combinations of alleles not seen in either of the F_1 female's chromosomes, they can be called “recombinant” chromosomes. (Note that in this example, the allele combinations on the recombinant chromosomes, $b^+ vg^+$ and $b vg$, are the allele combinations that were on the parental chromosomes in the cross shown in Figures 15.9 and 15.10. The basis for calling them parental chromosomes is that they have the combination of alleles that was present on the P generation chromosomes.)



Concept Check 15.1

1. To show the mutant phenotype, a male needs to possess only one mutant allele. If this gene had been on a pair of autosomes, an individual would show the recessive phenotype only if both alleles were mutant, a much less probable situation. 2. The law of segregation describes the inheritance of alleles for a single character. The law of independent assortment of alleles describes the inheritance of alleles for two characters. 3. The physical basis for the law of segregation is the separation of homologs in anaphase I. The physical basis for the law of independent assortment is the alternative arrangements of all the different homologous chromosome pairs in metaphase I.

Concept Check 15.2

1. Because the gene for this eye color character is located on the X chromosome, all female offspring will be red-eyed and heterozygous ($X^{w+}X^w$); all male offspring will inherit a Y chromosome from the father and be white-eyed (X^wY). (Another way to say this is that $\frac{1}{2}$ of the offspring will be red-eyed heterozygous [carrier] females, and $\frac{1}{2}$ will be white-eyed males.) 2. $\frac{1}{4}$ ($\frac{1}{2}$) chance that the child will inherit a Y chromosome from the father and be male $\times \frac{1}{2}$ chance that he will inherit the X carrying the disease allele from his mother). If the child is a boy, there is a $\frac{1}{2}$ chance he will have the disease; a female would have zero chance (but $\frac{1}{2}$ chance of being a carrier). 3. In a disorder caused by a dominant allele, there is no such thing as a “carrier,” since those with the allele have the disorder. Because the allele is dominant, the females lose any “advantage” in having two X chromosomes, since one disorder-associated allele is sufficient to result in the disorder. All fathers who have the dominant allele will pass it along to *all* their daughters, who will also have the disorder. A mother who has the allele (and thus the disorder) will pass it to half of her sons and half of her daughters.

Concept Check 15.3

1. Crossing over during meiosis I in the heterozygous parent produces some gametes with recombinant genotypes for the two genes. Offspring with a recombinant phenotype arise from fertilization of the recombinant gametes by homozygous recessive gametes from the double-mutant parent. 2. In each case, the alleles contributed by the female parent (in the egg) determine the phenotype of the offspring because the male in this cross contributes only recessive alleles. Thus, identifying the phenotype of the offspring tells you what alleles were in the mother's (the dihybrid female's) egg. 3. No. The order could be A-C-B or C-A-B. To determine which possibility is correct, you need to know the recombination frequency between *B* and *C*.

Concept Check 15.4

1. In meiosis, a combined 14-21 chromosome will behave as one chromosome. If a gamete receives the combined 14-21 chromosome and a normal copy of chromosome 21, trisomy 21 will result when this gamete combines with a normal gamete (with its own chromosome 21) during fertilization. 2. No. The child can be either I^1I^4i or I^4ii . A sperm of genotype I^1I^1 could result from nondisjunction in the father during meiosis II, while an egg with the genotype ii could result from nondisjunction in the mother during either meiosis I or meiosis II. 3. Activation of this gene could lead to the production of too much of this kinase. If the kinase is involved in a signaling pathway that triggers cell division, too much of it could trigger unrestricted cell division, which in turn could contribute to the development of a cancer (in this case, a cancer of one type of white blood cell).

Concept Check 15.5

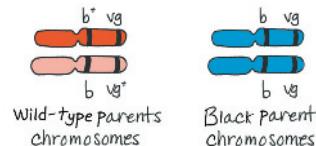
1. Inactivation of an X chromosome in females and genomic imprinting. Because of X inactivation, the effective dose of genes on the X chromosome is the same in males and females. As a result of genomic imprinting, only one allele of certain genes is phenotypically expressed. 2. The genes for leaf coloration are located in plastids within the cytoplasm. Normally, only the maternal parent transmits plastid genes to offspring. Since variegated offspring are produced only when the female parent is of the B variety, we can conclude that variety B contains both the wild-type and mutant alleles of pigment genes, producing variegated leaves. (Variety A must contain only the wild-type allele of pigment genes.) 3. Each cell contains numerous mitochondria, and in affected individuals, most cells contain a variable mixture of normal and mutant mitochondria. The normal mitochondria carry out enough cellular respiration for survival. (The situation is similar for chloroplasts.)

Summary of Key Concepts Questions

15.1 Because the sex chromosomes are different from each other and because they determine the sex of the offspring, Morgan could use the sex of the offspring as a phenotypic character to follow the parental chromosomes. (He could also have followed them under a microscope, as the X and Y chromosomes look different.) At the same time, he could record eye color to follow the eye color alleles. **15.2** Males have only one X chromosome, along with a Y chromosome, while females have two X chromosomes. The Y chromosome has very few genes on it, while the X has about 1,000. When a recessive X-linked allele that causes a disorder is inherited by a male on the X from his mother, there isn't a second allele present on the Y (males are hemizygous), so the male has the disorder. Because females have two X chromosomes, they must inherit two recessive alleles in order to have the disorder, a rarer occurrence. **15.3** Crossing over results in new combinations of alleles. Crossing over is a random occurrence, and the more distance there is between two genes, the more chances there are for crossing over to occur, leading to new allele combinations. **15.4** In inversions and reciprocal translocations, the same genetic material is present in the same relative amount but just organized differently. In aneuploidy, duplications, deletions, and nonreciprocal translocations, the balance of genetic material is upset, as large segments are either missing or present in more than one copy. Apparently, this type of imbalance is very damaging to the organism. (Although it isn't lethal in the developing embryo, the reciprocal translocation that produces the Philadelphia chromosome can lead to a serious condition, cancer, by altering the expression of important genes.) **15.5** In these cases, the sex of the parent contributing an allele affects the inheritance pattern. For imprinted genes, either the paternal or the maternal allele is expressed, depending on the imprint. For mitochondrial and chloroplast genes, only the maternal contribution will affect offspring phenotype because the offspring inherit these organelles from the mother, via the egg cytoplasm.

Test Your Understanding

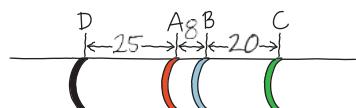
1. 0; $\frac{1}{2}$; $\frac{1}{16}$ **2.** Recessive; if the disorder were dominant, it would affect at least one parent of a child born with the disorder. The disorder's inheritance is sex-linked because it is seen only in boys. For a girl to have the disorder, she would have to inherit recessive alleles from *both* parents. This would be very rare, since males with the recessive allele on their X chromosome die in their early teens. **3.** 17%; yes, it is consistent. In Figure 15.9, the recombination frequency was also 17%. (You'd expect this to be the case since these are the very same two genes, and their distance from each other wouldn't change from one experiment to another.)



- 4.** Between *T* and *A*, 12%; between *A* and *S*, 5% **5.** Between *T* and *S*, 16%; sequence of genes is *T-A-S* **6.** 6%; wild-type heterozygous for normal wings and red eyes \times recessive homozygous for vestigial wings and purple eyes **7.** Fifty percent of the offspring will show phenotypes resulting from crossovers. These results would be the same as those from a cross where *A* and *B* were *not* on the same chromosome, and you would interpret the results to mean that the genes are unlinked. (Further crosses involving other genes between *A* and *B* on the same chromosome would reveal the genetic linkage and map distances.) **8.** 450 each of blue/oval and white/round (parents) and 50 each of blue/round and white/oval (recombinants) **9.** About one-third of the distance along the

chromosome from the vestigial wing locus toward the brown eye locus. **10.** Because bananas are triploid, homologous pairs cannot line up during meiosis. Therefore, it is not possible to generate gametes that can fuse to produce a zygote with the triploid number of chromosomes. **12.** (a) For each pair of genes, you had to generate an F₁ dihybrid fly; let's use the A and B genes as an example. You obtained homozygous parental flies, either the first with dominant alleles of the two genes (AABB) and the second with recessive alleles (aabb), or the first with dominant alleles of gene A and recessive alleles of gene B (AA^bb) and the second with recessive alleles of gene A and dominant alleles of gene B (aaBB). Breeding either of these pairs of P generation flies gave you an F₁ dihybrid, which you then testcrossed with a doubly homozygous recessive fly (aabb). You classed the offspring as parental or recombinant, based on the genotypes of the P generation parents (either of the two pairs described above). You added up the number of recombinant types and then divided by the total number of offspring. This gave you the recombination percentage (in this case, 8%), which you can translate into map units (8 map units) to construct your map.

(b)



Chapter 16

Figure Questions

Figure 16.2 The living S cells found in the blood sample were able to reproduce to yield more S cells, indicating that the S trait is a permanent, heritable change, rather than just a one-time use of the dead S cells' capsules. **Figure 16.4** The radioactivity would have been found in the pellet when proteins were labeled (batch 1) because proteins would have had to enter the bacterial cells to program them with genetic instructions. It's hard for us to imagine now, but the DNA might have played a structural role that allowed some of the proteins to be injected while it remained outside the bacterial cell (thus no radioactivity would be found in the pellet in batch 2). **Figure 16.7** (1) The nucleotides in a single DNA strand are held together by covalent bonds between an oxygen on the 3' carbon of one nucleotide and the phosphate group on the 5' carbon of the next nucleotide in the chain. Instead of covalent bonds, the bonds that hold the two strands together are hydrogen bonds between a nitrogenous base on one strand and the complementary nitrogenous base on the other strand. (Hydrogen bonds are weaker than covalent bonds, but there are so many hydrogen bonds in a DNA double helix that, together, they are enough to hold the two strands together.) (2) One end, the 5' end, has a phosphate group, which is attached to the 5' carbon of the sugar, the one that is not in the ring. The other end, the 3' end, has an —OH group attached to the 3' carbon of the sugar; this carbon is in the ring. (3) The left diagram shows the most detail. It shows that each sugar-phosphate backbone is made up of sugars (blue pentagons) and phosphates (yellow circles) joined by covalent bonds (black lines). The middle diagram doesn't show any detail in the backbone. Both the left and middle diagrams label the bases and represent their complementarity by the complementary shapes at the ends of the bases (curves/indentations for G/C or V's/notches for T/A). The diagram on the right is the least detailed, implying that the base pairs pair up, but showing all bases as the same shape so not including the information about specificity and complementarity visible in the other two diagrams. The left and right diagrams show that the strand on the left was synthesized most recently, as indicated by the light blue color. All three diagrams show the 5' and 3' ends of the strands.

Figure 16.12 The tube from the first replication would look the same, with a middle band of hybrid ¹⁵N-¹⁴N DNA, but the second tube would not have the upper band of DNA molecules made up of two light blue strands. Instead, it would have a bottom band of DNA made up of two dark blue strands, like the bottom band in the result predicted after one replication in the conservative model. **Figure 16.13** In the bubble at the top of the micrograph in (b), arrows should be drawn pointing left and right to indicate the two replication forks. **Figure 16.15**

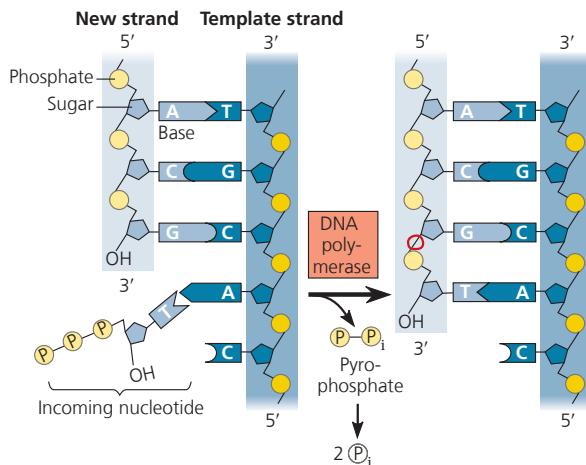


Figure 16.18

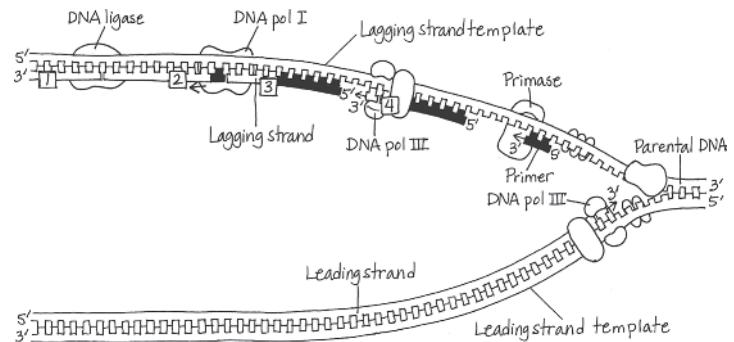


Figure 16.19

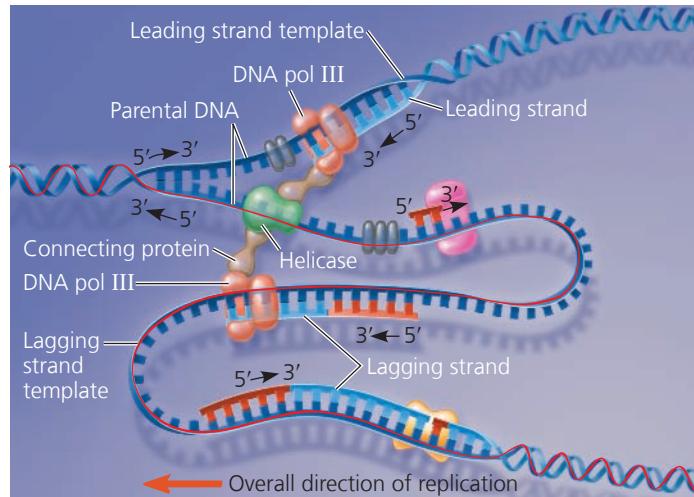


Figure 16.24 The two members of a homologous pair (which would be the same color) would be associated tightly together at the metaphase plate during metaphase I of meiosis I. In metaphase of mitosis, however, each chromosome would be lined up individually, so the two chromosomes of the same color would be in different places at the metaphase plate.

Concept Check 16.1

- In order to tell which end is the 5' end, you need to know which end has a phosphate group on the 5' carbon (the 5' end) and/or which end has an —OH group on the 3' carbon (the 3' end).
- Griffith expected that the mouse injected with the mixture of heat-killed S cells and living R cells would survive, since neither type of cell alone would kill the mouse.

Concept Check 16.2

- Complementary base pairing ensures that the two daughter molecules are exact copies of the parental molecule. When the two strands of the parental molecule separate, each serves as a template on which nucleotides are arranged by the base-pairing rules; they will then be polymerized by enzymes into new complementary strands.
- DNA pol III covalently adds nucleotides to new DNA strands and proofreads each added nucleotide for correct base pairing.
- In the cell cycle, DNA synthesis occurs during the S phase, between the G₁ and G₂ phases of interphase. DNA replication is therefore complete before the mitotic phase begins.
- Synthesis of the leading strand is initiated by an RNA primer, which must be removed and replaced with DNA, a task that could not be performed if the cell's DNA pol I were nonfunctional. In the overview box in Figure 16.18, just to the left of the top origin of replication, a functional DNA pol I would replace the RNA primer of the leading strand (shown in red) with DNA nucleotides (blue). The nucleotides would be added on to the 3' end of the first Okazaki fragment of the upper lagging strand (the right half of the replication bubble).

Concept Check 16.3

- A nucleosome is made up of eight histone proteins, two each of four different types, around which DNA is wound. Linker DNA runs from one nucleosome to the next.
- The 10-nm fiber of euchromatin is less compacted during interphase than in mitosis and is accessible to the cellular proteins responsible for gene expression. In contrast, the 10-nm fiber of heterochromatin is relatively compacted (densely arranged) during interphase, and genes in heterochromatin are largely inaccessible to proteins necessary for gene expression.
- The nuclear lamina is a netlike array of protein filaments that provides mechanical support just inside the nuclear envelope and thus maintains the shape of the nucleus. Considerable evidence also supports the existence of a nuclear matrix, a framework of protein fibers extending throughout the nuclear interior.

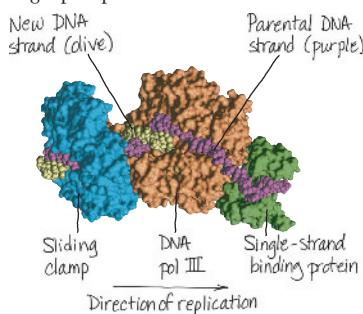
Summary of Key Concepts Questions

16.1 Each strand in the double helix has polarity; the end with a phosphate group on the 5' carbon of the sugar is called the 5' end, and the end with an —OH group on the 3' carbon of the sugar is called the 3' end. The two strands run in opposite directions, one running 5' → 3' and the other alongside it running 3' → 5'. Thus, each end of the molecule has both a 5' and a 3' end, one on each strand of the double helix. This arrangement is called antiparallel. If the strands were parallel, they would both run 5' → 3' in the same direction, so an end of the molecule would have either two 5' ends or two 3' ends. **16.2** On both the leading and lagging strands, DNA polymerase adds onto the 3' end of an RNA primer synthesized by primase, synthesizing DNA in the 5' → 3' direction. Because the parental strands are antiparallel, however, only on the leading strand does synthesis proceed continuously into the replication fork. The lagging strand is synthesized bit by bit in the direction away from the fork as a series of shorter Okazaki fragments, which are later joined together by DNA ligase. Each fragment is initiated by synthesis of an RNA primer by primase as soon as a given stretch of single-stranded template strand is opened up. Although both strands are synthesized at the same rate, synthesis of the lagging strand is delayed because initiation of each fragment begins only when sufficient template strand is available. **16.3** The chromatin in an interphase nucleus is present as the 10-nm fiber, either fairly loosely arranged in euchromatin or more densely arranged in heterochromatin (such as at the centromeres and telomeres). The euchromatin is also subdivided into larger compartments and smaller looped domains. This organization may reflect differences in gene expression occurring in these regions.

Test Your Understanding

- 1.C 2.C 3.B 4.D 5.A 6.D 7.B 8.A 9. Like histones, the *E. coli* proteins would be expected to contain many basic (positively charged) amino acids, such as lysine and arginine, which can form weak bonds with the negatively charged phosphate groups on the sugar-phosphate backbone of the DNA molecule.

11.



Chapter 17

Figure Questions

Figure 17.3 The previously presumed pathway would have been wrong. The new results would support this pathway: precursor → citrulline → ornithine → arginine. They would also indicate that class I mutants have a defect in the second step and class II mutants have a defect in the first step. **Figure 17.5** The mRNA sequence (5'-UGGUUUGCUA-3') is the same as the nontemplate DNA strand sequence (5'-TGGTTTGGCTCA-3'), except there is a U in the mRNA wherever there is a T in the DNA. The nontemplate strand is probably used to represent a DNA sequence because it so closely resembles the mRNA sequence, containing codons. (This is why it's called the coding strand.) **Figure 17.6** Arg (or R)-Glu (or E)-Pro (or P)-Arg (or R). **Figure 17.8** The processes are similar in that polymerases form polynucleotides complementary to an antiparallel DNA template strand. In replication, however, both strands act as templates, whereas in transcription, only one DNA strand acts as a template. This reflects, of course, the fact that replication results in a double-stranded product (DNA) while transcription results in a single-stranded product (an RNA). **Figure 17.9** The RNA polymerase would bind directly to the promoter, rather than being dependent on the previous binding of transcription factors.

Figure 17.12

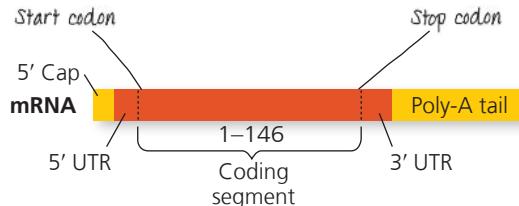


Figure 17.16 The anticodon on the tRNA is 3'-AAG-5', so it would bind to the mRNA codon 5'-UUC-3'. This codon codes for phenylalanine (Phe, or F), which is the amino acid this tRNA would carry. **Figure 17.22** It would be packaged in a vesicle, transported to the Golgi apparatus for further processing, and then transported via a vesicle to the plasma membrane. The vesicle would fuse with the membrane, releasing the protein outside the cell. **Figure 17.24** The mRNA farthest to the right (the longest one) started transcription first. The ribosome at the top, closest to the DNA, started translating first and thus has the longest polypeptide.

Concept Check 17.1

1. Recessive 2. A polypeptide made up of 10 Gly (glycine) amino acids

3.

Nontemplate sequence (from template sequence given in problem), written 3' → 5':
3'-ACGACTGAA-5'

If above used as template, mRNA sequence: 5'-UGCUAGCUU-3'

Translated:

Cys-STOP

If the nontemplate sequence could have been used as a template for transcribing the mRNA, the protein translated from the mRNA would have a completely different amino acid sequence, so it would not be able to function as the original protein (translated from an mRNA transcribed from the template strand). It would also be shorter because of the UGA stop signal shown in the mRNA sequence above—and possibly others earlier in the mRNA sequence.

Concept Check 17.2

1. A promoter is the region of DNA to which RNA polymerase binds to begin transcription. It is at the upstream end of the gene (transcription unit).

2. In a bacterial cell, part of the RNA polymerase recognizes the gene's promoter and binds to it. In a eukaryotic cell, transcription factors must bind to the promoter first, then the RNA polymerase binds to them. In both cases, sequences in the promoter determine the precise binding of RNA polymerase so the enzyme is in the right location and orientation. 3. The transcription factor that recognizes the TATA sequence would be unable to bind, so RNA polymerase could not bind and transcription of that gene most likely would not occur.

Concept Check 17.3

1. Due to alternative splicing of exons, each gene can result in multiple different mRNAs and can thus direct synthesis of multiple different proteins. 2. In watching a pre-recorded show, you watch segments of the show itself (exons) and fast-forward through the commercials, which are thus like introns. However, unlike introns, commercials remain in the recording, while the introns are cut out of the RNA transcript during RNA processing. 3. Once the mRNA has exited the nucleus, the cap prevents it from being degraded by hydrolytic enzymes and facilitates its attachment to ribosomes. If the cap were removed from all mRNAs, the cell would no longer be able to synthesize any proteins and would probably die.

Concept Check 17.4

1. First, each aminoacyl-tRNA synthetase specifically recognizes a single amino acid and attaches it only to an appropriate tRNA. Second, a tRNA charged with its specific amino acid binds only to an mRNA codon for that amino acid. 2. A signal peptide on the leading end (amino end, or N-terminus) of the polypeptide being synthesized is recognized by a signal-recognition particle that brings the ribosome to the ER membrane. There,

the ribosome attaches and continues to synthesize the polypeptide, depositing it in the ER lumen.

3. Because of wobble, the tRNA could bind to either 5'-GCA-3' or 5'-GCG-3', both of which code for alanine (Ala, or A). Alanine would be attached to the tRNA (see diagram, upper right). 4. When one ribosome terminates translation and dissociates, the two subunits would be very close to the cap. This could facilitate their rebinding and initiating synthesis of a new polypeptide, thus increasing the efficiency of translation.

Concept Check 17.5

1. In the mRNA, the reading frame downstream from the deletion is shifted, leading to a long string of incorrect amino acids in the polypeptide, and in most cases, a stop codon will occur, leading to premature termination. The polypeptide will most likely be nonfunctional. 2. Heterozygous individuals, said to have sickle-cell trait, have a copy each of the wild-type allele and the sickle-cell allele. Both alleles will be expressed, so these individuals will have both normal and sickle-cell hemoglobin molecules. Apparently, having a mix of the two forms of β -globin has no effect under most conditions, but during prolonged periods of low blood oxygen (such as at higher altitudes), these individuals can show some signs of sickle-cell disease.

3.

Normal DNA sequence
(Template strand is on top): 5'-TACTTGTCGATATC-5'
5'-ATGAAACAGGCTATAG-3'

mRNA sequence: 5'-AUGAAACAGGCUAUAG-3'

Amino acid sequence: Met-Asn-Arg-Leu-STOP

Mutated DNA sequence
(Template strand is on top): 5'-TACTTGTCCAAATATC-5'
5'-ATGAAACAGGTTATAG-3'

mRNA sequence: 5'-AUGAAACAGGUUAUAG-3'

Amino acid sequence: Met-Asn-Arg-Leu-STOP

No effect: The amino acid sequence is Met-Asn-Arg-Leu both before and after the mutation because the mRNA codons 5'-CUA-3' and 5'-UUA-3' both code for Leu. (The fifth codon is a stop codon.) **4.** A Cas9-guide RNA could be synthesized complementary to the mutated sequence, and the Cas9-guide RNA complex injected into a cell with the mutation. A region of double-stranded DNA with the correct sequence would also be provided. Cas9 would cut the mutated sequence, and the DNA repair system in the cell would repair the DNA, using the correct sequence as a template. Based on the answer to question 3, however, this would not be worthwhile because there is no amino acid change in the encoded protein, so the function of the protein encoded by the mutated gene is normal.

Summary of Key Concepts Questions

17.1 A gene contains genetic information in the form of a nucleotide sequence. The gene is first transcribed into an RNA molecule, and a messenger RNA molecule is ultimately translated into a polypeptide. The polypeptide makes up part or all of a protein, which performs a function in the cell and contributes to the phenotype of the organism. **17.2** Both bacterial and eukaryotic genes have promoters, regions where RNA polymerase ultimately binds and begins transcription. In bacteria, RNA polymerase binds directly to the promoter; in eukaryotes, transcription factors bind first to the promoter, and then RNA polymerase binds to the transcription factors and promoter together.

17.3 Both the 5' cap and the 3' poly-A tail help the mRNA exit from the nucleus and then, in the cytoplasm, help ensure mRNA stability and allow it to bind to ribosomes. **17.4** In the context of the ribosome, tRNAs function as translators between the nucleotide-based language of mRNA and the amino-acid-based language of polypeptides. A tRNA carries a specific amino acid, and the anticodon on the tRNA is complementary to the codon on the mRNA that codes for that amino acid. In the ribosome, the tRNA binds to the A site. Then the polypeptide being synthesized (currently on the tRNA in the P site) is joined to the new amino acid, which becomes the new (C-terminal) end of the polypeptide. Next, the tRNA in the A site moves to the P site. After the polypeptide is transferred to the new tRNA, thus adding the new amino acid, the now empty tRNA moves from the P site to the E site, where it exits the ribosome. **17.5** When a nucleotide base is altered chemically, its base-pairing characteristics may be changed. When that happens, an incorrect nucleotide is likely to be incorporated into the complementary strand during the next replication of the DNA, and successive rounds of replication will perpetuate the mutation. Once the gene is transcribed, the mutated codon may code for a different amino acid that inhibits or changes the function of a protein. If, however, the chemical change in the base is detected and repaired by the DNA repair system before the next replication, no mutation will result.

Test Your Understanding

1.B **2.C** **3.A** **4.B** **5.B** **6.C** **7.D** **8.** No. Transcription and translation are separated in space and time in a eukaryotic cell, as a result of the eukaryotic cell's nuclear membrane

9.

Type of RNA	Functions
Messenger RNA (mRNA)	Carries information specifying amino acid sequences of polypeptides from DNA to ribosomes
Transfer RNA (tRNA)	Serves as translator molecule in protein synthesis; translates mRNA codons into amino acids
Ribosomal RNA (rRNA)	In a ribosome, plays a structural role; as a ribozyme, plays a catalytic role (catalyzes peptide bond formation)
Primary transcript	Is a precursor to mRNA, rRNA, or tRNA, before being processed; some rRNA acts as a ribozyme, catalyzing its own splicing
Small RNAs in spliceosomes	Play structural and catalytic roles in spliceosomes, the complexes of protein and RNA that splice pre-mRNA

Chapter 18

Figure Questions

Figure 18.3 As the concentration of tryptophan in the cell falls, eventually there will be none bound to *trp* repressor molecules. These will then change into their inactive shapes and dissociate from the operator, allowing transcription of the operon to resume. The enzymes for tryptophan synthesis will be made, and they will again synthesize tryptophan in the cell.

Figure 18.10 Each of the two polypeptides has two regions—one that makes up part of MyoD's DNA-binding domain and one that makes up part of MyoD's activation domain. Each functional domain in the complete MyoD protein is made up of parts of both polypeptides. **Figure 18.12** In both types of cell, the albumin gene enhancer has the three control elements colored yellow, gray, and red. The sequences in the liver and lens cells would be identical, since the cells are in the same organism. **Figure 18.18** Even if the mutant MyoD protein couldn't activate the *myoD* gene, it could still turn on genes for the other proteins in the pathway (other transcription factors, which would turn on the genes for muscle-specific proteins, for example). Therefore, some differentiation would occur. But unless there were other activators that could compensate for the loss of the MyoD protein's activation of the *myoD* gene, the cell would not be able to maintain its differentiated state. **Figure 18.22** Normal Bicoid protein would be made in the anterior end and compensate for the presence of mutant *bicoid* mRNA put into the egg by the mother. Development should be normal, with a head present. (This is what was observed.) **Figure 18.25** The mutation is likely to be recessive

because it is more likely to have an effect if both copies of the gene are mutated and code for nonfunctional proteins. If one normal copy of the gene is present, its product could inhibit the cell cycle. (However, there are also known cases of dominant *p53* mutations, and the HNPCC gene, discussed later, is a dominant mutation in a tumor-suppressor pathway.) **Figure 18.27** Cancer is a disease in which cell division occurs without its usual regulation. Cell division can be stimulated by growth factors (see Figure 12.18), which bind to cell-surface receptors (see Figure 11.8). Cancer cells evade these normal controls and can often divide in the absence of growth factors (see Figure 12.19). This suggests that the receptor proteins or some other components in a signaling pathway are abnormal in some way (see, for example, the mutant Ras protein in Figure 18.24) or are expressed at abnormal levels, as seen for the receptors in this figure. Under some circumstances in the mammalian body, steroid hormones such as estrogen and progesterone can also promote cell division. These molecules also use cell-signaling pathways, as described in Concept 11.2 (see Figure 11.9). Because signaling receptors are involved in triggering cells to undergo cell division, it is not surprising that altered genes encoding these proteins might play a significant role in the development of cancer. Genes might be altered through either a mutation that changes the function of the protein product or a mutation that causes the gene to be expressed at abnormal levels that disrupt the overall regulation of the signaling pathway.

Concept Check 18.1

- 1.** Binding by the *trp* corepressor (tryptophan) activates the *trp* repressor, which binds to the *trp* operator, shutting off transcription of the *trp* operon. Binding by the *lac* inducer (allolactose) inactivates the *lac* repressor, so that it can no longer bind to the *lac* operator, leading to transcription of the *lac* operon. **2.** When glucose is scarce, CAP is bound to CRP and CRP is bound to the *lac* promoter, favoring the binding of RNA polymerase. However, in the absence of lactose, the *lac* repressor is bound to the *lac* operator, blocking RNA polymerase from transcribing the *lac* operon genes. **3.** The cell would continuously produce β -galactosidase and the two other enzymes for using lactose, even in the absence of lactose, thus wasting cell resources.

Concept Check 18.2

- 1.** Histone acetylation is generally associated with gene expression, while DNA methylation is generally associated with lack of expression. **2.** The same enzyme could not methylate both a histone and a DNA base. Enzymes are very specific in structure, and an enzyme that could methylate an amino acid of a protein would not be able to fit the base of a DNA nucleotide into the same active site. **3.** General transcription factors function in assembling the transcription initiation complex at the promoters for all genes. Specific transcription factors bind to control elements associated with a particular gene and, once bound, either increase (activators) or decrease (repressors) transcription of that gene. **4.** Regulation of translation initiation, degradation of the mRNA, activation of the protein (by chemical modification, for example), and protein degradation **5.** The three genes should have some similar or identical sequences in the control elements of their enhancers. Because of this similarity, the same specific transcription factors that are present in muscle cells could bind to the enhancers of all three genes and stimulate their expression coordinately.

Concept Check 18.3

- 1.** Both miRNAs and siRNAs are small, single-stranded RNAs that associate with a complex of proteins and then can base-pair with mRNAs that have a complementary sequence. This base pairing leads to either degradation of the mRNA or blockage of its translation. In some yeasts, siRNAs associated with proteins in a different complex can bind back to centromeric chromatin, recruiting enzymes that cause condensation of that chromatin into heterochromatin. Both miRNAs and siRNAs are processed from double-stranded RNA precursors but have subtle variations in the structure of those precursors. **2.** The mRNA would persist and be translated into the cell division-promoting protein, and the cell would probably divide. If the intact miRNA is necessary for inhibition of cell division, then division of this cell might be inappropriate. Uncontrolled cell division could lead to formation of a mass of cells (tumor) that prevents proper functioning of the organism and could contribute to the development of cancer. **3.** The *XIST* RNA is transcribed from the *XIST* gene on the X chromosome that will be inactivated. It then binds to that chromosome and induces heterochromatin formation. A likely model is that *XIST* RNA somehow recruits chromatin modification enzymes that lead to formation of heterochromatin.

Concept Check 18.4

- 1.** Cells undergo differentiation during embryonic development, becoming different from each other. Therefore, the adult organism is made up of many highly specialized cell types that are different from each other. **2.** By binding to a receptor on the receiving cell's surface and triggering a signal transduction pathway, involving intracellular molecules such as second messengers and transcription factors that affect gene expression **3.** The products of maternal effect genes, made and deposited into the egg by the mother, determine the head and tail ends, as well as the back and belly, of the egg and embryo (and eventually the adult fly). **4.** The lower cell is synthesizing signaling molecules because the gene encoding them is activated, meaning that the appropriate specific transcription factors are binding to the gene's enhancer. The genes encoding these specific transcription factors are also being expressed in this cell because the transcription factor activators that can turn them on were expressed in the precursor to this cell. A similar explanation also applies to the cells expressing the

receptor proteins. This scenario began with specific cytoplasmic determinants localized in specific regions of the egg. These cytoplasmic determinants were distributed unevenly to daughter cells, resulting in cells going down different developmental pathways.

Concept Check 18.5

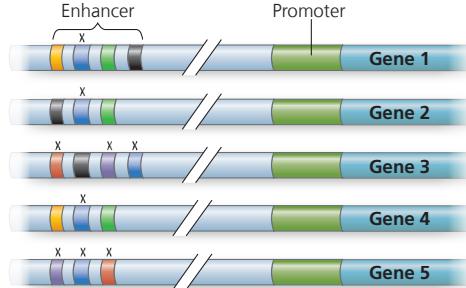
1. A cancer-causing mutation in a proto-oncogene usually makes the gene product overactive, whereas a cancer-causing mutation in a tumor-suppressor gene usually makes the gene product nonfunctional. 2. When an individual has inherited an oncogene or a mutant allele of a tumor-suppressor gene 3. Apoptosis is signaled by the p53 protein when a cell has extensive DNA damage, so apoptosis plays a protective role in eliminating a cell that might contribute to cancer. If mutations in the genes in the apoptotic pathway blocked apoptosis, a cell with such damage could continue to divide and might lead to tumor formation.

Summary of Key Concepts Questions

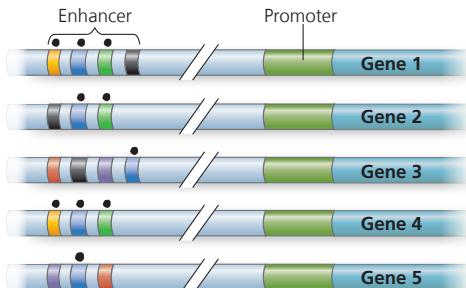
- 18.1** A corepressor and an inducer are both small molecules that bind to the repressor protein in an operon, causing the repressor to change shape. In the case of a corepressor (like tryptophan), this shape change allows the repressor to bind to the operator, blocking transcription. In contrast, an inducer causes the repressor to dissociate from the operator, allowing transcription to begin.
- 18.2** In that specific type of cell, the chromatin must not be tightly condensed because it must be accessible to transcription factors. The appropriate specific transcription factors (activators), which are made in that type of cell, must bind to the control elements in the enhancer of the gene, while repressors must not be bound. The DNA must be bent by a bending protein so the activators can contact the mediator proteins and form a complex with general transcription factors at the promoter. Then RNA polymerase must bind and begin transcription.
- 18.3** miRNAs do not “code” for the amino acids of a protein—they are never translated. Each miRNA associates with a group of proteins to form a complex. Binding of the complex to an mRNA with a complementary sequence causes that mRNA to be degraded or blocks its translation. This is considered gene regulation because it controls the amount of a particular mRNA that can be translated into a functional protein.
- 18.4** The first process involves cytoplasmic determinants, including mRNAs and proteins, placed into specific locations in the egg by maternal cells. The embryonic cells that are formed from different regions of the egg during early cell divisions will have different proteins in them, which will direct different programs of gene expression. The second process involves the cell in question responding to signaling molecules secreted by neighboring cells (induction). The signaling pathway in the responding cell also leads to a different pattern of gene expression. The coordination of these two processes results in each cell following a unique pathway in the developing embryo.
- 18.5** The protein product of a proto-oncogene is usually involved in a pathway that stimulates cell division. The protein product of a tumor-suppressor gene is usually involved in a pathway that inhibits cell division.

Test Your Understanding

- 1.C 2.A 3.B 4.C 5.C 6.D 7.A 8.C 9.B 10.D
11.(a)



The purple, blue, and red activator proteins would be present.
(b)



Only gene 4 would be transcribed.

(c) In nerve cells, the yellow, blue, green, and black activators would have to be present, thus activating transcription of genes 1, 2, and 4. In skin cells, the red, black, purple, and blue activators would have to be present, thus activating genes 3 and 5.

Chapter 19

Figure Questions

Figure 19.2 Beijerinck might have concluded that the agent was a toxin produced by the plant that was able to pass through a filter but that became more and more dilute. In this case, he would have concluded that the infectious agent could not replicate.

Figure 19.4

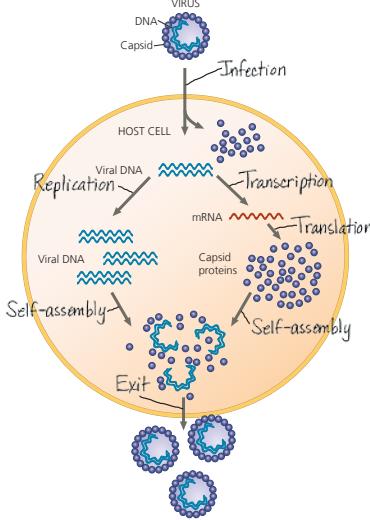


Figure 19.9 The main protein on the cell surface that HIV binds to is called CD4. However, HIV also requires a “co-receptor,” which in many cases is a protein called CCR5. HIV binds to both of these proteins together and then is taken into the cell. Researchers discovered this requirement by studying individuals who seemed to be resistant to HIV infection despite multiple exposures. These individuals turned out to have mutations in the gene that encodes CCR5 such that the protein apparently cannot act as a co-receptor, and so HIV can't enter and infect cells.

Concept Check 19.1

- 1.** Both viruses consist of RNA as the genetic material, associated with proteins. However, TMV consists of one molecule of RNA surrounded by a helical array of proteins, while the influenza virus has eight molecules of RNA, each associated with proteins and wound into a double helix. Another difference between the viruses is that the influenza virus has an outer envelope and TMV does not. **2.** The T2 phages were an excellent choice for use in the Hershey-Chase experiment because they consist of only DNA surrounded by a protein coat, and DNA and protein were the two candidates for macromolecules that carried genetic information. Hershey and Chase were able to radioactively label each type of molecule alone and follow it during separate infections of *E. coli* cells with T2. Only the DNA entered the bacterial cell during infection, and only labeled DNA showed up in some of the progeny phage. Hershey and Chase concluded that the DNA must carry the genetic information necessary for the phage to reprogram the cell and produce progeny phages.

Concept Check 19.2

- 1.** Lytic phages can only carry out lysis of the host cell, whereas lysogenic phages may either lyse the host cell or integrate into the host chromosome. In the latter case, the viral DNA (prophage) is simply replicated along with the host chromosome. Under certain conditions, a prophage may exit the host chromosome and initiate a lytic cycle. **2.** Both the CRISPR-Cas system and miRNAs involve RNA molecules bound in a protein complex and acting as “homing devices” that enable the complex to bind a complementary sequence. However, miRNAs are involved in regulating gene expression (by affecting mRNAs) and the CRISPR-Cas system protects bacterial cells from foreign invaders—infected phages. Thus the CRISPR-Cas system is more like an immune system than is the miRNA system. **3.** Both the viral RNA polymerase and the RNA polymerase in Figure 17.10 synthesize an RNA molecule complementary to a template strand. However, the RNA polymerase in Figure 17.10 uses one of the strands of the DNA double helix as a template, whereas the viral RNA polymerase uses the RNA of the viral genome as a template. **4.** HIV is called a retrovirus because it synthesizes DNA using its RNA genome as a template. This is the reverse (“retro”) of the usual DNA → RNA information flow. **5.** There are many steps that could be interfered with: binding of the virus to the cell, reverse transcriptase function, integration into the host cell chromosome, genome synthesis (in this case, transcription of RNA from the integrated provirus), assembly of the virus inside the cell, and budding of the virus. (Many of these, if not all, are targets of actual medical strategies to block progress of the infection in HIV-infected people.)

Concept Check 19.3

- 1.** Mutations can lead to a new strain of a virus that can no longer be effectively fought by the immune system, even if an animal had been exposed to the original strain; a virus can jump from one species to a new host; and a rare virus can spread if a host population becomes less isolated. **2.** In horizontal transmission, a plant is infected from an external source of virus, which enters through a break in the plant's epidermis due to damage by herbivores or other agents. In vertical transmission, a plant inherits viruses from its parent either via infected seeds (sexual reproduction) or via an infected cutting (asexual reproduction). **3.** Humans are not within the host range of TMV, so they can't be infected by the virus. (TMV can't bind to receptors on human cells and infect them.)

Summary of Key Concepts Questions

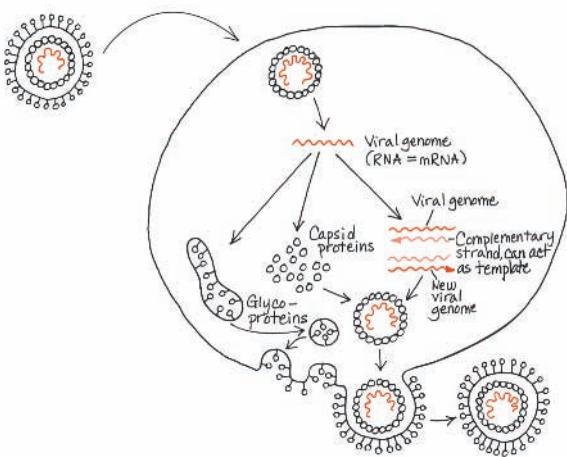
- 19.1** Viruses are generally considered nonliving because they are not capable of replicating outside of a host cell and are unable to carry out the

energy-transforming reactions of metabolism. To replicate and carry out metabolism, they depend completely on host enzymes and resources. **19.2** Single-stranded RNA viruses require an RNA polymerase that can make RNA using an RNA template. (Cellular RNA polymerases make RNA using a DNA template.) Retroviruses require reverse transcriptases to make DNA using an RNA template. (Once the first DNA strand has been made, the same enzyme can promote synthesis of the second DNA strand.) **19.3** The mutation rate of RNA viruses is higher than that of DNA viruses because RNA polymerase has no proofreading function, so errors in replication are not corrected. Their higher mutation rate is one reason that RNA viruses change faster than DNA viruses, leading to their being able to have an altered host range and to evade immune defenses in possible hosts.

Test Your Understanding

1.C 2.D 3.C 4.D 5.B

6. As shown below, the viral genome would be translated into capsid proteins and envelope glycoproteins directly, rather than after a complementary RNA copy was made. A complementary RNA strand would still be made, however, that could be used as a template for many new copies of the viral genome.



Chapter 20

Figure Questions

Figure 20.5

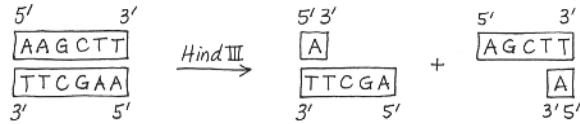
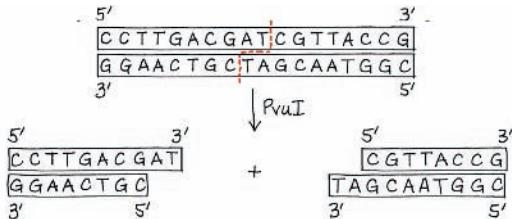


Figure 20.16 None of the eggs with the transplanted nuclei from the four-cell embryo at the upper left would have developed into a tadpole. Also, the result might include only some of the tissues of a tadpole, which might differ, depending on which nucleus was transplanted. (This assumes that there was some way to tell the four cells apart, as one can in some frog species.) **Figure 20.21** Using converted iPS cells would not carry the same risk, which is its major advantage. Because the donor cells would come from the patient, they would be perfectly matched. The patient's immune system would recognize them as "self" cells and would not mount an attack (which is what leads to rejection). On the other hand, cells that are rapidly dividing might carry a risk of inducing some type of tumor or contributing to development of cancer.

Concept Check 20.1

1. The covalent sugar-phosphate bonds of the DNA strands 2. Yes, *Pvu*I will cut the molecule (at the position indicated by the dashed red line).



3. Some eukaryotic genes are too large to be incorporated into bacterial plasmids. Bacterial cells lack the means to process RNA transcripts into mRNA, and even if the need for RNA processing is avoided by using cDNA, bacteria lack enzymes to catalyze the post-translational processing that many eukaryotic proteins require to function properly. (This is often the case for human proteins, which are a focus of biotechnology.) 4. During the replication of the ends of linear DNA molecules (see Figure 16.21), an RNA primer is used at the 5' end of

each new strand. The RNA must be replaced by DNA nucleotides, but DNA polymerase is incapable of starting from scratch at the 5' end of a new DNA strand. During PCR, the primers are made of DNA nucleotides already, so they don't need to be replaced—they just remain as part of each new strand. Therefore, there is no problem with end replication during PCR, and the fragments don't shorten with each replication.

Concept Check 20.2

1. Complementary base pairing is involved in cDNA synthesis, which is required for all three techniques: RT-PCR, DNA microarray analysis, and RNA sequencing. Reverse transcriptase uses mRNA as a template to synthesize the first strand of cDNA, adding nucleotides complementary to those on the mRNA. Complementary base pairing is also involved when DNA polymerase synthesizes the second strand of the cDNA. Furthermore, in RT-PCR, the primers must base-pair with their target sequences in the DNA mixture, locating one specific region among many. Also, the DNA polymerase (for example, Taq polymerase) used in PCR relies on complementary base pairing to the template strand to add new nucleotides during synthesis of the fragments. In DNA microarray analysis, the labeled cDNA probe binds only to the specific target sequence due to complementary nucleic acid hybridization (DNA-DNA hybridization). In RNA-seq, when sequencing the cDNAs, base complementarity plays a role in the sequencing process. 2. As a researcher interested in how cancer develops, you would want to study genes represented by spots that are green or red because these are genes for which the expression level differs between the two types of tissue. Some of these genes may be expressed differently as a result of cancer, while others might play a role in causing cancer, so both would be of interest.

Concept Check 20.3

1. The state of chromatin modification in the nucleus from the intestinal cell was undoubtedly less similar to that of a nucleus from a fertilized egg, explaining why many fewer of these nuclei were able to be reprogrammed. In contrast, the chromatin in a nucleus from a cell at the four-cell stage would have been much more like that of a nucleus in a fertilized egg and therefore much more easily programmed to direct development. 2. No, primarily because of subtle (and perhaps not so subtle) differences in the environment in which the clone develops and lives compared with that in which the original pet lived (see the differences noted in Figure 20.18). This does provoke ethical questions. To produce Dolly, also a mammal, several hundred embryos were cloned, but only one survived to adulthood. If any of the "reject" dog embryos survived to birth as defective dogs, would they be killed? Is it ethical to produce living animals that may be defective? You can probably think of other ethical issues as well. 3. Given that muscle cell differentiation involves a master regulatory gene (*MyoD*), you might start by introducing either the *MyoD* protein or an expression vector carrying the *MyoD* gene into stem cells. (This is not likely to work, because the embryonic precursor cell in Figure 18.18 is more differentiated than the stem cells you are working with, and some other changes would have to be introduced as well. But it's a good way to start! And you may be able to think of others.)

Concept Check 20.4

1. Stem cells continue to reproduce themselves, ensuring that the corrective gene product will continue to be made. 2. Herbicide resistance, pest resistance, disease resistance, drought resistance, and delayed ripening 3. Because hepatitis A is an RNA virus, you could isolate RNA from the blood and try to detect copies of hepatitis A RNA by RT-PCR. You would first reverse-transcribe the blood mRNA into cDNA and then use PCR to amplify the cDNA, using primers specific to hepatitis A sequences. If you then ran the products on an electrophoretic gel, the presence of a band of the appropriate size would support your hypothesis. Alternatively, you could use RNA-seq to sequence all the RNAs in your patient's blood and see whether any of the sequences match up with that of hepatitis A. (Since you are only seeking one sequence, though, RT-PCR is probably a better choice.)

Summary of Key Concepts Questions

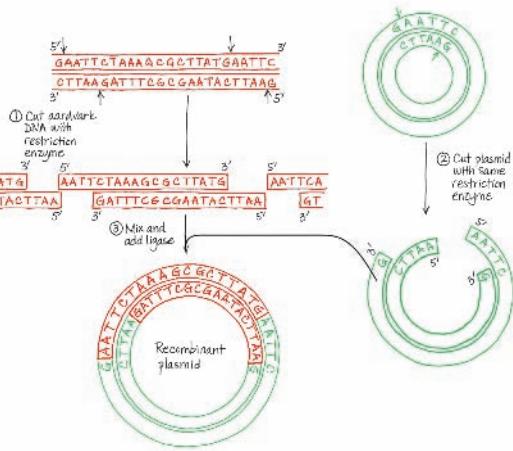
- 20.1 A plasmid vector and a source of foreign DNA to be cloned are both cut with the same restriction enzyme, generating restriction fragments with sticky ends. These fragments are mixed together, ligated, and reintroduced into bacterial cells. The plasmid has a gene for resistance to an antibiotic. That antibiotic is added to the host cells, and only cells that have taken up a plasmid will grow. (Another technique allows researchers to select only the cells that have a recombinant plasmid, rather than the original plasmid without an inserted gene.) 20.2 The genes that are expressed in a given tissue or cell type determine the proteins (and noncoding RNAs) that are the basis of the structure and functions of that tissue or cell type. Understanding which groups of interacting genes establish particular structures and carry out certain functions will help us learn how the parts of an organism work together. We will also be better able to treat diseases that occur when faulty gene expression leads to malfunctioning tissues. 20.3 (1) Cloning a mouse involves transplanting a nucleus from a differentiated mouse cell into a mouse egg cell that has had its own nucleus removed. Activating the egg cell and promoting its development into an embryo in a surrogate mother results in a mouse that is genetically identical to the mouse that donated the nucleus. In this case, the differentiated nucleus has been reprogrammed by factors in the egg cytoplasm. (2) Mouse ES cells are generated from inner cells in mouse blastocysts, so in this case the cells are "naturally" reprogrammed by the process of reproduction and development. (Cloned mouse embryos can also be used as a source of ES cells.) (3) iPS cells can be generated without the use of embryos from a differentiated adult mouse cell by adding certain transcription factors into the cell. In this case, the transcription factors are reprogramming the cells to become pluripotent. 20.4 First, the disease must be caused by a single gene, and the molecular basis of the problem must be understood. Second, the cells that are going to be introduced

into the patient must be cells that will integrate into body tissues and continue to multiply (and provide the needed gene product). Third, the gene must be able to be introduced into the cells in question in a safe way, as there have been instances of cancer resulting from some gene therapy trials. (Note that this will require testing the procedure in mice; moreover, the factors that determine a safe vector are not yet well understood. Maybe one of you will go on to solve this problem!)

Test Your Understanding

1. D 2. B 3. C 4. B 5. C 6. A 7. B 8. You would use PCR to amplify the gene. This could be done from genomic DNA. Alternatively, mRNA could be isolated from lens cells and reverse-transcribed by reverse transcriptase to make cDNA. This cDNA could then be used for PCR. In either case, the gene would then be inserted into an expression vector so you could produce the protein and study it. 9. Crossing over, which causes recombination, is a random event. The chance of crossing over occurring between two loci increases as the distance between them increases. If a SNP is located very close to a disease-associated allele, it is said to be genetically linked. Crossing over will rarely occur between the SNP and the allele, so the SNP can be used as a genetic marker indicating the presence of the particular allele.

10.



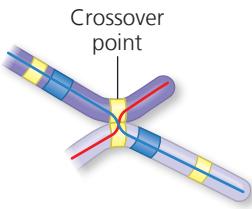
Chapter 21

Figure Questions

Figure 21.2 In step 2 of this figure, the order of the fragments relative to each other is not known and will be determined later by computer. The unordered nature of the fragments is reflected by their scattered arrangement in the diagram. **Figure 21.8** The transposon would be cut out of the DNA at the original site rather than copied, so the figure would show the original stretch of DNA without the transposon after the mobile transposon had been cut out.

Figure 21.10 The RNA transcripts extending from the DNA in each transcription unit are shorter on the left and longer on the right. This means that RNA polymerase must be starting on the left end of the unit and moving toward the right.

Figure 21.13



in the EGF gene, and the same TE was present in the intron to the right of the indicated F exon in the fibronectin gene. During meiotic recombination, these TEs could cause nonsister chromatids on homologous chromosomes to pair up incorrectly, as seen in Figure 21.13. One gene might end up with an F exon next to an EGF exon. Further mistakes in pairing over many generations might result in these two exons being separated from the rest of the gene and placed next to a single or duplicated K exon. In general, the presence of repeated sequences in introns and between genes facilitates these processes because it allows incorrect pairing of nonsister chromatids, leading to novel exon combinations. **Figure 21.18** Since you know that chimpanzees do not speak but humans do, you'd probably want to know how many amino acid differences there are between the human wild-type FOXP2 protein and that of the chimpanzee and whether these changes affect the function of the protein. (As we explain later in the text, there are two amino acid differences.) You know that humans with mutations in this gene have severe language impairment. You would want to learn more about the human mutations by checking whether they affect the same amino acids in the gene product that the chimpanzee sequence differences affect. If so, those amino acids might play an important role in the function of the protein in language. Going further, you could analyze the differences between the chimpanzee and mouse FOXP2 proteins. You might ask: Are they more similar than the

chimpanzee and human proteins? (It turns out that the chimpanzee and mouse proteins have only one amino acid difference and thus are more similar than the chimpanzee and human proteins, which have two differences, and also are more similar than the human and mouse proteins, which have three differences.)

Concept Check 21.1

1. In the whole-genome shotgun approach, short fragments are generated by cutting the genome with multiple restriction enzymes. These fragments are cloned, sequenced, and then ordered by computer programs that identify overlapping regions.

Concept Check 21.2

1. The Internet allows centralization of databases such as GenBank and software resources such as BLAST, making them freely accessible. Having all the data in a central database, easily accessible on the Internet, minimizes the possibility of errors and of researchers working with different data. It streamlines the process of science, since all researchers are able to use the same software programs, rather than each having to obtain their own, possibly different, software. It speeds up dissemination of data and ensures as much as possible that errors are corrected in a timely fashion. These are just a few answers; you can probably think of more. 2. Cancer is a disease caused by multiple factors. Focusing on a single gene or a single defect would mean ignoring other factors that may influence the cancer and even the behavior of the single gene being studied. The systems approach, because it takes into account many factors at the same time, is more likely to lead to an understanding of the causes and most useful treatments for cancer. 3. Some of the transcribed region is accounted for by introns. The rest is transcribed into noncoding RNAs, including small RNAs, such as microRNAs (miRNAs), siRNAs, and piRNAs. Some of these RNAs help regulate gene expression by blocking translation, causing degradation of mRNA, binding to the promoter and repressing transcription, or causing remodeling of chromatin structure. The long noncoding RNAs (lncRNAs) may also contribute to gene regulation or to remodeling of chromatin structure. 4. Genome-wide association studies use the systems biology approach in that they consider the correlation of many single nucleotide polymorphisms (SNPs) with particular diseases, such as heart disease and diabetes, in an attempt to find patterns of SNPs that correlate with each disease.

Concept Check 21.3

1. Alternative splicing of RNA transcripts from a gene and post-translational processing of polypeptides 2. At the top of the web page, you can see the number of genomes completed and those considered permanent drafts in a bar graph by year. Scrolling down, you can see the number of complete and incomplete sequencing projects by year, the number of projects by domain by year (the genomes of viruses and metagenomes are counted too, even though these are not "domains"), the phylogenetic distribution of bacterial genome projects, and projects by sequencing center. Finally, near the bottom, you can see a pie chart of the "Project Relevance of Bacterial Genome Projects," which shows that about 58.6% have medical relevance. (This number may vary over time.) The web page ends with another pie chart showing the sequencing centers for archaeal and bacterial projects. 3. A prokaryotic cell is generally smaller than a eukaryotic cell, and prokaryotes reproduce by binary fission. The evolutionary process involved is natural selection for more quickly reproducing cells: The faster they can replicate their DNA and divide, the more likely they will be able to dominate a population of prokaryotes. The less DNA they have to replicate, then, the faster they will reproduce.

Concept Check 21.4

1. The number of genes is higher in mammals, and the amount of noncoding DNA is greater. Also, the presence of introns in mammalian genes makes them larger, on average, than prokaryotic genes. 2. The copy-and-paste transposon mechanism and retrotransposition. 3. In the rRNA gene family, identical transcription units, each containing genes for all three different RNA products, are present in long arrays, repeated one after the other. The large number of copies of the rRNA genes enable organisms to produce the rRNA for enough ribosomes to carry out active protein synthesis, and the single transcription unit for the three rRNAs ensures that the relative amounts of the different rRNA molecules produced are correct—every time one rRNA is made, a copy of each of the other two is made as well. Rather than numerous identical units, each globin gene family consists of a relatively small number of non-identical genes. The differences in the globin proteins encoded by these genes result in production of hemoglobin molecules adapted to particular developmental stages of the organism. 4. The exons would be classified as exons (1.5%); the enhancer region containing the distal control elements, the region closer to the promoter containing the proximal control elements, and the promoter itself would be classified as regulatory sequences (5%); and the introns would be classified as introns (20%).

Concept Check 21.5

1. If meiosis is faulty, two copies of the entire genome can end up in a single cell. Errors in crossing over during meiosis can lead to one segment being duplicated while another is deleted. During DNA replication, slippage backward along the template strand can result in segment duplication. Also, a "copy-and-paste" transposable element could copy and paste a segment of DNA, resulting in a duplication of that segment (and of the transposable element itself.) 2. For either gene, a mistake in crossing over during meiosis could have occurred between the two copies of that gene, such that one ended up with a duplicated exon. (The other copy would have ended up with a deleted exon.) This could have happened several times, resulting in the multiple copies of a particular exon in each gene. 3. Homologous transposable elements scattered throughout the genome provide sites where recombination can occur between different chromosomes. Movement of these elements into coding or regulatory sequences may change expression of genes, which can affect the phenotype in a way that is subject to natural selection.

Transposable elements also can carry genes with them, leading to dispersion of genes and in some cases different patterns of expression. Transport of an exon during transposition and its insertion into a gene may add a new functional domain to the originally encoded protein, a type of exon shuffling. (For any of these changes to be heritable, they must happen in germ cells, cells that will give rise to gametes.) **4.** Because more offspring are born to women who have this inversion, it must provide some advantage during the process of reproduction and development. Because proportionally more offspring have this inversion, we would expect it to persist and spread in the population. (In fact, evidence in the study allowed the researchers to conclude that it has been increasing in proportion in the population. You'll learn more about population genetics in the next unit.)

Concept Check 21.6

- Because both humans and macaques are primates, their genomes are expected to be more similar than the macaque and mouse genomes are. The mouse lineage diverged from the primate lineage before the human and macaque lineages diverged.
- Homeotic genes differ in their *non*homeobox sequences, which determine the interactions of homeotic gene products with other transcription factors and hence which genes are regulated by the homeotic genes. These nonhomeobox sequences differ in the two species, as do the expression patterns of the homeobox genes.
- Alu* elements underwent transposition more actively in the human genome for some reason. Their increased sites of insertion may have then allowed more recombination errors in the human genome, resulting in more or different duplications. The divergence of the organization and content of the two genomes presumably made the chromosomes of each genome less similar to those of the other, thus accelerating divergence of the two species by making matings less and less likely to result in fertile offspring due to the mismatch of genetic information.

Summary of Key Concepts Questions

21.1 One focus of the Human Genome Project was to improve sequencing technology in order to speed up the process. During the project, many advances in sequencing technology allowed faster reactions and detection of products, which were therefore less expensive. **21.2** The most significant finding is that more than 75% of the human genome appears to be transcribed at some point in at least one of the cell types studied. Also, at least 80% of the genome contains an element that is functional, participating in gene regulation or maintaining chromatin structure in some way. The project was expanded to include other species to further investigate the functions of these transcribed DNA elements. It is necessary to carry out this type of analysis on the genomes of species that can be used in laboratory experiments. **21.3** (a) In general, bacteria and archaea have smaller genomes, lower numbers of genes, and higher gene density than eukaryotes. (b) Among eukaryotes, there is no apparent systematic relationship between genome size and phenotype. The number of genes is often lower than would be expected from the size of the genome—in other words, the gene density is often lower in larger genomes. (Humans are a good example.) **21.4** Transposable element-related sequences can move from place to place in the genome, and some of these sequences make a new copy of themselves when they do so. Thus, it is not surprising that they make up a significant percentage of the genome, and this percentage might be expected to increase over evolutionary time. **21.5** Chromosomal rearrangements within a species lead to some individuals having different chromosomal arrangements. Each of these individuals could still undergo meiosis and produce gametes, and fertilization involving gametes with different chromosomal arrangements could result in viable offspring. However, during meiosis in the offspring, the maternal and paternal chromosomes might not be able to pair up, causing gametes with incomplete sets of chromosomes to form. Most often, when zygotes are produced from such gametes, they do not survive. Ultimately, a new species could form if two different chromosomal arrangements became prevalent within a population and individuals could mate successfully only with other individuals having the same arrangement. **21.6** Comparing the genomes of two closely related species can reveal information about more recent evolutionary events, perhaps events that resulted in the distinguishing characteristics of the two species. Comparing the genomes of very distantly related species can tell us about evolutionary events that occurred a very long time ago. For example, genes that are shared between two distantly related species must have arisen before the two species diverged.

Test Your Understanding

- 1. B 2. A 3. C 4.** Answers for (a) through (c):

Chimpanzee	PKSSD ... TSSTT ... NARRD
Mouse	PKSSE ... TSS T ... N ARRD
Gorilla	PKSSD ... TSSTT ... NARRD
Human	PKSSD ... TSSNT ... SARRD
Rhesus monkey	PKSSD ... TSSTT ... NARRD

(d) There is one difference between the sequence for the mouse and the sequence for the chimpanzee, gorilla, and rhesus monkey. There are two differences between the human sequence and the sequence for the chimpanzee, gorilla, and rhesus monkey. These facts might lead to the hypothesis that the *FOXP2* gene has been evolving faster in the human lineage than in other primates. Two differences between humans and other primates occurred during the 6 million years since they diverged, but only one difference occurred during the much longer period of 65 million years since rodents and primates diverged. However, as described in the text, later analysis that included more genomes that were more diverse failed to support this hypothesis.

Chapter 22

Figure Questions

Figure 22.6 You should have circled the branch located at the far left of Figure 1.20. Although three of the descendants (*Certhidea olivacea*, *Camarhynchus pallidus*, and *Camarhynchus parvulus*) of this common ancestor ate insects, the other three species that descended from this ancestor did not eat insects. **Figure 22.8** The common ancestor lived about 5.5 million years ago. **Figure 22.13** These results show that being reared from the egg stage on one plant species or the other did not result in the adult having a beak length appropriate for that host; instead, adult beak lengths were determined primarily by the population from which the eggs were obtained. Because an egg from a balloon vine population likely had long-beaked parents, while an egg from a golden rain tree population likely had short-beaked parents, these results indicate that beak length is an inherited trait.

Figure 22.14 Both strategies should increase the time that it takes *S. aureus* to become resistant to a new drug. If a drug that harms *S. aureus* does not harm other bacteria, natural selection will not favor resistance to that drug in the other species. This would decrease the chance that *S. aureus* would acquire resistance genes from other bacteria—thus slowing the evolution of resistance. Similarly, selection for resistance to a drug that slows the growth but does not kill *S. aureus* is much weaker than selection for resistance to a drug that kills *S. aureus*—again slowing the evolution of resistance. **Figure 22.17** Based on this evolutionary tree, crocodiles are more closely related to birds than to lizards because they share a more recent common ancestor with birds (ancestor **5**) than with lizards (ancestor **4**).

Figure 22.20 Hind limb structure changed first. *Rodhocetus* lacked flukes, but its pelvic bones and hind limbs had changed substantially from how those bones were shaped and arranged in *Pakicetus*. For example, in *Rodhocetus*, the pelvis and hind limbs appear to be oriented for paddling, whereas they were oriented for walking in *Pakicetus*.

Concept Check 22.1

1. Hutton and Lyell proposed that geologic events in the past were caused by the same processes operating today, at the same gradual rate. This principle suggested that Earth must be much older than a few thousand years, the age that was widely accepted in the early 19th century. Hutton's and Lyell's ideas also stimulated Darwin to reason that the slow accumulation of small changes could ultimately produce the profound changes documented in the fossil record. In this context, the age of Earth was important to Darwin, because unless Earth was very old, he could not envision how there would have been enough time for evolution to occur. **2.** By this criterion, Cuvier's explanation of the fossil record and Lamarck's hypothesis of evolution are both scientific. Cuvier thought that species did not evolve over time. He also suggested that sudden, catastrophic events caused extinctions in particular areas and that such regions were later repopulated by a different set of species that immigrated from other areas. These assertions can be tested against the fossil record. Lamarck's principle of use and disuse can be used to make testable predictions for fossils of groups such as whale ancestors as they adapted to a new habitat. Lamarck's principle of use and disuse and his associated principle of the inheritance of acquired characteristics can also be tested directly in living organisms.

Concept Check 22.2

1. Organisms share characteristics (the unity of life) because they share common ancestors; the great diversity of life occurs because new species have repeatedly formed when descendant organisms gradually adapted to different environments, thereby becoming different from their ancestors. **2.** The fossil mammal species (or its ancestors) would most likely have colonized the Andes from within South America, whereas ancestors of mammals currently found in Asian mountains would most likely have colonized those mountains from other parts of Asia. As a result, the Andes fossil species would share a more recent common ancestor with South American mammals than with mammals in Asia. Thus, for many of its traits, the fossil mammal species would probably more closely resemble mammals that live in South American jungles than mammals that live on Asian mountains. It is also possible that for some of its features, the Andean fossil mammal species could closely resemble a mammal from the mountains of Asia. This could happen because similar environments had selected for similar adaptations (even though the fossil and Asian species were only distantly related to one another). **3.** As long as the white phenotype (encoded by the genotype *pp*) continues to be favored by natural selection, the proportion of white individuals in the population should increase over time relative to the proportion of purple individuals (encoded by the genotypes *PP* and *Pp*). As a result, the frequency of the *p* allele in the population would likely increase over time.

Concept Check 22.3

1. An environmental factor such as a drug does not create new traits, such as drug resistance, but rather selects for traits among those that are already present in the population. **2.** (a) Despite their different functions, the forelimbs of different mammals are structurally similar because they all represent modifications of a structure found in the common ancestor; thus, they are homologous structures. (b) In this case, the similar features of these mammals represent analogous features that arose by convergent evolution. The similarities between the sugar glider and flying squirrel indicate that similar environments selected for similar adaptations despite different ancestry. **3.** At the time that dinosaurs originated, Earth's landmasses formed a single large continent, Pangaea. Because many dinosaurs were large and mobile, it is likely that early members of these groups lived on many different parts of Pangaea. When Pangaea broke apart, fossils of these organisms would have moved with the rocks in which they were deposited. As a result, we would predict that fossils of early dinosaurs would have a broad geographic distribution (this prediction has been upheld).

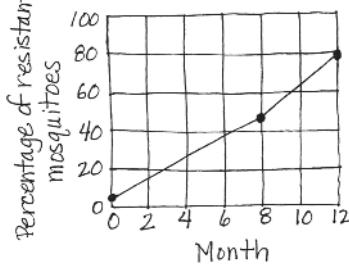
Summary of Key Concepts Questions

Concept 22.1 Darwin thought that descent with modification occurred as a gradual, steplike process. The age of Earth was important to him because if Earth were only a few thousand years old (as conventional wisdom suggested), there wouldn't have been sufficient time for major evolutionary change.

Concept 22.2 All species have the potential to overreproduce—that is, to produce more offspring than can be supported by the environment. This ensures that there will be what Darwin called a “struggle for existence” in which many of the offspring are eaten, starved, diseased, or unable to reproduce for a variety of other reasons. Members of a population exhibit a range of heritable variations, some of which make it likely that their bearers will leave more offspring than other individuals (for example, the bearer may escape predators more effectively or be more tolerant of the physical conditions of the environment). Over time, natural selection resulting from factors such as predators, lack of food, or the physical conditions of the environment can increase the proportion of individuals with favorable traits in a population (evolutionary adaptation). **Concept 22.3** The hypothesis that cetaceans originated from a terrestrial mammal and are closely related to even-toed ungulates is supported by several lines of evidence. For example, fossils document that early cetaceans had hind limbs, as expected for organisms that descended from a land mammal; these fossils also show that cetacean hind limbs became reduced over time. Other fossils show that early cetaceans had a type of ankle bone that is otherwise found only in even-toed ungulates, providing strong evidence that even-toed ungulates are the land mammals to which cetaceans are most closely related. DNA sequence data also indicate that even-toed ungulates are the land mammals to which cetaceans are, most closely related.

Test Your Understanding

1. C 2. D 3. C 4. A 5. B
7. (a)



(b) The rapid rise in the percentage of mosquitoes resistant to DDT was most likely caused by natural selection in which mosquitoes resistant to DDT could survive and reproduce while other mosquitoes could not.
(c) In India—where DDT resistance first appeared—natural selection would have caused the frequency of resistant mosquitoes to increase over time. If resistant mosquitoes then migrated from India (for example, transported by wind or in planes, trains, or ships) to other parts of the world, the frequency of DDT resistance would increase there as well. In addition, if resistance to DDT were to arise independently in mosquito populations outside of India, those populations would also experience an increase in the frequency of DDT resistance.

world, the frequency of DDT resistance would increase there as well. In addition, if resistance to DDT were to arise independently in mosquito populations outside of India, those populations would also experience an increase in the frequency of DDT resistance.

Chapter 23

Figure Questions

Figure 23.4 The genetic code is redundant, meaning that more than one codon can specify the same amino acid. As a result, a substitution at a particular site in a coding region of the *Adh* gene might change the codon but not the translated amino acid, and thus not the resulting protein encoded by the gene. One way an insertion in an exon would not affect the gene produced is if it occurs in an untranslated region of the exon. (This is the case for the insertion at location 1,703.) **Figure 23.7** There should be 24 red balls. **Figure 23.8** The predicted frequencies are 36% $C^R C^R$, 48% $C^R C^W$, and 16% $C^W C^W$. **Figure 23.9** Overall, by chance the frequency of the C^W allele first increases in generation 2 and then falls to zero in generation 3—causing the C^R allele to become fixed (reach a frequency of 100%). **Figure 23.12** The frequency of banded color patterns in island populations would probably increase in the year immediately after the storm. Since mainland populations did not decline in size, the number of individuals migrating from the mainland to the islands would probably not decline either. As a result, after island populations had decreased in size (because of the storm), alleles encoding banded coloration that were transferred from the mainland would comprise a larger proportion of the gene pool in island populations. This would cause the frequency of banded color patterns in island populations to increase. **Figure 23.13** Directional selection. The seeds of golden rain tree are buried less deeply than are the seeds of the native host, balloon vine. Thus, in soapberry bug populations feeding on golden rain tree, bugs with shorter beaks had an advantage, resulting in directional selection for shorter beak length. **Figure 23.16** Crossing a single female's eggs with both an SC and an LC male's sperm allowed the researchers to directly compare the effects of the males' contribution to the next generation since both batches of offspring had the same maternal contribution. This isolation of the male's impact enabled researchers to draw conclusions about differences in genetic “quality” between the SC and LC males. **Figure 23.18** Under prolonged low-oxygen conditions, some of the red blood cells of a heterozygote may sickle, leading to harmful effects. This does not occur in individuals with two wild-type hemoglobin alleles, suggesting that there may be selection against heterozygotes in malaria-free regions (where heterozygote advantage does not occur). However, since heterozygotes are healthy under most conditions, selection against them is unlikely to be strong.

Concept Check 23.1

1. Within a population, genetic differences among individuals provide the raw material on which natural selection and other mechanisms can act. Without such differences, allele frequencies could not change over time—and hence the population could not evolve. 2. Many mutations occur in somatic cells, which do not produce gametes and so are lost when the organism dies. Of the mutations that do occur in cell lines that produce gametes, many do not have a phenotypic effect on which natural selection can act. Others have a harmful effect and are thus unlikely to increase in frequency because they decrease the reproductive success of their bearers. 3. Its genetic variation (whether measured at the level of the gene or at the level of nucleotide sequences) would probably drop over time. During meiosis, crossing over and the independent assortment of chromosomes produce many new combinations of alleles. In addition, a population contains a vast number of possible mating combinations, and fertilization brings together the gametes of individuals with different genetic backgrounds. Thus, via crossing over, independent assortment of chromosomes, and fertilization, sexual reproduction reshuffles alleles into fresh combinations each generation. Without sexual reproduction, the rate of forming new combinations of alleles would be vastly reduced, causing the overall amount of genetic variation to drop.

Concept Check 23.2

1. There are 700 individuals in the population: 85 of genotype AA , 320 of genotype Aa , and 295 of genotype aa . The genotype frequencies are thus 0.12 (85/700) for genotype AA , 0.46 (320/700) for genotype Aa , and 0.42 (295/700) for genotype aa . Each individual has two alleles, so the total number of alleles is 1,400. To calculate the frequency of allele A , note that each of the 85 individuals of genotype AA has two A alleles, each of the 320 individuals of genotype Aa has one A allele, and each of the 295 individuals of genotype aa has zero A alleles. Thus, the frequency (p) of allele A is

$$p = \frac{(2 \times 85) + (1 \times 320) + (0 \times 295)}{1,400} = 0.35$$

There are only two alleles (A and a) in our population, so the frequency of allele a must be $q = 1 - p = 0.65$. 2. Because the frequency of allele a is 0.45, the frequency of allele A must be 0.55. Thus, the expected genotype frequencies are $p^2 = 0.3025$ for genotype AA , $2pq = 0.495$ for genotype Aa , and $q^2 = 0.2025$ for genotype aa . 3. There are 120 individuals in the population, so there are 240 alleles. Of these, there are 124 V alleles—32 from the 16 VV individuals and 92 from the 92 Vv individuals. Thus, the frequency of the V allele is $p = 124/240 = 0.52$; hence, the frequency of the v allele is $q = 0.48$. Based on the Hardy-Weinberg equation, if the population were not evolving, the frequency of genotype VV should be $p^2 = 0.52 \times 0.52 = 0.27$; the frequency of genotype Vv should be $2pq = 2 \times 0.52 \times 0.48 = 0.5$; and the frequency of genotype vv should be $q^2 = 0.48 \times 0.48 = 0.23$. In a population of 120 individuals, these expected genotype frequencies lead us to predict that there would be 32 VV individuals (0.27×120), 60 Vv individuals (0.5×120), and 28 vv individuals (0.23×120). The actual numbers for the population (16 VV , 92 Vv , 12 vv) deviate from these expectations (fewer homozygotes and more heterozygotes than expected). This indicates that the population is not in Hardy-Weinberg equilibrium and hence may be evolving at this locus.

Concept Check 23.3

1. Natural selection is more “predictable” in that it alters allele frequencies in a nonrandom way: It tends to increase the frequency of alleles that increase the organism’s reproductive success in its environment and decrease the frequency of alleles that decrease the organism’s reproductive success. Alleles subject to genetic drift increase or decrease in frequency by chance alone, whether or not they are advantageous. 2. Genetic drift results from chance events that cause allele frequencies to fluctuate at random from generation to generation; within a population, this process tends to decrease genetic variation over time. Gene flow is the transfer of alleles between populations, a process that can introduce new alleles to a population and hence may increase its genetic variation (albeit slightly, since rates of gene flow are often low). 3. Selection is not important at this locus; furthermore, the populations are not small, and hence the effects of genetic drift should not be pronounced. Gene flow is occurring via the movement of pollen and seeds. Thus, allele and genotype frequencies in these populations should become more similar over time as a result of gene flow.

Concept Check 23.4

1. The relative fitness of a mule is zero, because fitness includes reproductive contribution to the next generation, and a sterile mule cannot produce offspring. 2. Although both gene flow and genetic drift can increase the frequency of advantageous alleles in a population, they can also decrease the frequency of advantageous alleles or increase the frequency of harmful alleles. Only natural selection consistently results in an increase in the frequency of alleles that enhance survival or reproduction. Thus, natural selection is the only mechanism that consistently leads to adaptive evolution. 3. The three modes of natural selection (directional, stabilizing, and disruptive) are defined in terms of the selective advantage of different phenotypes, not different genotypes. Thus, the type of selection represented by heterozygote advantage depends on the phenotype of the heterozygotes. In this question, because heterozygous individuals have a more extreme phenotype than either homozygote, heterozygote advantage represents directional selection.

Summary of Key Concepts Questions

23.1 Much of the nucleotide variability at a genetic locus occurs within introns. Nucleotide variation at these sites typically does not affect the phenotype because

introns do not code for the protein product of the gene. (Note: In certain circumstances, it is possible that a change in an intron could affect RNA splicing and ultimately have some phenotypic effect on the organism, but such mechanisms are not covered in this introductory text.) There are also many variable nucleotide sites within exons. However, most of the variable sites within exons reflect changes to the DNA sequence that do not change the sequence of amino acids encoded by the gene (and hence may not affect the phenotype). **23.2** No, this is not an example of circular reasoning. Calculating p and q from observed genotype frequencies does not imply that those genotype frequencies must be in Hardy-Weinberg equilibrium. For example, consider a population that has 195 individuals of genotype AA , 10 of genotype Aa , and 195 of genotype aa . Calculating p and q from these values yields $p = q = 0.5$. Using the Hardy-Weinberg equation, the predicted equilibrium frequencies are $p^2 = 0.25$ for genotype AA , $2pq = 0.5$ for genotype Aa , and $q^2 = 0.25$ for genotype aa . Since there are 400 individuals in the population, these predicted genotype frequencies indicate that there should be 100 AA individuals, 200 Aa individuals, and 100 aa individuals—numbers that differ greatly from the values that we used to calculate p and q . **23.3** It is unlikely that two such populations would evolve in similar ways. Since their environments are very different, the alleles favored by natural selection would probably differ between the two populations. Although genetic drift may have important effects in each of these small populations, drift causes unpredictable changes in allele frequencies, so it is unlikely that drift would cause the populations to evolve in similar ways. Both populations are geographically isolated, suggesting that little gene flow would occur between them (again making it less likely that they would evolve in similar ways). **23.4** Compared to males, it is likely that the females of such species would be larger, more colorful, endowed with more elaborate ornamentation (for example, a large morphological feature such as the peacock's tail), and more apt to engage in behaviors intended to attract mates or prevent other members of their sex from obtaining mates.

Test Your Understanding

1. D 2. C 3. B 4. A 5. C

Chapter 24

Figure Questions

Figure 24.7 If this had not been done, the strong preference of “starch flies” and “maltose flies” to mate with like-adapted flies could have occurred simply because the flies could detect (for example, by sense of smell) what their potential mates had eaten as larvae—and preferred to mate with flies that had a similar smell to their own. **Figure 24.11** *Tragopogon dubius* and *T. pratensis* are the parent species of the polyploid species *T. miscellus*. *T. dubius* and *T. porrifolius* are the parent species of the other polyploid species, *T. mirus*. **Figure 24.12** In murky waters where females distinguish colors poorly, females of each species might mate often with males of the other species. Hence, since hybrids between these species are viable and fertile, the gene pools of the two species might become more similar over time.

Figure 24.13 The graph indicates that there has been gene flow of some fire-bellied toad alleles into the range of the yellow-bellied toad. Otherwise, all individuals located to the left of the hybrid zone portion of the graph would have allele frequencies equal to 1. **Figure 24.15** Because the populations had only just begun to diverge from one another at this point in the process, it is likely that any existing barriers to reproduction would weaken over time. **Figure 24.19** Over time, the chromosomes of the experimental hybrids came to resemble those of *H. anomalous*. This occurred even though conditions in the laboratory differed greatly from conditions in the field, where *H. anomalous* is found, suggesting that selection for laboratory conditions was not strong. Thus, it is unlikely that the observed rise in the fertility of the experimental hybrids was due to selection for life under laboratory conditions. **Figure 24.20** The presence of *M. cardinalis* plants that carry the *M. lewisi* *yup* allele would make it more likely that bumblebees would transfer pollen between the two monkey flower species. As a result, we would expect the number of hybrid offspring to increase.

Concept Check 24.1

1. (a) All except the biological species concept can be applied to both asexual and sexual species because they define species on the basis of characteristics other than the ability to reproduce. In contrast, the biological species concept can be applied only to sexual species. (b) The easiest species concept to apply in the field would be the morphological species concept because it is based only on the appearance of the organism. Additional information about its ecological habits or reproduction is not required. 2. Because these birds live in fairly similar environments and can breed successfully in captivity, the reproductive barrier in nature is probably prezygotic; given the species' differences in habitat preference, this barrier could result from habitat isolation.

Concept Check 24.2

1. In allopatric speciation, a new species forms while in geographic isolation from its parent species; in sympatric speciation, a new species forms in the absence of geographic isolation. Geographic isolation greatly reduces gene flow between populations, whereas ongoing gene flow is more likely in sympatric populations. As a result, allopatric speciation is more common than sympatric speciation. 2. Gene flow between subsets of a population that live in the same area can be reduced in a variety of ways. In some species—especially plants—changes in chromosome number can block gene flow and establish reproductive isolation in a single generation. Gene flow can also be reduced in sympatric populations by habitat differentiation (as seen in the apple maggot fly, *Rhagoletis*) and sexual selection (as seen in Lake Victoria cichlids). 3. Allopatric speciation would be less likely to occur on an island near a mainland than on a more isolated island of the same size. We expect this result because continued gene flow between mainland populations and those on a nearby island reduces the chance that enough genetic divergence will take place for allopatric speciation to occur. 4. If all of the homologs failed to separate during anaphase I of meiosis, some gametes would end up with an extra set of chromosomes (and others would end

up with no chromosomes). If a gamete with an extra set of chromosomes fused with a normal gamete, a triploid would result; if two gametes with an extra set of chromosomes fused with each other, a tetraploid would result.

Concept Check 24.3

1. Hybrid zones are regions in which members of different species meet and mate, producing some offspring of mixed ancestry. Such regions can be viewed as “natural laboratories” in which to study speciation because scientists can directly observe factors that cause (or fail to cause) reproductive isolation. 2. (a) If hybrids consistently survived and reproduced poorly compared with the offspring of intraspecific matings, reinforcement could occur. If it did, natural selection would cause prezygotic barriers to reproduction between the parent species to strengthen over time, decreasing the production of unfit hybrids and leading to a completion of the speciation process. If reinforcement did not occur, hybrids may continue to be produced even though they are selected against (as in the *Bombina* hybrid zone). (b) If hybrid offspring survived and reproduced as well as the offspring of intraspecific matings, indiscriminate mating between the parent species would lead to the production of large numbers of hybrid offspring. As these hybrids mated with each other and with members of both parent species, the gene pools of the parent species could fuse over time, reversing the speciation process.

Concept Check 24.4

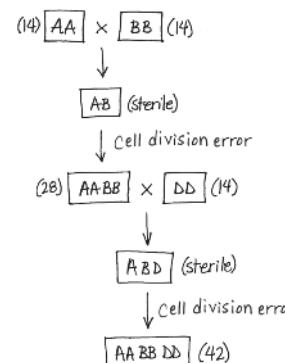
1. The time between speciation events includes (1) the length of time that it takes for populations of a newly formed species to begin diverging reproductively from one another and (2) the time it takes for speciation to be complete once this divergence begins. Although speciation can occur rapidly once populations have begun to diverge from one another, it may take millions of years for that divergence to begin. 2. Investigators transferred alleles at the *yup* locus (which influences flower color) from each parent species to the other. *M. lewisi* plants with an *M. cardinalis* *yup* allele received many more visits from hummingbirds than usual; hummingbirds usually pollinate *M. cardinalis* but avoid *M. lewisi*. Similarly, *M. cardinalis* plants with an *M. lewisi* *yup* allele received many more visits from bumblebees than usual; bumblebees usually pollinate *M. lewisi* and avoid *M. cardinalis*. Thus, alleles at the *yup* locus can influence pollinator choice, which in these species provides the primary barrier to interspecific mating. Nevertheless, the experiment does not prove that the *yup* locus alone controls barriers to reproduction between *M. lewisi* and *M. cardinalis*; other genes might enhance the effect of the *yup* locus (by modifying flower color) or cause entirely different barriers to reproduction (for example, gametic isolation or a postzygotic barrier). 3. Crossing over. If crossing over did not occur, each chromosome in an experimental hybrid would remain as in the F_1 generation: composed entirely of DNA from one parent species or the other.

Summary of Key Concepts Questions

24.1 According to the biological species concept, a species is a group of populations whose members interbreed and produce viable, fertile offspring; thus, gene flow occurs between populations of a species. In contrast, members of different species do not interbreed and hence no gene flow occurs between their populations. Overall, then, in the biological species concept, species can be viewed as designated by the *absence* of gene flow—making gene flow of central importance to the biological species concept. 24.2 Sympatric speciation can be promoted by factors such as polyploidy, sexual selection, and habitat shifts, all of which can reduce gene flow between the subpopulations of a larger population. Of these factors, sexual selection and habitat shifts can also occur in allopatric populations and hence can also promote allopatric speciation. 24.3 If the hybrids are selected against, the hybrid zone could persist if individuals from the parent species regularly travel into the zone, where they mate to produce hybrid offspring. If hybrids are not selected against, there is no cost to the continued production of hybrids, and large numbers of hybrid offspring may be produced. However, natural selection for life in different environments may keep the gene pools of the two parent species distinct, thus preventing the loss (by fusion) of the parent species and once again causing the hybrid zone to be stable over time. 24.4 As the goats-beard plant, Bahamas mosquitofish, and apple maggot fly illustrate, speciation continues to happen today. A new species can begin to form whenever gene flow is reduced between populations of the parent species. Such reductions in gene flow can occur in many ways: A new, geographically isolated population may be founded by a few colonists; some members of the parent species may begin to utilize a new habitat; or sexual selection may isolate formerly connected populations or subpopulations. These and many other such events are happening today.

Test Your Understanding

1. B 2. C 3. B 4. A 5. D 6. C
8. Here is one possibility:



Chapter 25

Figure Questions

Figure 25.2 Proteins are almost always composed of the same 20 amino acids shown in Figure 5.14. However, many other amino acids could potentially form in this or any other experiment. For example, any molecule that had an R group that differed from those listed in Figure 5.14 would still be an amino acid as long as it also contained an α carbon, an amino group, and a carboxyl group—but that molecule would not be one of the 20 amino acids commonly found in nature. **Figure 25.4** The hydrophobic regions of such molecules are attracted to one another and excluded from water, whereas the hydrophilic regions have an affinity for water. As a result, the molecules can form a bilayer in which the hydrophilic regions are on the outside of the bilayer (facing water on each side of the bilayer) and the hydrophobic regions point toward each other (that is, toward the inside of the bilayer). **Figure 25.6** Because uranium-238 has a half-life of 4.5 billion years, the x-axis would be relabeled (in billions of years) as 4.5, 9, 13.5, and 18. **Figure 25.8** (1) The earliest direct evidence of life comes from fossils of prokaryotes that date to 3.5 billion years ago. Fossil evidence also shows that for the next 2 billion years (3.5 to 1.5 billion years ago), life on Earth consisted entirely of unicellular organisms. In fact, from 3.5 billion years ago to 1.8 billion years ago, all of Earth's organisms were prokaryotes; around 1.8 billion years ago, these unicellular prokaryotes were joined by unicellular eukaryotes (multicellular eukaryotes emerged about 1.3 billion years ago). (2) Sample answer: In Figure 25.12, there are two hatch marks on the x-axis. These hatch marks represent large time spans. Unless the graph was very wide, showing these entire time spans would obscure key details for the figure, such as when selected animal groups first appear in the fossil record. (3) The horizontal time scale indicates that prokaryotes originated 3.5 billion years ago and that the colonization of land took place 500 million years ago. On a 1-hour time scale, this indicates that prokaryotes appeared about 46 minutes ago, while the colonization of land took place less than 7 minutes ago. **Figure 25.12** You should have circled the node, shown in the tree diagram at approximately 635 million years ago (mya), that leads to the echinoderm/chordate lineage and to the lineage that gave rise to brachiopods, annelids, molluscs, and arthropods. To determine a minimum estimate of the age of the ancestor represented by this node, note that the most recent common ancestor of chordates and annelids must be at least as old as any of its descendants. Since fossil molluscs date to about 560 mya, the common ancestor represented by the circled branch point must be at least 560 million years old. **Figure 25.14** There are two speciation events and five extinctions in lineage A, while there are five speciation events and one extinction in lineage B during the last 2 million years. **Figure 25.17** The Australian plate's current direction of movement is roughly similar to the northeasterly direction the continent traveled over the past 66 million years. **Figure 25.27** The coding sequence of the *Pitx1* gene would differ between the marine and lake populations, but patterns of gene expression would not.

Concept Check 25.1

1. The hypothesis that conditions on early Earth could have permitted the synthesis of organic molecules from inorganic ingredients 2. In contrast to random mingling of molecules in an open solution, segregation of molecular systems by membranes could concentrate organic molecules, assisting biochemical reactions. 3. Today, genetic information usually flows from DNA to RNA, as when the DNA sequence of a gene is used as a template to synthesize the mRNA encoding a particular protein. However, the life cycle of retroviruses such as HIV shows that genetic information can flow in the reverse direction (from RNA to DNA). In these viruses, the enzyme reverse transcriptase uses RNA as a template for DNA synthesis, suggesting that a similar enzyme could have played a key role in the transition from an RNA world to a DNA world.

Concept Check 25.2

1. The fossil record shows that different groups of organisms dominated life on Earth at different points in time and that many organisms once alive are now extinct; specific examples of these points can be found in Figure 25.5. The fossil record also indicates that new groups of organisms can arise via the gradual modification of previously existing organisms, as illustrated by fossils that document the origin of mammals from their cynodont ancestors (see Figure 25.7). 2. 22,920 years (four half-lives: $5,730 \times 4$)

Concept Check 25.3

1. Free oxygen attacks chemical bonds and can inhibit enzymes and damage cells. As a result, the appearance of oxygen in the atmosphere probably caused many prokaryotes that had thrived in anaerobic environments to survive and reproduce poorly, ultimately driving many of these species to extinction. 2. All eukaryotes have mitochondria or remnants of these organelles, but not all eukaryotes have plastids. 3. A fossil record of life today would include many organisms with hard body parts (such as vertebrates and many marine invertebrates), but might not include some species we are very familiar with, such as those that have small geographic ranges and/or small population sizes (for example, endangered species such as the giant panda, tiger, and several rhinoceros species).

Concept Check 25.4

1. The theory of plate tectonics describes the movement of Earth's continental plates, which alters the physical geography and climate of Earth, as well as the extent to which organisms are geographically isolated. Because these factors affect extinction and speciation rates, plate tectonics has a major impact on life on Earth. 2. Mass extinctions; major evolutionary innovations; the diversification of another group of organisms (which can provide new sources of food);

migration to new locations where few competitor species exist 3. Evidence from previous mass extinctions indicates that the diversity of life on Earth would not recover, for millions of years, to what it had been before the mass extinction—a much greater period of time than our species has been in existence (about 200,000 years). Although new speciation events would eventually cause the total number of species on Earth to recover, the many species and evolutionary lineages driven to extinction would be gone forever, thus forever changing the course of evolution on our planet. In addition, previous evidence suggests that a sixth mass extinction would reduce thriving and complex ecological communities (such as forests and coral reefs) so greatly that they might hardly resemble what they are like now. A sixth mass extinction would also change the types of organisms that live in ecological communities and how those organisms interact with one another. Finally, a sixth mass extinction would pave the way for new adaptive radiations in some of the groups that survive the extinction.

Concept Check 25.5

1. Heterochrony can cause a variety of morphological changes. For example, if the timing of the onset of sexual maturity changes, retention of juvenile characteristics (paedomorphosis) may result. Paedomorphosis can be caused by small genetic changes that result in large changes in morphology, as seen in the axolotl salamander. 2. In animal embryos, *Hox* genes influence the development of structures such as limbs and feeding appendages. As a result, changes in these genes—or in the regulation of these genes—are likely to have major effects on morphology. 3. From genetics, we know that gene regulation is altered by how well transcription factors bind to noncoding DNA sequences called control elements. Thus, if changes in morphology are often caused by changes in gene regulation, portions of noncoding DNA that contain control elements are likely to be strongly affected by natural selection.

Concept Check 25.6

1. Complex structures do not evolve all at once, but in increments, with natural selection selecting for adaptive variants of the earlier versions. 2. Although the myxoma virus is highly lethal, initially some of the rabbits are resistant (0.2% of infected rabbits are not killed). Thus, assuming resistance is an inherited trait, we would expect the rabbit population to show a trend for increased resistance to the virus. We would also expect the virus to show an evolutionary trend toward reduced lethality. We would expect this trend because a rabbit infected with a less lethal virus would be more likely to live long enough for a mosquito to bite it and hence potentially transmit the virus to another rabbit. (A virus that kills its rabbit host before a mosquito transmits the virus to another rabbit dies with its host.)

Summary of Key Concepts Questions

Concept 25.1 Particles of montmorillonite clay may have provided surfaces on which organic molecules became concentrated and hence were more likely to react with one another. Montmorillonite clay particles may also have facilitated the transport of key molecules, such as short strands of RNA, into vesicles. These vesicles can form spontaneously from simple precursor molecules, "reproduce" and "grow" on their own, and maintain internal concentrations of molecules that differ from those in the surrounding environment. These features of vesicles represent key steps in the emergence of protocells and (ultimately) the first living cells. **Concept 25.2** One challenge is that radioisotopes with very long half-lives are not used by organisms to build their bones or shells. As a result, fossils older than 75,000 years cannot be dated directly. Fossils are often found in sedimentary rock, but those rocks typically contain sediments of different ages, again posing a challenge when trying to date old fossils. To circumvent these challenges, geologists use radioisotopes with long half-lives to date layers of volcanic rock that surround old fossils. This approach provides minimum and maximum estimates for the ages of fossils sandwiched between two layers of volcanic rock. **Concept 25.3** The "Cambrian explosion" refers to a relatively short interval of time (535–525 million years ago) during which large forms of many present-day animal phyla first appear in the fossil record. The evolutionary changes that occurred during this time, such as the appearance of large predators and well-defended prey, were important because they set the stage for many of the key events in the history of life over the last 500 million years. **Concept 25.4** The broad evolutionary changes documented by the fossil record reflect the rise and fall of major groups of organisms. In turn, the rise or fall of any particular group results from a balance between speciation and extinction rates: A group increases in size when the rate at which its members produce new species is greater than the rate at which its member species are lost to extinction, while a group shrinks in size if extinction rates are greater than speciation rates.

Concept 25.5 A change in the sequence or regulation of a developmental gene can produce major morphological changes. In some cases, such morphological changes may enable organisms to perform new functions or live in new environments—thus potentially leading to an adaptive radiation and the formation of a new group of organisms. **Concept 25.6** Evolutionary change results from interactions between organisms and their current environments. No goal is involved in this process. As environments change over time, the features of organisms favored by natural selection may also change. When this happens, what once may have seemed like a "goal" of evolution (for example, improvements in the function of a feature previously favored by natural selection) may cease to be beneficial or may even be harmful.

Test Your Understanding

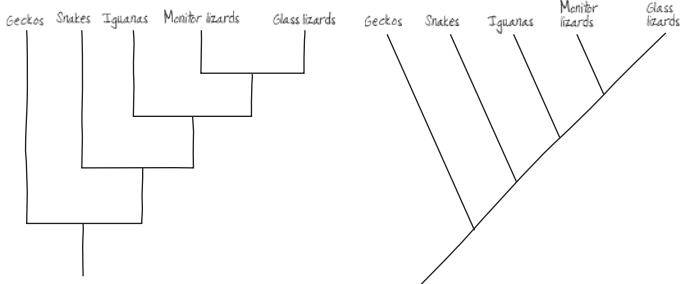
- 1.B 2.A 3.D 4.B 5.D 6.C 7.A

Chapter 26

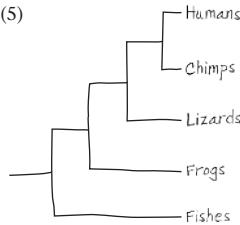
Figure Questions

Figure 26.5 (1) In this tree, frogs are most closely related to a group consisting of lizards, chimp, and humans. (2) You should have circled the branch point splitting the frog lineage from the lineage leading to lizards, chimp, and humans. (3) Four: chimps–humans, lizards–chimps/humans; frogs–lizards/chimps/humans; and fishes–frogs/lizards/chimps/humans.

(4)



(5)



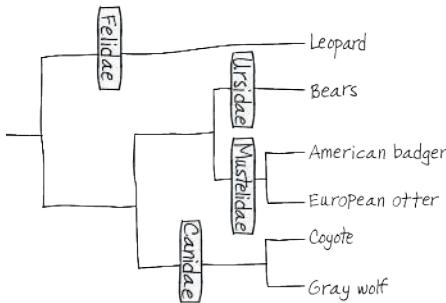
Each of the three trees identifies chimps and lizards as the two closest relatives of humans in these trees because they are the groups shown with whom we share the two most recent common ancestors.

Figure 26.6 Unknown 1b (a portion of sample 1) and unknowns 9–13 all would have to be located on the branch of the tree that currently leads to Minke (Southern Hemisphere) and unknowns 1a and 2–8. **Figure 26.9** There are four possible bases (A, C, G, T) at each nucleotide position. If the base at each position depends on chance,

not common descent, we would expect roughly one out of four (25%) of them to be the same. **Figure 26.11** You should have circled the branch point that is drawn farthest to the left (the common ancestor of all taxa shown). Both cetaceans and seals descended from terrestrial lineages of mammals, indicating that the cetacean-seal common ancestor lacked a streamlined body form and hence would not be part of the cetacean-seal group. **Figure 26.12** Hinged jaws are a shared ancestral character for the group that includes frogs, turtles, and leopards. Thus, you should have circled the frog, turtle, and leopard lineages, along with their most recent common ancestor. **Figure 26.16** Crocodilians are the sister taxon to the dinosaur clade (which includes birds) because crocodilians and the dinosaur clade share an immediate common ancestor that is not shared by any other group. **Figure 26.21** This tree indicates that the sequences of rRNA and other genes in mitochondria are most closely related to those of proteobacteria, while the sequences of chloroplast genes are most closely related to those of cyanobacteria. These gene sequence relationships are what would be predicted from endosymbiont theory, which posits that both mitochondria and chloroplasts originated as engulfed prokaryotic cells.

Concept Check 26.1

1. In Figure 26.4, leopards are the sister taxon to a group consisting of the family Mustelidae (which includes badgers) and the family Canidae (which includes wolves). Since members of a sister group are each other's closest relatives, leopards are equally related to badgers and to wolves. 2. The tree in (c) shows a different pattern of evolutionary relationships. In (c), C and B are sister taxa, whereas C and D are sister taxa in (a) and (b). 3. The redrawn version of Figure 26.4 is shown below.



Concept Check 26.2

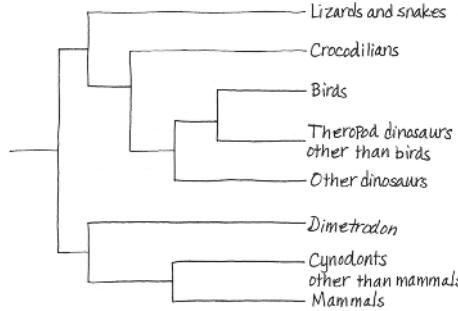
1. (a) Analogy, since porcupines and cacti are not closely related and since most other animals and plants do not have similar structures; (b) homology, since cats and humans are both mammals and have homologous forelimbs, of which the hand and paw are the lower part; (c) analogy, since owls and hornets are not closely related and since the structure of their wings is very different. 2. Species B and C are more likely to be closely related. Small genetic changes (as between species B and C) can produce divergent physical

appearances, but if many genes have diverged greatly (as in species A and B), then the lineages have probably been separate for a long time.

Concept Check 26.3

1. No; hair is a shared ancestral character common to all mammals and thus is not helpful in distinguishing different mammalian subgroups. 2. The principle of maximum parsimony states that the hypothesis about nature we investigate first should be the simplest explanation found to be consistent with the facts. Actual evolutionary relationships may differ from those inferred by parsimony owing to complicating factors such as convergent evolution.

3.



The traditional classification provides a poor match to evolutionary history, thus violating the basic principle of cladistics—that classification should be based on common descent. Both birds and mammals originated from groups traditionally designated as reptiles, making reptiles (as traditionally delineated) a paraphyletic group. These problems can be addressed by removing *Dimetrodon* and cynodonts from the reptiles and by regarding birds as a group of reptiles (specifically, as a group of dinosaurs).

Concept Check 26.4

1. Proteins are gene products. Their amino acid sequences are determined by the nucleotide sequences of the DNA that codes for them. Thus, differences between comparable proteins in two species reflect underlying genetic differences that have accumulated as the species diverged from one another. As a result, differences between the proteins can reflect the evolutionary history of the species.

2. Orthologous genes are homologous genes in which the homology results from a speciation event and hence occurs between genes found in different species. Paralogous genes are homologous genes in which the homology results from gene duplication. Orthologous genes should be used to infer phylogeny since differences among them reflect the history of speciation events. 3. In RNA processing, the exons or coding regions of a gene can be spliced together in different ways, yielding different mRNAs and hence different protein products. As a result, different proteins could potentially be produced from the same gene in different tissues, thereby enabling the gene to perform different functions in these different tissues.

Concept Check 26.5

1. A molecular clock is a method of estimating the actual time of evolutionary events based on numbers of base changes in orthologous genes. It is based on the assumption that the regions of genomes being compared evolve at constant rates. 2. There are many portions of the genome that do not code for genes; mutations that alter the sequence of bases in such regions could accumulate through drift without affecting an organism's fitness. Even in coding regions of the genome, some mutations may not have a critical effect on genes or proteins.

Concept Check 26.6

1. The kingdom Monera included bacteria and archaea, but we now know that these organisms are in separate domains. Kingdoms are subsets of domains, so a single kingdom (like Monera) that includes taxa from different domains is not valid. 2. Because of horizontal gene transfer, some genes in eukaryotes are more closely related to bacteria, while others are more closely related to archaea; thus, depending on which genes are used, phylogenetic trees constructed from DNA data can yield conflicting results. 3. Eukaryotes are hypothesized to have originated when a heterotrophic prokaryote (an archaeal host cell) engulfed a bacterium that would later become an organelle found in all eukaryotes—the mitochondrion. Over time, a fusion of organisms occurred as the archaeal host cell and its bacterial endosymbiont evolved to become a single organism. As a result, we would expect the cell of a eukaryote to include both archaeal DNA and bacterial DNA, making the origin of eukaryotes an example of horizontal gene transfer.

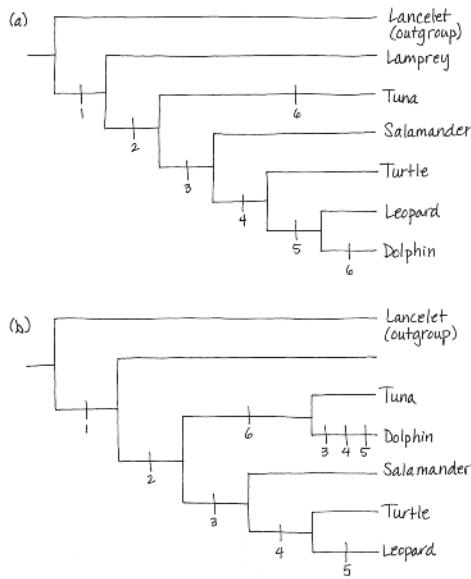
Summary of Key Concepts Questions

26.1 The fact that humans and chimpanzees are sister species indicates that we share a more recent common ancestor with chimpanzees than we do with any other living primate species. But that does not mean that humans evolved from chimpanzees, or vice versa; instead, it indicates that both humans and chimpanzees are descendants of that common ancestor. **26.2** Homologous characters result from shared ancestry. As organisms diverge over time, some of their homologous characters will also diverge. The homologous characters of organisms that diverged long ago typically differ more than do the homologous characters of organisms that diverged more recently. As a result, differences in homologous characters can be used to infer phylogeny. In

contrast, analogous characters result from convergent evolution, not shared ancestry, and hence can give misleading estimates of phylogeny. **26.3** All features of organisms arose at some point in the history of life. In the group in which a new feature first arose, that feature is a shared derived character that is unique to that clade. The group in which each shared derived character first appeared can be determined, and the resulting nested pattern can be used to infer evolutionary history. **26.4** Orthologous genes should be used; for such genes, the homology results from speciation and hence reflects evolutionary history. **26.5** A key assumption of molecular clocks is that nucleotide substitutions occur at fixed rates, and hence the number of nucleotide differences between two DNA sequences is proportional to the time since the sequences diverged from each other. Some limitations of molecular clocks: No gene marks time with complete precision; natural selection can favor certain DNA changes over others; nucleotide substitution rates can change over long periods of time (causing molecular clock estimates of when events in the distant past occurred to be highly uncertain); and the same gene can evolve at different rates in different organisms. **26.6** Genetic data indicated that many prokaryotes differed as much from each other as they did from eukaryotes. This indicated that organisms should be grouped into three “super-kingdoms,” or domains (Archaea, Bacteria, Eukarya). These data also indicated that the previous kingdom Monera (which had contained all the prokaryotes) did not make biological sense and should be abandoned. Later genetic and morphological data also indicated that the former kingdom Protista (which had primarily contained single-celled organisms) should be abandoned because some protists are more closely related to plants, fungi, or animals than they are to other protists.

Test Your Understanding

1. A 2. C 3. B 4. C 5. B 6. A 7. D
9.



(c) The tree in (a) requires seven evolutionary changes, while the tree in (b) requires nine evolutionary changes. Thus, the tree in (a) is more parsimonious since it requires fewer evolutionary changes.

Chapter 27

Figure Questions

Figure 27.7 The top ring, to which the hook is attached, is embedded within the interior, hydrophobic portion of the lipid bilayer of the outer membrane, suggesting that the top ring is hydrophobic. Likewise, the third ring down is embedded within the hydrophobic portion of the plasma membrane's lipid bilayer, suggesting that this ring also is hydrophobic. **Figure 27.9** The third plasmid is the separate, small twisted loop located just above and to the left of the line pointing to the label “Chromosome.” **Figure 27.10** It is likely that the expression or sequence of genes that affect glucose metabolism may have changed; genes for metabolic processes no longer needed by the cell also may have changed.

Figure 27.11 Transduction results in horizontal gene transfer when the host and recipient cells are members of different species. **Figure 27.16** Eukarya

Figure 27.18 Thermophiles live in very hot environments, so it is likely that their enzymes can continue to function normally at much higher temperatures than can the enzymes of other organisms. At low temperatures, however, the enzymes of thermophiles may not function as well as the enzymes of other organisms.

Figure 27.19 From the graph, plant uptake can be estimated as 0.72, 0.62, and 0.96 mg K⁺ for strains 1, 2, and 3, respectively. These values average to 0.77 mg K⁺. If bacteria had no effect, the average plant uptake of K⁺ for strains 1, 2, and 3 should be close to 0.51 mg K⁺, the value observed for plants grown in bacteria-free soil.

Figure 27.22 Penicillin

Concept Check 27.1

1. Adaptations include the capsule (shields prokaryotes from the host's immune system) and endospores (enable cells to survive harsh conditions and to revive when the environment becomes favorable). 2. Prokaryotic cells lack the complex compartmentalization associated with the membrane-enclosed organelles of eukaryotic cells. Prokaryotic genomes have much less DNA than eukaryotic genomes, and most of this DNA is contained in a single ring-shaped chromosome located in the nucleoid rather than within a true membrane-enclosed nucleus. In addition, many prokaryotes also have plasmids, small ring-shaped DNA molecules containing a few genes. 3. Plastids such as chloroplasts are thought to have evolved from an endosymbiotic photosynthetic prokaryote. More specifically, the phylogenetic tree shown in Figure 26.21 indicates that plastids are closely related to cyanobacteria. Hence, we can hypothesize that the thylakoid membranes of chloroplasts resemble those of cyanobacteria because chloroplasts evolved from an endosymbiotic cyanobacterium.

Concept Check 27.2

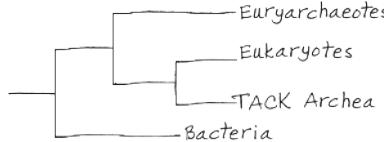
1. Prokaryotes can have extremely large population sizes, in part because they often have short generation times. The large number of individuals in prokaryotic populations makes it likely that in each generation there will be many individuals that have new mutations at any particular gene, thereby adding considerable genetic diversity to the population. 2. In transformation, naked, foreign DNA from the environment is taken up by a bacterial cell. In transduction, phages carry bacterial genes from one bacterial cell to another. In conjugation, a bacterial cell directly transfers plasmid or chromosomal DNA to another cell via a mating bridge that temporarily connects the two cells. 3. Yes. Genes for antibiotic resistance could be transferred (by transformation, transduction, or conjugation) from the nonpathogenic bacterium to a pathogenic bacterium; this could make the pathogen an even greater threat to human health. In general, transformation, transduction, and conjugation tend to increase the spread of resistance genes.

Concept Check 27.3

1. A phototroph derives its energy from light, while a chemotroph gets its energy from chemical sources. An autotroph derives its carbon from CO₂, HCO₃⁻, or related compounds, while a heterotroph gets its carbon from organic nutrients such as glucose. Thus, there are four nutritional modes: photoautotrophic, photoheterotrophic (unique to prokaryotes), chemoautotrophic (unique to prokaryotes), and chemoheterotrophic. 2. Chemoheterotrophy: the bacterium must rely on chemical sources of energy, since it is not exposed to light, and it must be a heterotroph if it requires a source of carbon other than CO₂ (or a related compound, such as HCO₃⁻). 3. If humans could fix nitrogen, we could build proteins using atmospheric N₂ and hence would not need to eat high-protein foods such as meat, fish, or soy. Our diet would, however, need to include a source of carbon, along with minerals and water. Thus, a typical meal might consist of carbohydrates as a carbon source, along with fruits and vegetables to provide essential minerals (and additional carbon).

Concept Check 27.4

1. Molecular systematic studies indicate that some organisms once classified as bacteria are more closely related to eukaryotes and belong in a domain of their own: Archaea. Such studies have also shown that horizontal gene transfer is common and plays an important role in the evolution of prokaryotes. By not requiring that organisms be cultured in the laboratory, metagenomic studies have revealed an immense diversity of previously unknown prokaryotic species. Over time, the ongoing discovery of new species by metagenomic analyses may alter our understanding of prokaryotic phylogeny greatly. 2. The three domains shown in Figure 27.16 are not valid under this assumption because domain Eukarya would be nested within domain Archaea. As such, Eukarya would be a subset of Archaea, not a separate domain of its own.



Concept Check 27.5

1. Although prokaryotes are small, their large numbers and metabolic abilities enable them to play key roles in ecosystems by decomposing wastes, recycling chemicals, and affecting the concentrations of nutrients available to other organisms. 2. Cyanobacteria produce oxygen when water is split in the light reactions of photosynthesis. The Calvin cycle incorporates CO₂ from the air into organic molecules, which are then converted to sugars.

Concept Check 27.6

1. Sample answers: eating fermented foods such as yogurt, sourdough bread, or cheese; receiving clean water from sewage treatment; taking medicines produced by bacteria 2. No. If the poison is secreted as an exotoxin, live bacteria could be transmitted to another person. But the same is true if the poison is an endotoxin—only in this case, the live bacteria that are transmitted may be descendants of the (now-dead) bacteria that produced the poison. 3. Some of the many different species of prokaryotes that live in the human gut compete with one another for resources (from the food that you eat). Because different prokaryotic species have different adaptations, a change in diet may alter which species can grow most rapidly, thus altering species abundance.

Summary of Key Concepts Questions

27.1 Specific structural features that enable prokaryotes to thrive in diverse environments include their cell walls (which provide shape and protection), flagella (which function in directed movement), and ability to form capsules or endospores (both of which can protect against harsh conditions). Prokaryotes also possess biochemical adaptations for growth in varied conditions, such as those that enable them to tolerate extremely hot or salty environments. **27.2** Many prokaryotic species can reproduce extremely rapidly, and their populations can number in the trillions. As a result, even though mutations are rare, every day many offspring are produced that have new mutations at particular gene loci. In addition, even though prokaryotes reproduce asexually and hence the vast majority of offspring are genetically identical to their parent, the genetic variation of their populations can be increased by transduction, transformation, and conjugation. Each of these (nonreproductive) processes can increase genetic variation by transferring DNA from one cell to another—even among cells that are of different species. **27.3** Prokaryotes have an exceptionally broad range of metabolic adaptations. As a group, prokaryotes perform all four modes of nutrition (photoautotrophy, chemoautotrophy, photoheterotrophy, and chemoheterotrophy), whereas eukaryotes perform only two of these (photoautotrophy and chemoheterotrophy). Prokaryotes are also able to metabolize nitrogen in a wide variety of forms (again unlike eukaryotes), and they frequently cooperate with other prokaryotic cells of the same or different species. **27.4** Phenotypic criteria such as shape, motility, and nutritional mode do not provide a clear picture of the evolutionary history of the prokaryotes. In contrast, molecular data have elucidated relationships among major groups of prokaryotes. Molecular data have also allowed researchers to sample genes directly from the environment; using such genes to construct phylogenies has led to the discovery of major new groups of prokaryotes. **27.5** Prokaryotes play key roles in the chemical cycles on which life depends. For example, prokaryotes are important decomposers, breaking down corpses and waste materials, thereby releasing nutrients to the environment where they can be used by other organisms. Prokaryotes also convert inorganic compounds to forms that other organisms can use. With respect to their ecological interactions, many prokaryotes form life-sustaining mutualisms with other species. In some cases, such as hydrothermal vent communities, the metabolic activities of prokaryotes provide an energy source on which hundreds of other species depend; in the absence of the prokaryotes, the community would collapse. **27.6** Human well-being depends on our associations with mutualistic prokaryotes, such as the many species that live in our intestines and digest food that we cannot. Humans also can harness the remarkable metabolic capabilities of prokaryotes to produce a wide range of useful products and to perform key services such as bioremediation. Negative effects of prokaryotes result primarily from bacterial pathogens that cause disease.

Test Your Understanding

1. D 2. A 3. B 4. C 5. D 6. A

Chapter 28

Figure Questions

Figure 28.3 The diagram shows that a single secondary endosymbiosis event gave rise to the stramenopiles and alveolates—thus, these groups can trace their ancestry back to a single heterotrophic protist (shown in yellow) that ingested a red alga. In contrast, euglenids and chlorarachniophytes each descended from a different heterotrophic protist (one of which is shown in gray, the other in brown). Hence, it is likely that stramenopiles and alveolates are more closely related than are euglenids and chlorarachniophytes.

Figure 28.5

Simplified tree that shows 4 supergroups:



Simplified tree that shows Unikonta as sister group to all other eukaryotes:

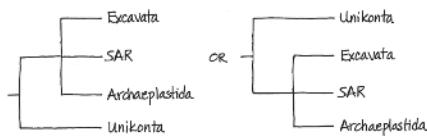


Figure 28.14 The sperm cells in the diagram are produced by the asexual (mitotic) division of cells in a single male gametophyte, which was itself produced by the asexual (mitotic) division of a single zoospore. Thus, the sperm cells are all derived from a single zoospore and so are genetically identical to one another. **Figure 28.18** Merozoites are produced by the asexual (mitotic) cell division of haploid sporozoites; similarly, gametocytes are produced by the asexual cell division of merozoites. Hence, it is likely that individuals in these three stages have the same complement of genes and that morphological differences between them result from changes in gene expression.

Figure 28.19 These events have a similar overall effect to fertilization. In both cases, haploid nuclei that were originally from two genetically different cells fuse to form a diploid nucleus. **Figure 28.25** The following stage should be

circled: step 6, where a mature cell undergoes mitosis and forms four or more daughter cells. In step 7, the zoospores eventually grow into mature haploid cells, but they do not produce new daughter cells. Likewise, in step 2, a mature cell develops into a gamete, but it does not produce new daughter cells.

Figure 28.26

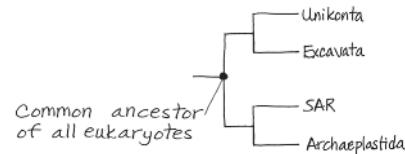


Figure 28.28 They would be haploid because originally each of these cells was a haploid, solitary amoeba.

Concept Check 28.1

1. Sample response: Protists include unicellular, colonial, and multicellular organisms; photoautotrophs, heterotrophs, and mixotrophs; species that reproduce asexually, sexually, or both ways; and organisms with diverse physical forms and adaptations. 2. Strong evidence shows that eukaryotes acquired mitochondria after a host cell (either an archaeon or a cell closely related to the archaea) first engulfed and then formed an endosymbiotic association with an alpha proteobacterium. Similarly, chloroplasts in red and green algae appear to have descended from a photosynthetic cyanobacterium that was engulfed by an ancient heterotrophic eukaryote. Secondary endosymbiosis also played an important role: Various protistan lineages acquired plastids by engulfing unicellular red or green algae. 3. Four. The first (and primary) genome is the DNA located in the chlorarachniophyte nucleus. A chlorarachniophyte also contains remnants of a green alga's nuclear DNA, located in the nucleomorph. Finally, mitochondria and chloroplasts contain DNA from the (different) bacteria from which they evolved. These two prokaryotic genomes comprise the third and fourth genomes contained within a chlorarachniophyte.

Concept Check 28.2

1. Their mitochondria do not have an electron transport chain and so cannot function in aerobic respiration. 2. Since the unknown protist is more closely related to diplomonads than to euglenids, it must have originated after the lineage leading to the diplomonads and parabasalids diverged from the euglenozoans. In addition, since the unknown species has fully functional mitochondria—yet both diplomonads and parabasalids do not—it is likely that the unknown species originated *before* the last common ancestor of the diplomonads and parabasalids.

Concept Check 28.3

1. Because foram tests are hardened with calcium carbonate, they form long-lasting fossils in marine sediments and sedimentary rocks. 2. The plastid DNA would likely be more similar to the chromosomal DNA of cyanobacteria based on the well-supported hypothesis that eukaryotic plastids (such as those found in the eukaryotic groups listed) originated by an endosymbiosis event in which a eukaryote engulfed a cyanobacterium. If the plastid is derived from the cyanobacterium, its DNA would be derived from the bacterial DNA. 3. Figure 13.6b. Algae and plants with alternation of generations have a multicellular haploid stage *and* a multicellular diploid stage. In the other two life cycles, either the haploid stage or the diploid stage is unicellular. 4. During photosynthesis, aerobic algae produce O₂ and use CO₂. O₂ is produced as a by-product of the light reactions, while CO₂ is used as an input to the Calvin cycle (the end products of which are sugars). Aerobic algae also perform cellular respiration, which uses O₂ as an input and produces CO₂ as a waste product.

Concept Check 28.4

1. Many red algae contain a photosynthetic pigment called phycoerythrin, which gives them a reddish color and allows them to carry out photosynthesis in relatively deep coastal water. Also unlike brown algae, red algae have no flagellated stages in their life cycle and must depend on water currents to bring gametes together for fertilization. 2. *Ulva* contains many cells and its body is differentiated into leaflike blades and a rootlike holdfast. *Caulerpa*'s body is composed of multinucleate filaments without cross-walls, so it is essentially one large cell. 3. Red algae have no flagellated stages in their life cycle and hence must depend on water currents to bring their gametes together. This feature of their biology might increase the difficulty of reproducing on land. In contrast, the gametes of green algae are flagellated, making it possible for them to swim in thin films of water. In addition, a variety of green algae contain compounds in their cytoplasm, cell wall, or zygote coat that protect against intense sunlight and other terrestrial conditions. Such compounds may have increased the chance that descendants of green algae could survive on land.

Concept Check 28.5

1. Amoebozoans have lobe- or tube-shaped pseudopodia, whereas forams have threadlike pseudopodia. 2. Slime molds are fungus-like in that they produce fruiting bodies that aid in the dispersal of spores, and they are animal-like in that they are motile and ingest food. However, slime molds are more closely related to tubulinids and entamoebas than to fungi or animals. 3. The genes used to estimate the tree shown in Figure 28.26 were transferred from an alpha proteobacterium to an early eukaryote. Based on the sequences of these genes, the eukaryotes should be more closely related to alpha proteobacteria than they are to any other lineage of prokaryotes. Thus, alpha proteobacteria are well suited as an outgroup to the eukaryotes (the group of species whose relationships we are trying to determine).

Concept Check 28.6

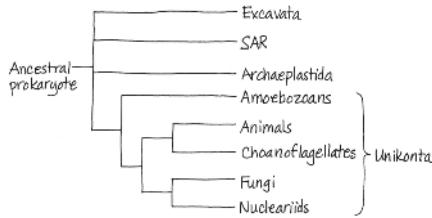
- Because photosynthetic protists constitute the base of aquatic food webs, many aquatic organisms depend on them for food, either directly or indirectly. (In addition, a substantial percentage of the oxygen produced by photosynthesis is made by photosynthetic protists.)
- Protists form mutualistic and parasitic associations with other organisms. Examples include photosynthetic dinoflagellates that form a mutualistic symbiosis with coral polyps; parabasalids that form a mutualistic symbiosis with termites; and the stramenopile *Phytophthora ramorum*, a parasite of oak trees.
- Corals depend on their dinoflagellate symbionts for nourishment, so coral bleaching could cause the corals to die. As the corals die, less food would be available for fishes and other species that eat coral. As a result, populations of these species might decline, and that, in turn, might cause populations of their predators to decline.
- The two approaches differ in the evolutionary changes they may bring about. A strain of *Wolbachia* that confers resistance to infection by *Plasmodium* and does not harm mosquitoes would spread rapidly through the mosquito population. In this case, natural selection would favor any *Plasmodium* individuals that could overcome the resistance to infection conferred by *Wolbachia*. If insecticides are used, mosquitoes that are resistant to the insecticide would be favored by natural selection. Hence, use of *Wolbachia* could cause evolution in *Plasmodium* populations, while using insecticides could cause evolution in mosquito populations.

Summary of Key Concepts Questions

- 28.1** Sample response: Protists, plants, animals, and fungi are similar in that their cells have a nucleus and other membrane-enclosed organelles, unlike the cells of prokaryotes. These membrane-enclosed organelles make the cells of eukaryotes more complex than the cells of prokaryotes. Protists and other eukaryotes also differ from prokaryotes in having a well-developed cytoskeleton that enables them to have asymmetric forms and to change in shape as they feed, move, or grow. With respect to differences between protists and other eukaryotes, most protists are unicellular, unlike animals, plants, and most fungi. Protists also have greater nutritional diversity than other eukaryotes.
- 28.2** Unique cytoskeletal features are shared by many excavates. In addition, some members of Excavata have an “excavated” feeding groove for which the group was named. Moreover, recent genomic studies support the monophyly of the excavate supergroup.
- 28.3** Stramenopiles and alveolates are hypothesized to have originated by secondary endosymbiosis. Under this hypothesis, we can infer that the common ancestor of these two groups had a plastid, in this case of red algal origin. Thus, we would expect that apicomplexans (and alveolate or stramenopile protists) either would have plastids or would have lost their plastids over the course of evolution.
- 28.4** Red algae, green algae, and plants are placed in the same supergroup because considerable evidence indicates that these organisms all descended from the same ancestor, an ancient heterotrophic protist that acquired a cyanobacterial endosymbiont.
- 28.5** The unikonta are a diverse group of eukaryotes that includes many protists, along with animals and fungi. Most of the protists in Unikonta are amoebozoans, a clade of amoebas that have lobe- or tube-shaped pseudopodia (as opposed to the threadlike pseudopodia of rhizarians). Other protists in Unikonta include several groups that are closely related to fungi and several other groups that are closely related to animals.
- 28.6** Sample response: Ecologically important protists include photosynthetic dinoflagellates that provide essential sources of energy to their symbiotic partners, the corals that build coral reefs. Other important protistan symbionts include those that enable termites to digest wood and *Plasmodium*, the pathogen that causes malaria. Photosynthetic protists such as diatoms are among the most important producers in aquatic communities; as such, many other species in aquatic environments depend on them for food.

Test Your Understanding

1. D 2. B 3. B 4. D 5. D 6. C
7.



Pathogens that share a relatively recent common ancestor with humans will likely also share metabolic and structural characteristics with humans. Because drugs target the pathogen's metabolism or structure, developing drugs that harm the pathogen but not the patient should be most difficult for pathogens with whom we share the most recent evolutionary history. Working backward in time, we can use the phylogenetic tree to determine the order in which humans shared a common ancestor with pathogens in different taxa. This process leads to the prediction that it should be hardest to develop drugs to combat animal pathogens, followed by choanoflagellate pathogens, fungal and nucleariid pathogens, amoebozoans, other protists, and finally prokaryotes.

Chapter 29**Figure Questions**

Figure 29.5 The life cycles of plants and some algae, shown in Figure 13.6b, have alternation of generations; other life cycles do not. Unlike in the animal life cycle (Figure 13.6a), in the plant/algae life cycle, meiosis produces spores, not gametes. These haploid spores then divide repeatedly by mitosis, ultimately forming a multicellular haploid individual that produces gametes. There is no multicellular haploid stage in the animal life cycle. An alternation of generations life cycle also has a multicellular diploid stage, whereas the life cycle of most fungi and

some protists shown in Figure 13.6c does not. **Figure 29.10** Plants, vascular plants, and seed plants are monophyletic because each of these groups includes the common ancestor of the group and all of the descendants of that common ancestor. The other two categories of plants, the nonvascular plants and the seedless vascular plants, are paraphyletic: These groups do not include all of the descendants of the group's most recent common ancestor. **Figure 29.11** Yes. As shown in the diagram, the sperm cell and the egg cell that fuse each resulted from the mitotic division of spores produced by the same sporophyte. However, these spores would differ genetically from one another because they were produced by meiosis, a cell division process that generates genetic variation among the offspring cells. **Figure 29.14** Because the moss reduces nitrogen loss from the ecosystem, species that typically colonize the soils after the moss probably experience higher soil nitrogen levels than they otherwise would. The resulting increased availability of nitrogen may benefit these species because nitrogen is an essential nutrient that often is in short supply. **Figure 29.17** A fern that had wind-dispersed sperm would not require water for fertilization, thus removing a difficulty that ferns face when they live in arid environments. The fern would also be under strong selection to produce sperm above ground (as opposed to the current situation, where some fern gametophytes are located below ground).

Concept Check 29.1

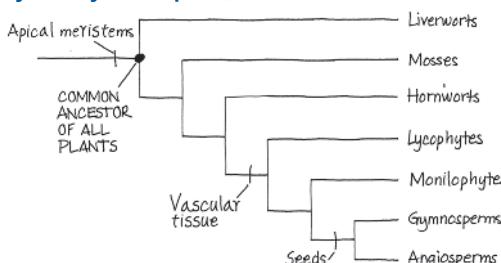
- Plants share some key traits only with charophytes: rings of cellulose-synthesizing complexes and similarity in sperm structure. Comparisons of nuclear, chloroplast, and mitochondrial DNA sequences also indicate that certain groups of charophytes (such as *Zygnea*) are the closest living relatives of plants.
- Possible answers include walls toughened by sporopollenin (protects against harsh environmental conditions); multicellular, dependent embryos (provide nutrients and protection to the developing embryo); cuticle (reduces water loss); stomata (control gas exchange and reduce water loss).
- The multicellular diploid stage of the life cycle would not produce gametes. Instead, both males and females would produce haploid spores by meiosis. These spores would give rise to multicellular male and female haploid stages—a major change from the single-celled haploid stages (sperm and eggs) that we actually have. The multicellular haploid stages would produce gametes and reproduce sexually. An individual at the multicellular haploid stage of the human life cycle might look like us, or it might look completely different.

Concept Check 29.2

- Most bryophytes do not have a vascular transport system, and their life cycle is dominated by gametophytes rather than sporophytes.
- Answers may include the following: Large surface area of protonema enhances absorption of water and minerals; the vase-shaped archegonia protect eggs during fertilization and transport nutrients to the embryos via placental transfer cells; the stalk-like seta conducts nutrients from the gametophyte to the capsule, where spores are produced; the peristome enables gradual spore discharge; stomata enable CO₂/O₂ exchange while minimizing water loss; lightweight spores are readily dispersed by wind.
- Effects of global warming on peatlands could result in positive feedback, which occurs when an end product of a process increases its own production. In this case, global warming is expected to lower the water levels of some peatlands. This would expose peat to air and cause it to decompose, thereby releasing stored CO₂ to the atmosphere. The release of more stored CO₂ to the atmosphere could cause additional global warming, which in turn could cause further drops in water levels, the release of still more CO₂ to the atmosphere, additional warming, and so on: an example of positive feedback.

Concept Check 29.3

- Lycophytes have microphylls, whereas seed plants and monilophytes (ferns and their relatives) have megaphylls. Monilophytes and seed plants also share other traits not found in lycophytes, such as the initiation of new root branches at various points along the length of an existing root.
- Both seedless vascular plants and bryophytes have flagellated sperm that require moisture for fertilization; this shared similarity poses challenges for these species in arid regions. With respect to key differences, seedless vascular plants have lignified, well-developed vascular tissue, a trait that enables the sporophyte to grow tall and that has transformed life on Earth (via the formation of forests). Seedless vascular plants also have true leaves and roots, which, when compared with bryophytes, provide increased surface area for photosynthesis and improve their ability to extract nutrients from soil.
- Three mechanisms contribute to the production of genetic variation in sexual reproduction: independent assortment of chromosomes, crossing over, and random fertilization. If fertilization were to occur between gametes from the same gametophyte, all of the offspring would be genetically identical. This would be the case because all of the cells produced by a gametophyte—including its sperm and egg cells—are the descendants of a single spore and hence are genetically identical. Although crossing over and the independent assortment of chromosomes would continue to generate genetic variation during the production of spores (which ultimately develop into gametophytes), overall the amount of genetic variation produced by sexual reproduction would drop.

Summary of Key Concepts Questions**29.1**

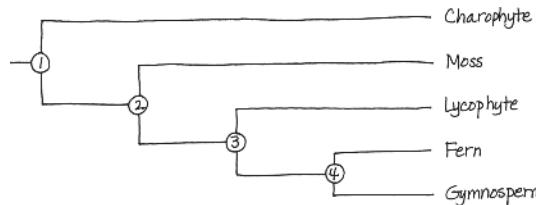
29.2 Some mosses colonize bare, sandy soils, leading to the increased retention of nitrogen in these otherwise low-nitrogen environments. Other mosses harbor nitrogen-fixing cyanobacteria that increase the availability of nitrogen in the ecosystem. The moss *Sphagnum* is often a major component of deposits of peat (partially decayed organic material). Boggy regions with thick layers of peat, known as peatlands, cover broad geographic regions and contain large reservoirs of carbon. By storing large amounts of carbon—in effect, removing CO₂ from the atmosphere—peatlands affect the global climate, making them of considerable ecological importance. **29.3** Lignified vascular tissue provided the strength needed to support a tall plant against gravity, as well as a means to transport water and nutrients to plant parts located high above ground. Roots were another key trait, anchoring the plant to the ground and providing additional structural support for plants that grew tall. Tall plants could shade shorter plants, thereby outcompeting them for light. Because the spores of a tall plant disperse farther than the spores of a short plant, it is also likely that tall plants could colonize new habitats more rapidly than short plants.

Test Your Understanding

1. B 2. D 3. C 4. A 5. C

6. (a) diploid; (b) haploid; (c) haploid; (d) diploid

7. Based on our current understanding of the evolution of major plant groups, the phylogeny has the four branch points shown here:



Derived characters unique to the charophyte and plant clade (indicated by branch point 1) include rings of cellulose-synthesizing complexes and flagellated sperm structure. Derived characters unique to the plant clade (branch point 2) include alternation of generations; multicellular, dependent embryos; walled spores produced in sporangia; and apical meristems. Derived characters unique to the vascular plant clade (branch point 3) include life cycles with dominant sporophytes, complex vascular systems (xylem and phloem), and well-developed roots and leaves. Derived characters unique to the monilophyte and seed plant clade (branch point 4) include megaphylls and roots that can branch at various points along the length of an existing root.

Chapter 30

Figure Questions

Figure 30.2 Retaining the gametophyte within the sporophyte shields the egg-containing gametophyte from UV radiation. UV radiation is a mutagen. Hence, we would expect fewer mutations to occur in the egg cells produced by a gametophyte retained within the body of a sporophyte. Most mutations are harmful. Thus, the fitness of embryos should increase because fewer embryos would carry harmful mutations. **Figure 30.3** The seed contains cells from three generations: (1) the current sporophyte (cells of ploidy 2n, found in the seed coat and in the megasporangium remnant that surrounds the spore wall), (2) the female gametophyte (cells of ploidy n, found in the food supply), and (3) the sporophyte of the next generation (cells of ploidy 2n, found in the embryo). **Figure 30.4** Mitosis. A single haploid megasporangium divides by mitosis to produce a multicellular, haploid female gametophyte. (Likewise, a single haploid microsporangium divides by mitosis to produce a multicellular male gametophyte.)

Figure 30.9



Figure 30.12 The largest number of seeds this flower could produce is six. We can infer this because the flower is shown as having six ovules, each of which can develop into a single seed. At least six pollen grains would have to germinate to produce six seeds. **Figure 30.14** No. The branching order shown could still be correct if species on the lineages leading to basal angiosperms and magnoliids had originated prior to 150 million years ago, but fossils of that age from those lineages had not yet been discovered. In such a situation, the 140-million-year-old date for the origin of the angiosperms shown on the phylogeny would be incorrect.

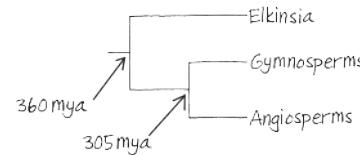
Concept Check 30.1

- To reach the eggs, the flagellated sperm of seedless plants must swim through a film of water, usually over a distance of no more than a few centimeters. In contrast, the sperm of seed plants do not require water because they are produced within pollen grains that can be transported long distances by wind or by animal pollinators. Although flagellated in some species, the sperm of seed plants do not require mobility because pollen tubes convey them from the point at which the pollen grain is deposited (near the ovules) directly to the eggs.
- The reduced gametophytes of seed plants are nurtured by sporophytes and protected from stress, such as drought conditions and UV radiation. Pollen grains, with walls containing sporopollenin, provide protection during transport by wind or animals. Seeds have one or two layers of protective tissue, the seed coat, that improve survival by providing more protection from environmental stresses than do the walls of spores. Seeds also contain a stored supply of food, which provides nourishment for growth after dormancy is broken and the embryo emerges as a seedling.
- If a seed could not enter dormancy, the

embryo would continue to grow after it was fertilized. As a result, the embryo might rapidly become too large to be dispersed, thus limiting its transport. The embryo's chance of survival might also be reduced because it could not delay growth until conditions become favorable.

Concept Check 30.2

- The pine life cycle illustrates heterospory, as ovulate cones produce megasporangia and pollen cones produce microsporangia. The reduced gametophytes are evident in the form of the microscopic pollen grains that develop from microsporangia and the microscopic female gametophyte that develops from the megasporangium. The egg is shown developing within an ovule, and a pollen tube is shown conveying the sperm. The figure also shows the protective and nutritive features of a seed.
- In pines, pollination occurs when a pollen grain is transferred to an ovulate cone scale, the part of a pine that contains ovules. Fertilization occurs when a sperm nucleus unites with an egg nucleus, forming a diploid zygote. Although pollination is required for fertilization, they are separate events: In pines, pollination usually occurs more than a year before fertilization.



Concept Check 30.3

- In the oak's life cycle, the tree (the sporophyte) produces flowers, which contain gametophytes in pollen grains and ovules; the eggs in ovules are fertilized; the mature ovaries develop into dry fruits called acorns. We can view the oak's life cycle as starting when the acorn seeds germinate, resulting in embryos giving rise to seedlings and finally to mature trees, which produce flowers—and then more acorns.
- Pine cones and flowers both have sporophylls, modified leaves that produce spores. Pine trees have separate pollen cones (with pollen grains) and ovulate cones (with ovules inside cone scales). In flowers, pollen grains are produced by the anthers of stamens, and ovules are within the ovaries of carpels. Unlike pine cones, many flowers produce both pollen and ovules.
- The fact that the clade with bilaterally symmetrical flowers had more species establishes a correlation between flower shape and the rate of plant speciation. Flower shape is not necessarily responsible for the result because the shape (that is, bilateral or radial symmetry) may have been correlated with another factor that was the actual cause of the observed result. Note, however, that flower shape was associated with increased speciation rates when averaged across 19 different pairs of plant lineages. Since these 19 lineage pairs were independent of one another, this association suggests—but does not establish—that differences in flower shape cause differences in speciation rates. In general, strong evidence for causation can come from controlled, manipulative experiments, but such experiments are usually not possible for studies of past evolutionary events.

Concept Check 30.4

- Plant diversity can be considered a resource because plants provide many important benefits to humans; as a resource, plant diversity is nonrenewable because if a species is lost to extinction, that loss is permanent.
- A detailed phylogeny of the seed plants would identify many different monophyletic groups of seed plants. Using this phylogeny, researchers could look for clades that contained species in which medicinally useful compounds had already been discovered. Identification of such clades would allow researchers to concentrate their search for new medicinal compounds among clade members—as opposed to searching for new compounds in species that were selected at random from the more than 290,000 existing species of seed plants.

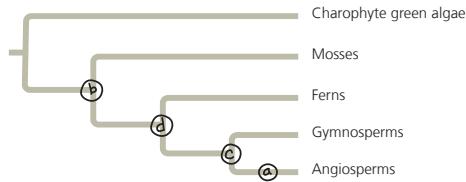
Summary of Key Concepts Questions

- The integument of an ovule develops into the protective coat of a seed. The ovule's megasporangium develops into a haploid female gametophyte, and two parts of the seed are related to that gametophyte: The food supply of the seed is derived from haploid gametophyte cells, and the embryo of the seed develops after the female gametophyte's egg cell is fertilized by a sperm cell. A remnant of the ovule's megasporangium surrounds the spore wall that encloses the seed's food supply and embryo.
- Gymnosperms arose about 305 million years ago, making them a successful group in terms of their evolutionary longevity. Gymnosperms have the five derived traits common to all seed plants (reduced gametophytes, heterospory, ovules, pollen, and seeds), making them well adapted for life on land. Finally, because gymnosperms dominate immense geographic regions today, the group is also highly successful in geographic distribution.
- Based on fossils known during his lifetime, Darwin was troubled by the relatively sudden and geographically widespread appearance of angiosperms in the fossil record. Recent fossil evidence shows that angiosperms arose and began to diversify over a period of 20–30 million years, a less rapid event than was suggested by the fossils known during Darwin's lifetime. Fossil discoveries have also uncovered extinct lineages of woody seed plants thought to have been more closely related to angiosperms than to gymnosperms; one such group, the Bennettitales, had flowerlike structures that may have been pollinated by insects. In addition, phylogenetic analyses have identified a woody species, *Amborella*, as the most basal lineage of extant angiosperms. The fact that both the extinct seed plant ancestors of angiosperms and the most basal taxon of extant angiosperms were woody suggests that the common ancestor of angiosperms also was woody.
- The loss of tropical forests could contribute to global warming (which would have negative effects on many human societies).

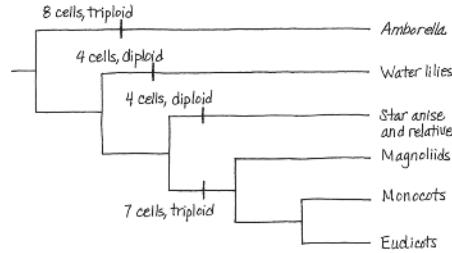
People also depend on Earth's biodiversity for many products and services and hence would be harmed by the loss of species that would occur if the world's remaining tropical forests were cut down. With respect to a possible mass extinction, tropical forests harbor at least 50% of the species on Earth. If the remaining tropical forests were destroyed, large numbers of these species could be driven to extinction, thus rivaling the losses that occurred in the five mass extinction events documented in the fossil record.

Test Your Understanding

1. C
 2. B
 3. A
 4. D
 5. C
- 6.



8. (a)



(b) The phylogeny indicates that basal angiosperms differed from other angiosperms in terms of the number of cells in female gametophytes and the ploidy of the endosperm. The ancestral state of the angiosperms cannot be determined from these data alone. It is possible that the common ancestor of angiosperms had seven-celled female gametophytes and triploid endosperm and hence that the eight-celled and four-celled conditions found in basal angiosperms represent derived traits for those lineages. Alternatively, either the eight-celled or four-celled condition may represent the ancestral state.

Chapter 31

Figure Questions

Figure 31.2 DNA from each of these mushrooms would be identical if each mushroom is part of a single hyphal network, as is likely. **Figure 31.5** The haploid spores produced in the sexual portion of the life cycle develop from haploid nuclei that were produced by meiosis; because genetic recombination occurs during meiosis, these spores will differ genetically from one another. In contrast, the haploid spores produced in the asexual portion of the life cycle develop from nuclei that were produced by mitosis; as a result, these spores are genetically identical to one another. **Figure 31.17** One or both of the following would apply to each species: DNA analyses would reveal that it is a member of the ascomycete clade, or aspects of its sexual life cycle would indicate that it is an ascomycete (for example, it would produce ascii and ascospores). **Figure 31.18** The hypha is composed of cells that are haploid (n), as indicated by the teal-colored arrow behind it. **Figure 31.20** The mushroom is a basidiocarp, or fruiting body, of the dikaryotic mycelium, and so a cell from its stalk would be dikaryotic ($n + n$). **Figure 31.22** Two possible controls would be E-P- and E+P-. Results from an E-P- control could be compared with results from the E-P+ experiment, and results from an E+P- control could be compared with results from the E+P+ experiment. Together, these two comparisons would indicate whether the addition of the pathogen causes an increase in leaf mortality. Results from an E-P- experiment could also be compared with results from the second control (E+P-) to determine whether adding the fungal endophytes has a negative effect on the plant.

Concept Check 31.1

1. Both a fungus and a human are heterotrophs. Many fungi digest their food externally by secreting enzymes into the food and then absorbing the small molecules that result from digestion. Other fungi absorb such small molecules directly from their environment. In contrast, humans (and most other animals) ingest relatively large pieces of food and digest the food within their bodies.
2. The ancestors of such a mutualist most likely secreted powerful enzymes to digest the body of their insect host. Since such enzymes would harm a living host, it is likely that the mutualist would not produce such enzymes or would restrict their secretion and use.
3. Carbon that enters the plant through stomata is fixed into sugar through photosynthesis. Some of these sugars are absorbed by the fungus that partners with the plant to form mycorrhizae; others are transported within the plant body and used in the plant. Thus, the carbon may be deposited in either the body of the plant or the body of the fungus.

Concept Check 31.2

1. The majority of the fungal life cycle is spent in the haploid stage, whereas the majority of the human life cycle is spent in the diploid stage.
2. The two mushrooms might be reproductive structures of the same mycelium (the same

organism). Or they might be parts of two separate organisms that have arisen from a single parent organism through asexual reproduction (for example, from two genetically identical asexual spores) and thus carry the same genetic information.

Concept Check 31.3

1. DNA evidence indicates that fungi, animals, and their protistan relatives form a clade, the opisthokonts. Furthermore, chytrids and other fungi thought to be members of basal lineages have posterior flagella, as do most other opisthokonts. This suggests that other fungal lineages lost their flagella after diverging from ancestors that had flagella. 2. Mycorrhizae form extensive networks of hyphae through the soil, enabling nutrients to be absorbed more efficiently than a plant can do on its own; this is true today, and similar associations were probably very important for the earliest plants (which lacked roots). Evidence for the antiquity of mycorrhizal associations includes fossils showing arbuscular mycorrhizae in the early plant *Aglaoiphyton* and molecular results showing that genes required for the formation of mycorrhizae are present in liverworts and other basal plant lineages. 3. Fungi are heterotrophs. Prior to the colonization of land by plants, terrestrial fungi would have lived where other organisms (or their remains) were present and provided a source of food. Thus, if fungi colonized land before plants, they could have fed on prokaryotes or protists that lived on land or by the water's edge—but not on the plants or animals on which many fungi feed today.

Concept Check 31.4

1. Flagellated spores; molecular evidence also suggests that chytrids include species that belong to lineages that diverged from other fungi early in the history of the group. 2. Possible answers include the following: In mucromycetes, the sturdy, thick-walled zygosporangium can withstand harsh conditions and then undergo karyogamy and meiosis when the environment is favorable for reproduction. In one group of mucromycetes, the glomeromycetes, the hyphae have a specialized morphology that enables the fungi to form arbuscular mycorrhizae with plant roots. In ascomycetes, the asexual spores (conidia) are often produced in chains or clusters at the tips of conidiophores, where they are easily dispersed by wind. The often cup-shaped ascocarps house the sexual spore-forming ascii. In basidiomycetes, the basidiocarp supports and protects a large surface area of basidia, from which spores are dispersed. 3. Such a change to the life cycle of an ascomycete would reduce the number and genetic diversity of ascospores that result from a mating event. Ascospore number would drop because a mating event would lead to the formation of only one ascus. Ascospore genetic diversity would also drop because in ascomycetes, one mating event leads to the formation of ascii by many different dikaryotic cells. As a result, genetic recombination and meiosis occur independently many different times—which could not happen if only a single ascus was formed. It is also likely that if such an ascomycete formed an ascocarp, the shape of the ascocarp would differ considerably from that found in its close relatives.

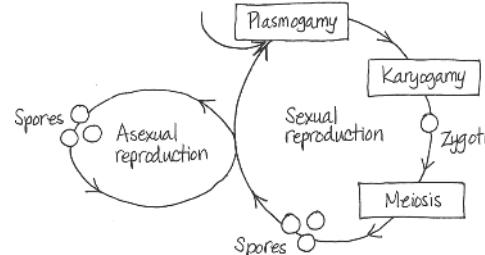
Concept Check 31.5

1. A suitable environment for growth, retention of water and minerals, protection from intense sunlight, and protection from being eaten
2. A hardy spore stage enables dispersal to host organisms through a variety of mechanisms; their ability to grow rapidly in a favorable new environment enables them to capitalize on the host's resources.
3. Many different outcomes might have occurred. Organisms that currently form mutualisms with fungi might have gained the ability to perform the tasks currently done by their fungal partners, or they might have formed similar mutualisms with other organisms (such as bacteria). Alternatively, organisms that currently form mutualisms with fungi might be less effective at living in their present environments. For example, the colonization of land by plants might have been more difficult. And if plants did eventually colonize land without fungal mutualists, natural selection might have favored plants that formed more highly divided and extensive root systems (in part replacing mycorrhizae).

Summary of Key Concepts Questions

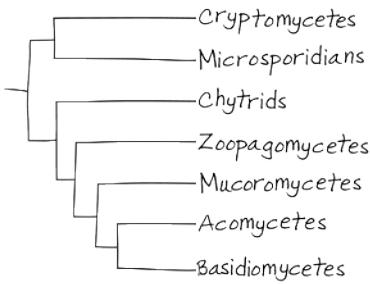
31.1 The body of a multicellular fungus typically consists of thin filaments called hyphae. These filaments form an interwoven mass (mycelium) that penetrates the substrate on which the fungus grows and feeds. Because the individual filaments are thin, the surface-to-volume ratio of the mycelium is maximized, making nutrient absorption highly efficient.

31.2



31.3 Phylogenetic analyses show that fungi and animals are more closely related to each other than either is to other multicellular eukaryotes (such as plants or multicellular algae). These analyses also show that fungi are more closely related to single-celled protists called nucleoids than they are to animals, whereas animals are more closely related to a different group of single-celled protists, the choanoflagellates, than they are to fungi. In combination, these results indicate that multicellularity evolved in fungi and animals independently, from different single-celled ancestors.

31.4



31.5 As decomposers, fungi break down the bodies of dead organisms, thereby recycling elements between the living and nonliving environments. Without the activities of fungi and bacterial decomposers, essential nutrients would remain tied up in organic matter, and life as we know it would cease. As an example of their key role as mutualists, fungi form mycorrhizal associations with plants. These associations improve the growth and survival of plants, thereby indirectly affecting the many other species (humans included) that depend on plants. As pathogens, fungi harm other species. In some cases, fungal pathogens have caused their host populations to decline across broad geographic regions, as in the case of the American chestnut.

Test Your Understanding

1.B 2.D 3.A 4.D

Chapter 32

Figure Questions

Figure 32.3 As described in ① and ②, choanoflagellates and a broad range of animals have collar cells. Since collar cells have never been observed in plants, fungi, or non-choanoflagellate protists, this suggests that choanoflagellates may be more closely related to animals than to other eukaryotes. If choanoflagellates are more closely related to animals than to any other group of eukaryotes, choanoflagellates and animals should share other traits that are not found in other eukaryotes. The data described in ③ are consistent with this prediction.

Figure 32.8 (1) Any imaginary slice through the central axis of a radial animal divides its body into mirror images. As a result, a radial animal has no front and back sides and no left and right sides.

(2)

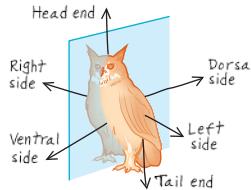


Figure 32.11 Cnidaria is the sister phylum in this tree.

Concept Check 32.1

1. In most animals, the zygote undergoes cleavage, which leads to the formation of a blastula. Next, in gastrulation, one end of the embryo folds inward, producing layers of embryonic tissue. As the cells of these layers differentiate, a wide variety of animal forms are produced. Despite the diversity of animal forms, animal development is controlled by a similar set of *Hox* genes across a broad range of taxa. 2. The imaginary plant would require tissues composed of cells that were analogous to the muscle and nerve cells found in animals: “Muscle” tissue would be necessary for the plant to chase prey, and “nerve” tissue would be required for the plant to coordinate its movements when chasing prey. To digest captured prey, the plant would need to either secrete enzymes into one or more digestive cavities (which could be modified leaves, as in a Venus flytrap) or secrete enzymes outside of its body and feed by absorption. To extract nutrients from the soil—yet be able to chase prey—the plant would need something other than fixed roots, perhaps retractable “roots” or a way to ingest soil. To conduct photosynthesis, the plant would require chloroplasts. Overall, such an imaginary plant would be very similar to an animal that had chloroplasts and retractable roots.

Concept Check 32.2

1.c, b, a, d 2. The red-colored portion of the tree represents ancestors of animals that lived between 1 billion years ago and 770 million years ago. Although these ancestors are more closely related to animals than to fungi, they would not be classified as animals. One example of an ancestor represented by the red-colored portion of this tree is the most recent common ancestor shared by choanoflagellates and animals (see Figure 32.3). That common ancestor was not an animal (or a choanoflagellate), but it was a direct ancestor of the animals. 3. In descent with modification, an organism shares characteristics with its ancestors (due to their shared ancestry), yet it also differs from its ancestors (because organisms accumulate differences over time as they adapt to their surroundings). As an example, consider the evolution of animal cadherin proteins, a key step in the origin of multicellular animals. These proteins illustrate both

of these aspects of descent with modification: Animal cadherin proteins share many protein domains with a cadherin-like protein found in their choanoflagellate ancestors, yet they also have a unique “CCD” domain that is not found in choanoflagellates.

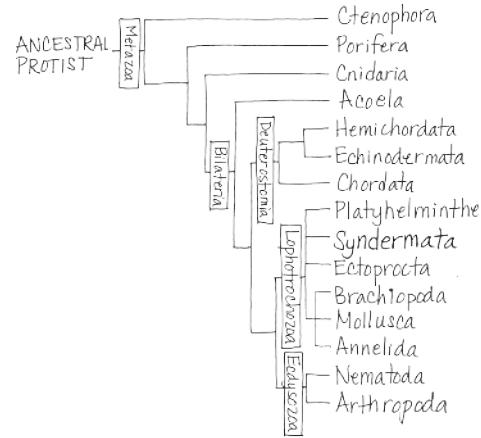
Concept Check 32.3

1. A snail has a spiral and determinate cleavage pattern; a human has radial, indeterminate cleavage. In a snail, the coelomic cavity is formed by splitting of mesoderm masses; in a human, the coelom forms from folds of archenteron. In a snail, the mouth forms from the blastopore; in a human, the anus develops from the blastopore. 2. Animals that lack a body cavity tend to have thin, flat bodies. Such animals don’t require an internal transport system: With bodies that are only a few cells thick, the exchange of nutrients, gases, and wastes can occur across the entire body surface. 3. Most triploblasts have two openings to their digestive tract, a mouth and an anus. As such, their bodies have a structure that is analogous to that of a doughnut: The digestive tract (the hole of the doughnut) runs from the mouth to the anus and is surrounded by various tissues (the solid part of the doughnut). The doughnut analogy is most obvious at early stages of development (see Figure 32.10c).

Concept Check 32.4

1. Cnidarians possess tissues, while sponges do not. Also unlike sponges, cnidarians exhibit body symmetry, though it is radial and not bilateral as in most other animal phyla.

2.



Under the hypothesis that ctenophores are basal metazoans, sponges (which lack tissues) would be nested within a clade whose other members all have tissues. As a result, a group composed of animals with tissues would not form a clade. 3. The phylogeny in Figure 32.11 indicates that molluscs are members of Lophotrochozoa, one of the three main groups of bilaterians (the others being Deuterostomia and Ecdysozoa). As seen in Figure 25.11, the fossil record shows that molluscs were present tens of millions of years before the Cambrian explosion. Thus, long before the Cambrian explosion, the lophotrochozoan clade had formed and was evolving independently of the evolutionary lineages leading to Deuterostomia and Ecdysozoa. Based on the phylogeny in Figure 32.11, we can also conclude that the lineages leading to Deuterostomia and Ecdysozoa were independent of one another before the Cambrian explosion. Since the lineages leading to the three main clades of bilaterians were evolving independently of one another prior to the Cambrian explosion, that explosion could be viewed as consisting of three “explosions,” not one.

Summary of Key Concepts Questions

32.1 Unlike animals, which are heterotrophs that ingest their food, plants are autotrophs, and fungi are heterotrophs that grow on their food and feed by absorption. Animals lack cell walls, which are found in both plants and fungi. Animals also have muscle tissue and nerve tissue, which are not found in either plants or fungi. In addition, the sperm and egg cells of animals are produced by meiotic division, unlike what occurs in plants and fungi (where reproductive cells such as sperm and eggs are produced by mitotic division). Finally, animals regulate the development of body form with *Hox* genes, a unique group of genes that is not found in either plants or fungi. **32.2** Current hypotheses about the cause of the Cambrian explosion include new predator-prey relationships, an increase in atmospheric oxygen, and an increase in developmental flexibility provided by the origin of *Hox* genes and other genetic changes. **32.3** Body plans provide a helpful way to compare and contrast key features of organisms. However, phylogenetic analyses show that similar body plans have arisen independently in different groups of organisms. As such, similar body plans may have arisen by convergent evolution and hence may not be informative about evolutionary relationships. **32.4** Listed in order from the most to the least inclusive clade, humans belong to Metazoa, Eumetazoa, Bilateria, Deuterostomia, and Chordata.

Test Your Understanding

1.A 2.D 3.C 4.C

Chapter 33

Figure Questions

Figure 33.7 *Obelia* is an animal, and its life cycle is indeed most similar to the generalized life cycle of animals (Figure 13.6a). In *Obelia*, both the polyp and the medusa are diploid organisms. As in other animals, in *Obelia* only the single-celled gametes are haploid. By contrast, plants and some algae (Figure 13.6b) have a multicellular haploid generation and a multicellular diploid generation. *Obelia* also differs from fungi and some protists (Figure 13.6c) in that the diploid stage of those organisms is unicellular. **Figure 33.8** Possible examples include the Golgi apparatus (flattening; increases area for receiving and transporting proteins), the cristae of mitochondria (folding; increases the surface area available for cellular respiration), the cardiovascular system (branching; increase area for materials exchange in tissues), and root hairs (projections; increase area for absorption). **Figure 33.10** Adding fertilizer to the water supply would probably increase the abundance of algae, and that, in turn, would likely increase the abundance of snails (which eat algae). If the water was also contaminated with infected human feces or urine, an increase in the number of snails would likely lead to an increase in the abundance of blood flukes (which require snails as an intermediate host). As a result, the occurrence of schistosomiasis might increase. **Figure 33.21** The extinction of freshwater bivalves might lead to an increase in the abundance of photosynthetic protists and bacteria. Because these organisms are at the base of aquatic food webs, increases in their abundance could have major effects on aquatic communities (including both increases and decreases in the abundance of other species). **Figure 33.29** Such a result would be consistent with the origin of the *Ubx* and *abd-A* *Hox* genes having played a major role in the evolution of increased body segment diversity in arthropods. However, note that such a result would simply show that the presence of the *Ubx* and *abd-A* *Hox* genes was correlated with an increase in body segment diversity in arthropods; it would not provide direct experimental evidence that the origin of the *Ubx* and *abd-A* genes caused an increase in arthropod body segment diversity. **Figure 33.35** You should have circled the clade that includes the insects, remipedians, and other crustaceans, along with the branch point that represents their most recent common ancestor.

Concept Check 33.1

1. The flagella of choanocytes draw water through their collars, which trap food particles. The particles are engulfed by phagocytosis and digested, either by choanocytes or by amoebocytes. 2. The collar cells of sponges bear a striking resemblance to a choanoflagellate cell. This suggests that the last common ancestor of animals and their protist sister group may have resembled a choanoflagellate. Nevertheless, mesomycetozoans could still be the sister group of animals. If this is the case, the lack of collar cells in mesomycetozoans would indicate that over time their structure evolved in ways that caused it to no longer resemble a choanoflagellate cell. It is also possible that choanoflagellates and sponges share similar looking collar cells as a result of convergent evolution.

Concept Check 33.2

1. Both the polyp and the medusa are composed of an outer epidermis and an inner gastrodermis separated by a gelatinous layer, the mesoglea. The polyp is a cylindrical form that adheres to the substrate by its aboral end; the medusa is a flattened, mouth-down form that moves freely in the water. 2. Both a feeding polyp and a medusa are diploid, as indicated by the pink arrow in the diagram. The medusa stage produces haploid gametes. 3. Evolution is not goal oriented; hence, it would not be correct to argue that cnidarians are not “highly evolved” simply because their form had changed relatively little over the past 560 million years. Instead, the fact that cnidarians have persisted for hundreds of millions of years indicates that the cnidarian body plan is a highly successful one.

Concept Check 33.3

1. Tapeworms can absorb food from their environment and release ammonia into their environment through their body surface because their body is very flat, due in part to the lack of a body cavity. 2. The inner tube is the alimentary canal, which runs the length of the body. The outer tube is the body wall. The two tubes are separated by the coelom. 3. All molluscs have inherited a foot from their common ancestor. However, in different groups of molluscs, the structure of the foot has been modified over time by natural selection. In gastropods, the foot is used as a holdfast or to move slowly on the substrate. In cephalopods, the foot has been modified into part of the tentacles and into an excurrent siphon, through which water is propelled (resulting in movement in the opposite direction).

Concept Check 33.4

1. Nematodes lack body segments and a coelom; annelids have both. 2. The arthropod exoskeleton, which had already evolved in the ocean, allows terrestrial species to retain water and support their bodies on land. Wings allow insects to disperse quickly to new habitats and to find food and mates. The tracheal system allows for efficient gas exchange despite the presence of an exoskeleton. 3. Yes. Under the traditional hypothesis, we would expect body segmentation to be controlled by similar *Hox* genes in annelids and arthropods. However, if annelids are in Lophotrochozoa and arthropods are in Ecdysozoa (as current evidence suggests), body segmentation may have evolved independently in these two groups. In such a case, we might expect that different *Hox* genes would control the development of body segmentation in the two clades.

Concept Check 33.5

1. Each tube foot consists of an ampulla and a podium. When the ampulla squeezes, it forces water into the podium, which causes the podium to expand and contact the substrate. Adhesive chemicals are then secreted from the base of the podium, thereby attaching the podium to the substrate. 2. Both insects and nematodes are members of Ecdysozoa, one of the three major clades of

bilaterians. Therefore, a characteristic shared by *Drosophila* and *Caenorhabditis* may be informative for other members of their clade—but not necessarily for members of Deuterostomia. Instead, Figure 33.2 suggests that a species within Echinodermata or Chordata might be a more appropriate invertebrate model organism from which to draw inferences about humans and other vertebrates. 3. Echinoderms include species with a wide range of body forms. However, even echinoderms that look very different from one another, such as sea stars and sea cucumbers, share characteristics unique to their phylum, including a water vascular system and tube feet. The differences between echinoderm species illustrate the diversity of life, while the characteristics they share illustrate the unity of life. The match between organisms and their environments can be seen in such echinoderm features as the eversible stomachs of sea stars (enabling them to digest prey that are larger than their mouth) and the complex, jaw-like structure that sea urchins use to eat seaweed.

Summary of Key Concepts Questions

33.1 The sponge body consists of two layers of cells, both of which are in contact with water. As a result, gas exchange and waste removal occur as substances diffuse into and out of the cells of the body. Choanocytes and amoebocytes ingest food particles from the surrounding water. Choanocytes also release food particles to amoebocytes, which then digest the food particles and deliver nutrients to other cells. **33.2** The cnidarian body plan consists of a sac with a central digestive compartment, the gastrovascular cavity. The single opening to this compartment serves as both a mouth and an anus. The two main variations on this body plan are sessile polyps (which adhere to the substrate at the end of the body opposite to the mouth/anus) and motile medusae (which move freely through the water and resemble flattened, mouth-down versions of polyps). **33.3** No. Some lophotrochozoans have a crown of ciliated tentacles that function in feeding (called a lophophore), while others go through a distinctive developmental stage known as trophophore larvae. Many other lophotrochozoans do not have either of these features. As a result, the clade is defined primarily by DNA similarities, not morphological similarities. **33.4** Many nematode species live in soil and in sediments on the bottom of bodies of water. These free-living species play important roles in decomposition and nutrient cycling. Other nematodes are parasites, including many species that attack the roots of plants and some that attack animals (including humans). Arthropods have profound effects on all aspects of ecology. In aquatic environments, crustaceans play key roles as grazers (of algae), scavengers, and predators and some species, such as krill, are important sources of food for whales and other vertebrates. On land, it is difficult to think of features of the natural world that are not affected in some way by insects and other arthropods, such as spiders and ticks. There are more than 1 million species of insects, many of which have enormous ecological effects as herbivores, predators, parasites, decomposers, and vectors of disease. Insects are also key sources of food for many organisms, including humans in some regions of the world. **33.5** Echinoderms and chordates are both members of Deuterostomia, one of the three main clades of bilaterian animals. As such, chordates (including humans) are more closely related to echinoderms than we are to animals in any of the other phyla covered in this chapter. Nevertheless, echinoderms and chordates have evolved independently for over 500 million years. This statement does not contradict the close relationship of echinoderms and chordates, but it does make clear that “close” is a relative term indicating that these two phyla are more closely related to each other than either is to animal phyla not in Deuterostomia.

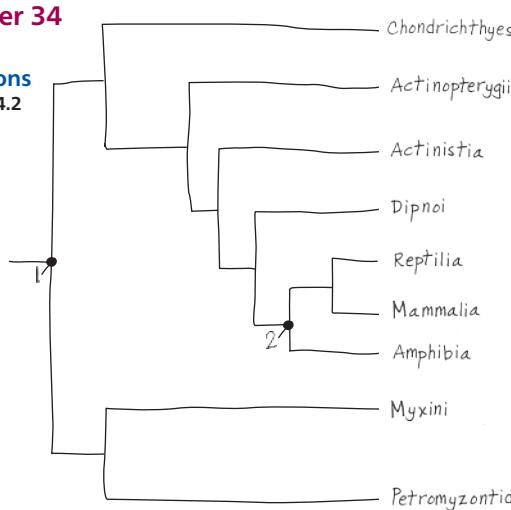
Test Your Understanding

1. A 2. C 3. B 4. C 5. C 6. D

Chapter 34

Figure Questions

Figure 34.2



The redrawn tree shows mammals (including humans) as nested near the middle of the evolutionary tree of vertebrates. Showing the vertebrate tree in this way provides a visual illustration of the fact that the evolutionary history of vertebrates did not consist of a series of steps “leading to”

humans. **Figure 34.6** The patterns in these figures suggest that specific *Hox* genes, as well as the order in which they are expressed, have been highly conserved over the course of evolution. **Figure 34.20** *Tiktaalik* was a lobe-fin fish that had both fish and tetrapod characters. Like a fish, *Tiktaalik* had fins, scales, and gills. As described by Darwin's concept of descent with modification, such shared characters can be attributed to descent from ancestral species—in this case, *Tiktaalik*'s descent from fish ancestors. *Tiktaalik* also had traits that were unlike a fish but like a tetrapod, including a flat skull, a neck, a full set of ribs, and the skeletal structure of its fin. These characters illustrate the second part of descent with modification, showing how ancestral features had become modified over time. **Figure 34.21** Sometime between 350 mya and 340 mya, we can infer this because amphibians must have originated after the most recent common ancestor of amphibians and amniotes (and that ancestor is shown as having lived 350 mya), but no later than the date of the earliest known fossils of amphibians (shown in the figure as 340 mya). **Figure 34.25** Pterosaurs did not descend from the common ancestor of all dinosaurs; hence, pterosaurs are not dinosaurs. However, birds are descendants of the common ancestor of the dinosaurs. As a result, a monophyletic clade of dinosaurs must include birds. In that sense, birds are dinosaurs. **Figure 34.37** In a catabolic pathway, like the aerobic processes of cellular respiration, water is released as a by-product when an organic compound such as glucose is mixed with oxygen. The kangaroo rat can retain and use that water, decreasing its need to drink water. **Figure 34.38** In general, the process of exaptation occurs as a structure that had one function acquires a different function via a series of intermediate stages. Each of these intermediate stages typically has some function in the organism in which it is found. The incorporation of articular and quadrate bones into the mammalian ear illustrates exaptation because these bones originally evolved as part of the jaw, where they functioned as the jaw hinge, but over time they became co-opted for another function, namely, the transmission of sound. **Figure 34.44** As shown in this phylogeny, chimpanzees and humans represent the tips of separate branches of evolution. As such, the human and chimpanzee lineages have evolved independently after they diverged from their common ancestor—an event that took place about 8 million years ago. Hence, it is incorrect to say that humans evolved from chimpanzees (or vice versa). If humans had descended from chimpanzees, for example, the human lineage would be nested within the chimpanzee lineage, much as birds are nested within the reptile clade (see Figure 34.25).

Concept Check 34.1

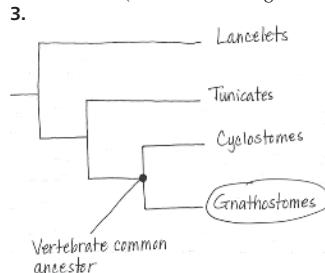
1. The four characters are a notochord; a dorsal, hollow nerve chord; pharyngeal slits or clefts; and a muscular, post-anal tail.
2. In humans, these characters are present only in the embryo. The notochord becomes disks between the vertebrae; the dorsal, hollow nerve cord develops into the brain and spinal cord; the pharyngeal clefts develop into various adult structures, and the tail is almost completely lost.
3. You would expect the vertebrate groups Actinopterygii, Actinistia, Diploï, Amphibia, Reptilia, and Mammalia to have lungs or lung derivatives. All of these groups originate to the right of (evolved after) the hatch mark indicating the appearance of this derived character in their lineage.

Concept Check 34.2

1. Parasitic lampreys have a round, rasping mouth, which they use to attach to fish. Non-parasitic lampreys feed only as larvae; these larvae resemble lancelets and like them, are suspension feeders. Conodonts had two sets of mineralized dental elements, which may have been used to impale prey and cut it into smaller pieces.
2. Such a finding suggests that early organisms with a head were favored by natural selection in several different evolutionary lineages. However, while a logical argument can be made that having a head was advantageous, fossils alone do not constitute proof.
3. In armored jawless vertebrates, bone served as external armor that may have provided protection from predators. Some species also had mineralized mouthparts, which could be used for either predation or scavenging.

Concept Check 34.3

1. Both are gnathostomes and have jaws, four clusters of *Hox* genes, enlarged forebrains, and lateral line systems. Shark skeletons consist mainly of cartilage, whereas tuna have bony skeletons. Sharks also have a spiral valve. Tuna have an operculum and a swim bladder, as well as flexible rays supporting their fins.
2. Aquatic gnathostomes have jaws (an adaptation for feeding) and paired fins and a tail (adaptations for swimming). Aquatic gnathostomes also typically have streamlined bodies for efficient swimming and swim bladders or other mechanisms (such as oil storage in sharks) for buoyancy.
- 3.



4. Yes, that could have happened. The paired appendages of aquatic gnathostomes other than the lobe-fins could have served as a starting point for the evolution of limbs. The colonization of land by aquatic gnathostomes other than the lobe-fins might have been facilitated in lineages that possessed lungs, as that would have enabled those organisms to breathe air.

Concept Check 34.4

1. Tetrapods are thought to have originated about 365 million years ago when the fins of some lobe-fins evolved into the limbs of tetrapods. In addition to their four limbs with digits—a key derived trait for which the group is named—other

derived traits of tetrapods include a neck (consisting of vertebrae that separate the head from the rest of the body) and a pelvic girdle that is fused to the backbone.

2. Some fully aquatic species are paedomorphic, retaining larval features for life in water as adults. Species that live in dry environments may avoid dehydration by burrowing or living under moist leaves, and they protect their eggs with foam nests, viviparity, and other adaptations.
3. Many amphibians spend part of their life cycle in aquatic environments and part on land. Thus, they may be exposed to a wide range of environmental problems, including water and air pollution and the loss or degradation of aquatic and/or terrestrial habitats. In addition, amphibians have highly permeable skin, providing relatively little protection from external conditions, and their eggs do not have a protective shell.

Concept Check 34.5

1. The amniotic egg provides protection to the embryo and allows the embryo to develop on land, eliminating the necessity of a watery environment for reproduction. Another key adaptation is rib cage ventilation, which improves the efficiency of air intake and may have allowed early amniotes to dispense with breathing through their skin. Finally, not breathing through their skin allowed amniotes to develop relatively impermeable skin, thereby conserving water.
2. Yes. Although snakes lack limbs, they descended from lizards with legs. Some snakes retain vestigial pelvic and leg bones, providing evidence of their descent from an ancestor with legs.
3. Birds have weight-saving modifications, including the absence of teeth, a urinary bladder, and a second ovary in females. The wings and feathers are adaptations that facilitate flight, as do efficient respiratory and circulatory systems that support a high metabolic rate.
4. (a) synapsids, (b) tuataras, (c) turtles

Concept Check 34.6

1. Monotremes lay eggs. Marsupials give birth to very small live young that attach to a nipple in the mother's pouch, where they complete development. Eutherians give birth to more developed live young.
2. Hands and feet adapted for grasping, flat nails, large brain, forward-looking eyes on a flat face, parental care, and movable big toe and thumb.
3. Mammals are endothermic, enabling them to live in a wide range of habitats. Milk provides young with a balanced set of nutrients, and hair and a layer of fat under the skin help mammals retain heat. Mammals have differentiated teeth, enabling them to eat many different kinds of food. Mammals also have relatively large brains, and many species are capable learners. Following the mass extinction at the end of the Cretaceous period, the absence of large terrestrial dinosaurs may have opened many new ecological niches to mammals, promoting an adaptive radiation. Continental drift also isolated many groups of mammals from one another, promoting the formation of many new species.

Concept Check 34.7

1. Hominins are a clade within the ape clade that includes humans and all species more closely related to humans than to other apes. The derived characters of hominins include bipedal locomotion and relatively larger brains.
2. In hominins, bipedal locomotion evolved long before large brain size. *Homo ergaster*, for example, was fully upright, bipedal, and as tall as modern humans, but its brain was significantly smaller than that of modern humans.
3. Yes, both can be correct. *Homo sapiens* may have established populations outside of Africa as early as 180,000 years ago, as indicated by the fossil record. However, those populations may have left few or no descendants today. Instead, all living humans may have descended from Africans that spread from Africa roughly 50,000 years ago, as indicated by genetic data.

Summary of Key Concepts Questions

- 34.1** Lancelets are the most basal group of living chordates, and as adults they have key derived characters of chordates. This suggests that the chordate common ancestor may have resembled a lancelet in having an anterior end with a mouth along with the following four derived characters: a notochord; a dorsal, hollow nerve cord; pharyngeal slits or clefts; and a muscular, post-anal tail.
- 34.2** Conodonts, among the earliest vertebrates in the fossil record, were very abundant for 300 million years. While jawless, their well-developed teeth provide early signs of bone formation. Other species of jawless vertebrates developed armor on the outside of their bodies, which probably helped protect them from predators. Like lampreys, these species had paired fins for locomotion and an inner ear with semicircular canals that provided a sense of balance. There were many species of these armored jawless vertebrates, but they all became extinct by the close of the Devonian period, 359 million years ago.
- 34.3** The origin of jaws altered how fossil gnathostomes obtained food, which in turn had large effects on ecological interactions. Predators could use their jaws to grab prey or remove chunks of flesh, stimulating the evolution of increasingly sophisticated means of defense in prey species. Evidence for these changes can be found in the fossil record, which includes fossils of 10-m-long predators with remarkably powerful jaws, as well as lineages of well-defended prey species whose bodies were covered by armored plates.
- 34.4** Amphibians require water for reproduction; their bodies can lose water rapidly through their moist, highly permeable skin; and amphibian eggs do not have a shell and hence are vulnerable to desiccation.
- 34.5** Birds are descended from theropod dinosaurs, and dinosaurs are nested within the archosaur lineage, one of the two main reptile lineages. Thus, the other living archosaur reptiles, the crocodilians, are more closely related to birds than they are to non-archosaur reptiles such as lizards. As a result, birds are considered reptiles. (Note that if reptiles were defined as excluding birds, the reptiles would not form a clade; instead, the reptiles would be a paraphyletic group.)
- 34.6** Mammals are members of a group of amniotes called synapsids. Early (nonmammalian) synapsids laid eggs and had a sprawling gait. Fossil evidence shows that mammalian features arose gradually over a period of more than 100 million years. For example, the jaw was modified over time in nonmammalian synapsids, eventually coming to resemble that of a mammal. By 180 million years ago, the first mammals had appeared. There were many species

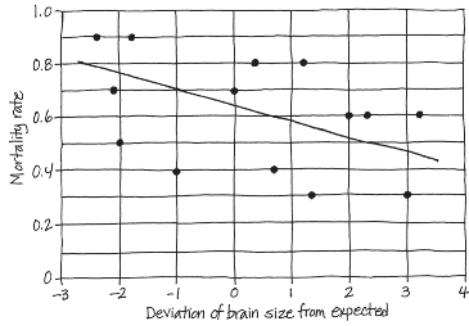
of early mammals, but most of them were small, and they were not abundant or dominant members of their community. Mammals did not rise to ecological dominance until after the extinction of the dinosaurs. **34.7** The fossil record shows that from 4.5 to 2.5 million years ago, a wide range of hominin species walked upright but had relatively small brain sizes. About 2.5 million years ago, the first members of genus *Homo* emerged. These species used tools and had larger brains than those of earlier hominins. Fossil evidence indicates that multiple members of our genus were alive at any given point in time. Furthermore, until about 1.3 million years ago, these various *Homo* species also coexisted with members of earlier hominin lineages, such as *Paranthropus*. The different hominins alive at the same periods of time varied in body size, body shape, brain size, dental morphology, and the capacity for tool use. Ultimately, except for *Homo sapiens*, all of these species became extinct. Overall, human evolution can be viewed as an evolutionary tree with many branches—the only surviving lineage of which is our own.

Test Your Understanding

1. D 2. C 3. B 4. C 5. D 6. A

8. (a) Because brain size tends to increase consistently in such lineages, we can conclude that natural selection favored the evolution of larger brains and hence that the benefits outweighed the costs. (b) As long as the benefits of brains that are large relative to body size are greater than the costs, large brains can evolve. Natural selection might favor the evolution of brains that are large relative to body size because such brains confer an advantage in obtaining mates and/or an advantage in survival.

(c)



Mortality tends to be lower in birds with larger brains.

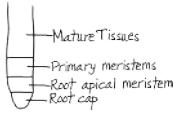
Chapter 35

Figure Questions

Figure 35.5 All three examples have nodes because they're all stems. The nodes are the locations where the axillary buds arise.

Figure 35.11

(1)



(2)



As a result of the addition of secondary xylem cells, the vascular cambium is pushed farther to the outside.

Figure 35.15

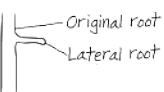
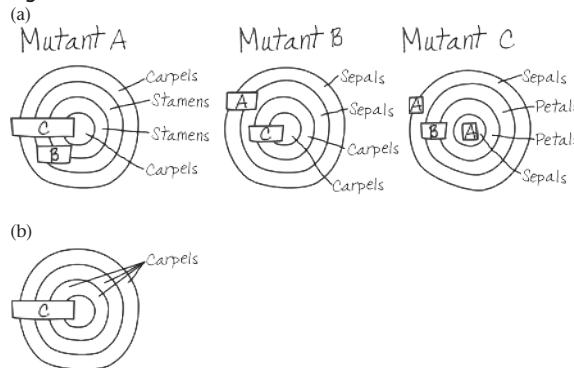
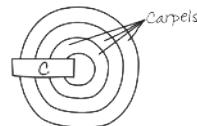


Figure 35.17 Pith and cortex are defined, respectively, as ground tissue that is internal and ground tissue that is external to vascular tissue. Since vascular bundles of monocot stems are scattered throughout the ground tissue, there is no clear distinction between internal and external relative to the vascular tissue. **Figure 35.19** The vascular cambium produces growth that increases the diameter of a stem or root. The tissues that are exterior to the vascular cambium cannot keep pace with the growth because their cells no longer divide. As a result, these tissues rupture. **Figure 35.23** Periderm (mainly cork and cork cambium), primary phloem, secondary phloem, vascular cambium, secondary xylem (sapwood and heartwood), primary xylem, and pith. At the base of ancient redwood that is many centuries old, the remnants of primary growth (primary phloem, primary xylem, and pith) would be quite insignificant. **Figure 35.30** Every root epidermal cell would develop a root hair. **Figure 35.32** Another example of homeotic gene mutation is the mutation in a *Hox* gene that causes legs to form in place of antennae in *Drosophila* (see Figure 18.20).

Figure 35.33



(b)



Concept Check 35.1

1. The vascular tissue system connects leaves and roots, allowing sugars to move from leaves to roots in the phloem and allowing water and minerals to move to the leaves in the xylem. **2.** To get sufficient energy from photosynthesis, we would need lots of surface area exposed to the sun. This large surface-to-volume ratio, however, would create a new problem—evaporative water loss. We would have to be permanently connected to a water source—the soil, also our source of minerals. In short, we would probably look and behave very much like plants. **3.** As plant cells enlarge, they typically form a huge central vacuole that contains a dilute, watery sap. Central vacuoles enable plant cells to become large with only a minimal investment of new cytoplasm. The orientation of the cellulose microfibrils in plant cell walls affects the growth pattern of cells.

Concept Check 35.2

1. Yes. In a woody plant, secondary growth is occurring in the older parts of the stem and root, while primary growth is occurring at the root and shoot tips. **2.** The largest, oldest leaves would be lowest on the shoot. Since they would probably be heavily shaded, they would not photosynthesize much regardless of their size. Determinate growth benefits the plant by keeping it from investing an ever-increasing amount of resources into organs that provide little photosynthetic product. **3.** No. The carrot roots will probably be smaller at the end of the second year because the food stored in the roots will be used to produce flowers, fruits, and seeds.

Concept Check 35.3

1. In roots, primary growth occurs in three successive stages, moving away from the tip of the root: the zones of cell division, elongation, and differentiation. In shoots, it occurs at the tip of apical buds, with leaf primordia arising along the sides of an apical meristem. Most growth in length occurs in older internodes below the shoot tip. **2.** The fossil probably came from a floating leaf because having stomata exclusively on the upper surface would be a poor adaptation for a desert plant since it would lead to water loss. A floating leaf, on the other hand, would benefit from having stomata on its upper surface since only that surface is in contact with the gaseous environment. **3.** Root hairs are cellular extensions that increase the surface area of the root epidermis, thereby enhancing the absorption of minerals and water. Microvilli are extensions that increase the absorption of nutrients by increasing the surface area of the gut.

Concept Check 35.4

1. The sign will still be 2 m above the ground because this part of the tree is no longer growing in length (primary growth); it is now growing only in thickness (secondary growth). **2.** Stomata must be able to close because evaporation is much more intensive from leaves than from the trunks of woody trees as a result of the higher surface-to-volume ratio in leaves. **3.** Since there is little seasonal temperature variation in the tropics, the growth rings of a tree from the tropics would be difficult to discern unless the tree came from an area that had pronounced wet and dry seasons. **4.** The tree would die slowly. Girdling removes an entire ring of secondary phloem (part of the bark), completely preventing transport of sugars and starches from the shoots to the roots. After several weeks, the roots would have used all of their stored carbohydrate reserves and would die.

Concept Check 35.5

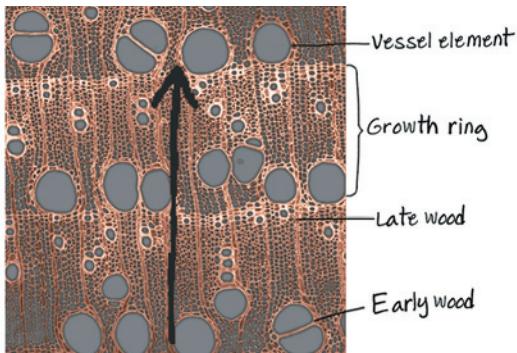
1. Although all the living vegetative cells of a plant have the same genome, they develop different forms and functions because of differential gene expression. **2.** Plants show indeterminate growth; juvenile and mature phases are found on the same individual plant; and cell differentiation in plants is more dependent on final position than on lineage. **3.** One hypothesis is that tepals arise if *B* gene activity is present in all three of the outer whorls of the flower.

Summary of Key Concepts Questions

35.1 Here are a few examples: The cuticle of leaves and stems protects these structures from desiccation. Collenchyma and sclerenchyma cells have thick walls that provide support for plants. Strong, branching root systems help anchor plants in the soil. **35.2** Primary growth arises from apical meristems and involves production and elongation of organs. Secondary growth arises from lateral meristems and adds to the diameter of roots and stems. **35.3** Lateral roots emerge from the pericycle and destroy plant cells as they emerge. In stems, branches arise from axillary buds and do not destroy any cells. **35.4** With the evolution of secondary growth, plants were able to grow taller and shade competitors. **35.5** The orientation of cellulose microfibrils in the innermost layers of the cell wall causes growth along one axis. Microtubules in the cell's outermost cytoplasm play a key role in regulating the axis of cell expansion because it is their orientation that determines the orientation of cellulose microfibrils.

Test Your Understanding

1.D 2.C 3.C 4.A 5.D 6.C 7.D 8.B 9.D 10.D
11.



- 12.** The tea and iris leaves differ in the arrangement of photosynthetic mesophyll cells. In the tea leaf, the mesophyll cells are divided into two layers, with the lower part of the leaf having a loosely arranged spongy layer with large air spaces, and the upper part having a palisade layer of tightly packed cells. In contrast, the mesophyll cells in the iris leaf are evenly distributed with no large air spaces. These differences are associated with the natural orientation of the leaves of these two species. Tea leaves are horizontally oriented and are more likely to receive light on the upper surface, so most of the mesophyll cells are concentrated in a palisade layer to absorb light efficiently. In contrast, iris leaves are vertically oriented with both sides illuminated about equally during the course of the day, so the mesophyll cells are evenly distributed. In both leaves, structure fits function because the arrangement of mesophyll cells maximizes photosynthesis.
- 13.** Pranksters must have been carried the bicycle high into the tree and threaded it over a young woody branch. Primary growth did not raise the bicycle off the ground. Over time, secondary growth in the region of the tree notch enveloped the bicycle.

Chapter 36**Figure Questions**

Figure 36.2 There would be no reference to photosynthesis because it ceases at night. Also, the directions of the CO₂ and O₂ arrows associated with the leaves would be reversed because at night only the gas exchange related to cellular respiration is occurring. **Figure 36.3** The leaves are being produced in a counterclockwise spiral. The next leaf primordium will emerge approximately between and to the inside of leaves 8 and 13. **Figure 36.4** A higher leaf area index will not necessarily increase photosynthesis because of upper leaves shading lower leaves. **Figure 36.6** A proton pump inhibitor would depolarize (increase) the membrane potential because fewer hydrogen ions would be pumped out across the plasma membrane. The immediate effect of an inhibitor of the H⁺/sucrose transporter would be to hyperpolarize (decrease) the membrane potential because fewer hydrogen ions would be leaking back into the cell through these cotransporters. An inhibitor of the H⁺/NO₃⁻ cotransporter would have no effect on the membrane potential because the simultaneous cotransport of a positively charged ion and a negatively charged ion has no net effect on charge difference across the membrane. An inhibitor of the potassium ion channels would decrease the membrane potential because additional positively charged ions would not be accumulating outside the cell. **Figure 36.8** Few, if any, mesophyll cells are more than three cells from a vein. **Figure 36.9** The Caspary strip blocks water and minerals from moving between endodermal cells or moving around an endodermal cell via the cell's wall. Therefore, water and minerals must pass through an endodermal cell's plasma membrane. **Figure 36.13** A section 500 μm by 300 μm is equal to 150,000 μm² or 0.0015 cm². Since there are five stomata visible in 0.0015 cm², the stomatal density of this bean leaf is approximately 3,333 stomata per square centimeter of leaf surface. **Figure 36.18** Because the xylem is under negative pressure (tension), excising a stylet that had been inserted into a tracheid or vessel element would probably introduce air into the cell. No xylem sap would exude unless positive root pressure was predominant.

Concept Check 36.1

1. Vascular plants must transport minerals and water absorbed by the roots to all the other parts of the plant. They must also transport sugars from sites of production to sites of use. **2.** Increased stem elongation would raise the plant's upper leaves. Erect leaves and reduced lateral branching would make the plant less subject to shading by the encroaching neighbors. **3.** Pruning shoot tips removes apical dominance, resulting in lateral shoots (branches) growing from axillary buds (see Concept 35.3). This branching produces a bushier plant with a higher leaf area index.

Concept Check 36.2

1. The cell's Ψ_p is 0.7 MPa. In a solution with a Ψ of -0.4 MPa, the cell's Ψ_p at equilibrium would be 0.3 MPa. **2.** The cell would still adjust to changes in its osmotic environment, but its responses would be slower. Although aquaporins do not affect the water potential gradient across membranes, they allow for more rapid osmotic adjustments. **3.** If tracheids and vessel elements were alive at maturity, their cytoplasm would impede water movement, preventing rapid long-distance transport. **4.** The protoplasts would burst. Because the cytoplasm has many dissolved solutes, water would enter the protoplast continuously without reaching equilibrium. (When present, the cell wall prevents rupturing by limiting expansion of the protoplast.)

Concept Check 36.3

1. At dawn, a drop is exuded from the rooted stump because the xylem is under positive pressure due to root pressure. At noon, the xylem is under negative pressure (tension) when it is cut, and the xylem sap is pulled back into the rooted stump. Root pressure cannot keep pace with the increased rate of transpiration at noon. **2.** Perhaps greater root mass helps compensate for the lower water permeability of the plasma membranes. **3.** The Caspary strip and tight junctions both prevent movement of fluid between cells.

Concept Check 36.4

1. Stomatal opening at dawn is controlled mainly by light, CO₂ concentration, and a circadian rhythm. Environmental stresses such as drought, high temperature, and wind can stimulate stomata to close during the day. Water deficiency during the peak of the day can trigger release of the plant hormone abscisic acid, which signals guard cells to close stomata. **2.** The activation of the proton pumps of stomatal cells would cause the guard cells to take up K⁺. The increased turgor of the guard cells would lock the stomata open and lead to extreme evaporation from the leaf. **3.** After the flowers are cut, transpiration from any leaves and from the petals (which are modified leaves) will continue to draw water up the xylem. If cut flowers are transferred directly to a vase, air pockets in xylem vessels prevent delivery of water from the vase to the flowers. Cutting stems again underwater, a few centimeters from the original cut, will sever the xylem above the air pocket. The water droplets prevent another air pocket from forming while the flowers are transferred to a vase. **4.** Water molecules are in constant motion, traveling at different speeds. If water molecules gain enough energy, the most energetic molecules near the liquid's surface will have sufficient speed, and therefore sufficient kinetic energy, to leave the liquid in the form of gaseous molecules (water vapor). As the molecules with the highest kinetic energy leave the liquid, the average kinetic energy of the remaining liquid decreases. Because a liquid's temperature is directly related to the average kinetic energy of its molecules, the temperature drops as evaporation proceeds.

Concept Check 36.5

1. In both cases, the long-distance transport is a bulk flow driven by a pressure difference at opposite ends of tubes. Pressure is generated at the source end of a sieve tube by the loading of sugar and resulting osmotic flow of water into the phloem, and this pressure pushes sap from the source end to the sink end of the tube. In contrast, transpiration generates a negative pressure potential (tension) that pulls the ascent of xylem sap. **2.** The main sources are fully grown leaves (producing sugar by photosynthesis) and fully developed storage organs (producing sugar by breakdown of starch). Roots, buds, stems, expanding leaves, and fruits are powerful sinks because they are actively growing. A storage organ may be a sink in the summer when accumulating carbohydrates but a source in the spring when breaking down starch into sugar for growing shoot tips. **3.** Positive pressure, whether it be in the xylem when root pressure predominates or in the sieve-tube elements of the phloem, requires active transport. Most long-distance transport in the xylem depends on bulk flow driven by the negative pressure potential generated ultimately by the evaporation of water from the leaf and does not require living cells. **4.** The spiral slash prevents optimal bulk flow of the phloem sap to the root sinks. Therefore, more phloem sap can move from the source leaves to the fruit sinks, making them sweeter.

Concept Check 36.6

1. Plasmodesmata, unlike gap junctions, have the ability to pass RNA, proteins, and viruses from cell to cell. **2.** Long-distance signaling is critical for the integrated functioning of all large organisms, but the speed of such signaling is much less critical to plants because their responses to the environment, unlike those of animals, do not typically involve rapid movements. **3.** Although this strategy would eliminate the systemic spread of viral infections, it would also severely impact the development of the plants.

Summary of Key Concepts Questions

36.1 Plants with tall shoots and elevated leaf canopies generally had an advantage over shorter competitors. A consequence of the selective pressure for tall shoots was the further separation of leaves from roots. This separation created problems for the transport of materials between root and shoot systems. Plants with xylem cells were more successful at supplying their shoot systems with soil resources (water and minerals). Similarly, those with phloem cells were more successful at supplying sugar sinks with carbohydrates. **36.2** Xylem sap is pulled up the plant by transpiration much more often than it is pushed up the plant by root pressure. **36.3** Hydrogen bonds are necessary for the cohesion of water molecules to each other and for the adhesion of water to other materials, such as cell walls. Both adhesion and cohesion of water molecules are involved in the ascent of xylem sap under conditions of negative pressure. **36.4** Although stomata account for most of the water lost from plants, they are necessary for exchange of gases—for example, for the uptake of carbon dioxide needed for photosynthesis. The loss of water through stomata also drives the long-distance transport of water that brings soil nutrients from roots to the rest of the plant. **36.5** Although the movement of phloem sap depends on bulk flow, the pressure gradient that drives phloem transport depends on the osmotic uptake of water in response to the loading of sugars into sieve-tube elements at sugar sources. Phloem loading depends on H⁺ gradients established by active K⁺ pumping. **36.6** Electrical signaling, cytoplasmic pH, cytoplasmic Ca²⁺ concentration, and viral movement proteins all affect symplastic communication, as do developmental changes in the number of plasmodesmata.

Test Your Understanding

1.A 2.B 3.B 4.C 5.B 6.C 7.A 8.D

Chapter 37

Figure Questions

Figure 37.3 Cations. At low pH, there would be more protons (H^+) to displace mineral cations from negatively charged soil particles into the soil solution.

Figure 37.4 The A horizon, which consists of the topsoil **Table 37.1** During photosynthesis, CO_2 is fixed into carbohydrates, which contribute to the dry mass. In cellular respiration, O_2 is reduced to H_2O and does not contribute to the dry mass. **Figure 37.9** Some other examples of mutualism are the following relationships. *Flashlight fish and bioluminescent bacteria*: The bacteria gain nutrients and protection from the fish, while the bioluminescence attracts prey and mates for the fish. *Flowering plants and pollinators*: Animals distribute the pollen and are rewarded by a meal of nectar or pollen. *Vertebrate herbivores and some bacteria in the digestive system*: Microorganisms in the alimentary canal break down cellulose to glucose and, in some cases, provide the animal with vitamins or amino acids. Meanwhile, the microorganisms have a steady supply of food and a warm environment. *Humans and some bacteria in the digestive system*: Some bacteria provide humans with vitamins, while the bacteria get nutrients from the digested food. **Figure 37.11** Both ammonium and nitrate. A decomposing animal would release amino acids into the soil that would be converted into ammonium by ammonifying bacteria. Some of this ammonium could be used directly by the plant. A large part of the ammonium, however, would be converted by nitrifying bacteria to form nitrate ions that could also be absorbed by the plant root system. **Figure 37.12** The legume plants benefit because the bacteria fix nitrogen that is absorbed by their roots. The bacteria benefit because they acquire photosynthetic products from the plants. **Figure 37.13** All three plant tissue systems are affected. Root hairs (dermal tissue) are modified to allow *Rhizobium* penetration. The cortex (ground tissue) and pericycle (vascular tissue) proliferate during nodule formation. The vascular tissue of the nodule connects to the vascular cylinder of the root to allow for efficient nutrient exchange.

Concept Check 37.1

- Overwatering deprives roots of oxygen. Overfertilizing is wasteful and can lead to soil salinization and water pollution.
- As lawn clippings decompose, they restore mineral nutrients to the soil. If they are removed, the minerals lost from the soil must be replaced by fertilization.
- Because of their small size and negative charge, clay particles would increase the number of binding sites for cations and water molecules and would therefore increase cation exchange and water retention in the soil.
- Due to hydrogen bonding between water molecules, water expands when it freezes, and this causes mechanical fracturing of rocks. Water also coheres to many objects, and this cohesion combined with other forces, such as gravity, can help tug particles from rock. Finally, water, because it is polar, is an excellent solvent that allows many substances, including ions, to become dissolved in solution.

Concept Check 37.2

- No. Even though macronutrients are required in greater amounts, all essential elements are necessary for a plant to complete its life cycle.
- No. The fact that the addition of an element results in an increase in the growth rate of a crop does not mean that the element is strictly required for the plant to complete its life cycle.
- Inadequate aeration of the roots of hydroponically grown plants would promote alcohol fermentation, which uses more energy and may lead to the accumulation of ethanol, a toxic by-product of fermentation.

Concept Check 37.3

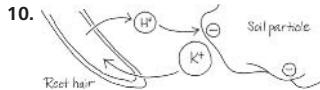
- The rhizosphere is the zone in the soil immediately adjacent to living roots. It harbors many rhizobacteria with which the root systems form beneficial mutualisms. Some rhizobacteria produce antibiotics that protect roots from disease. Others absorb toxic metals or make nutrients more available to roots. Still others convert gaseous nitrogen into forms usable by the plant or produce chemicals that stimulate plant growth.
- Soil bacteria and mycorrhizae enhance plant nutrition by making certain minerals more available to plants. For example, many types of soil bacteria are involved in the nitrogen cycle, and the hyphae of mycorrhizae provide a large surface area for the absorption of nutrients, particularly phosphate ions.
- Mixotrophy refers to the strategy of using photosynthesis and heterotrophy for nutrition. Euglenids are well-known mixotrophic protists.
- Saturating rainfall may deplete the soil of oxygen. A lack of soil oxygen would inhibit nitrogen fixation by the peanut root nodules and decrease the nitrogen available to the plants. Alternatively, heavy rain may leach nitrate from the soil. A symptom of nitrogen deficiency is yellowing of older leaves.

Summary of Key Concepts Questions

- 37.1** The term *ecosystem* refers to the communities of organisms within a given area and their interactions with the physical environment around them. Soil is teeming with many communities of organisms, including bacteria, fungi, animals, and the root systems of plants. The vigor of these individual communities depends on nonliving factors in the soil environment, such as minerals, oxygen, and water, as well as on interactions, both positive and negative, between different communities of organisms.
- 37.2** No. Plants can complete their life cycle when grown hydroponically, that is, in aerated salt solutions containing the proper ratios of all the minerals needed by plants.
- 37.3** No. Some parasitic plants obtain their energy by siphoning off carbon nutrients from other organisms.

Test Your Understanding

- B
- B
- A
- D
- B
- B
- C
- C
- D



Chapter 38

Figure Questions

Figure 38.4 Having a specific pollinator is more efficient because less pollen gets delivered to flowers of the wrong species. However, it is also a risky strategy: If the pollinator population suffers to an unusual degree from predation, disease, or climate change, then the plant may not be able to produce seeds.

Figure 38.6 The part of the angiosperm life cycle characterized by the most mitotic divisions is the step between seed germination and the mature sporophyte.

Figure 38.8 Make Connections In addition to having a single cotyledon, monocots have leaves with parallel leaf venation, scattered vascular bundles in their stems, a fibrous root system, floral parts in threes or multiples of threes, and pollen grains with only one opening. In contrast, eudicots have two cotyledons, netlike leaf venation, vascular bundles in a ring, taproots, floral parts in fours or fives or multiples thereof, and pollen grains with three openings.

Visual Skills The mature garden bean seed lacks an endosperm at maturity. Its endosperm was consumed during seed development, and its nutrients were stored anew in the cotyledons. **Figure 38.9** Beans use a hypocotyl hook to push through the soil. The delicate leaves and shoot apical meristem are also protected by being sandwiched between two large cotyledons. The coleoptile of maize seedlings helps protect the emerging leaves.

Concept Check 38.1

- In angiosperms, pollination is the transfer of pollen from an anther to a stigma. Fertilization is the fusion of the egg and sperm to form the zygote; it cannot occur until after the growth of the pollen tube from the pollen grain.
- Long styles help to weed out pollen grains that are genetically inferior and not capable of successfully growing long pollen tubes.
- No. The haploid (gametophyte) generation of plants is multicellular and arises from spores. The haploid phase of the animal life cycles is a single-celled gamete (egg or sperm) that arises directly from meiosis: There are no spores.

Concept Check 38.2

- Flowering plants can avoid self-fertilization by self-incompatibility, having male and female flowers on separate plants (dioecious species), or having stamens and styles of different heights on separate plants ("pin" and "thrush" flowers).
- Asexually propagated crops lack genetic diversity. Genetically diverse populations are less likely to become extinct in the face of an epidemic because there is a greater likelihood that a few individuals in the population are resistant.
- In the short term, selfing may be advantageous in a population that is so dispersed and sparse that pollen delivery is unreliable. In the long term, however, selfing is an evolutionary dead end because it leads to a loss of genetic diversity that may preclude adaptive evolution.

Concept Check 38.3

- Traditional breeding and genetic engineering both involve artificial selection for desired traits. However, genetic engineering techniques facilitate faster gene transfer and are not limited to transferring genes between closely related varieties or species.
- Bt* maize suffers less insect damage; therefore, *Bt* maize plants are less likely to be infected by fumonisin-producing fungi that infect plants through wounds.
- In such species, engineering the transgene into the chloroplast DNA would not prevent its escape in pollen; such a method requires that the chloroplast DNA be found only in the egg. An entirely different method of preventing transgene escape would therefore be needed, such as male sterility, apomixis, or self-pollinating closed flowers.

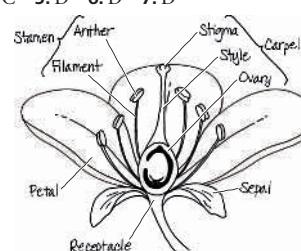
Summary of Key Concepts Questions

- 38.1** After pollination and fertilization, a flower changes into a fruit. The petals, sepals, and stamens typically fall off the flower. The stigma of the pistil withers, and the ovary begins to swell. The ovules (embryonic seeds) inside the ovary begin to mature.
- 38.2** Asexual reproduction can be advantageous in a stable environment because individual plants that are well suited to that environment pass on all their genes to offspring. Also, asexual reproduction generally results in offspring that are less fragile than the seedlings produced by sexual reproduction. However, sexual reproduction offers the advantage of dispersal of tough seeds. Moreover, sexual reproduction produces genetic variety, which may be advantageous in an unstable environment. The likelihood is better that at least one offspring of sexual reproduction will survive in a changed environment.
- 38.3** "Golden Rice," although not yet in commercial production, has been engineered to produce more vitamin A, thereby raising the nutritional value of rice. A protoxin gene from a soil bacterium has been engineered into *Bt* maize. This protoxin is lethal to invertebrates but harmless to vertebrates. *Bt* crops require less pesticide spraying and have lower levels of fungal infection and fungal toxins. The nutritional value of cassava is being increased in many ways by genetic engineering. Enriched levels of iron and beta-carotene (a vitamin A precursor) have been achieved, and cyanide-producing chemicals have been almost eliminated from the roots.

Test Your Understanding

- A
- C
- C
- C
- D
- D
- D

8.



Chapter 39

Figure Questions

Figure 39.4 Panel B in Figure 11.17 shows a branching signal transduction pathway that resembles the branching phytochrome-dependent pathway involved in de-etiolation. **Figure 39.5** To determine which wavelengths of light are most effective in phototropism, you could use a glass prism to split white light into its component colors and see which colors cause the quickest bending (the answer is blue; see Figure 39.15). **Figure 39.6** No. Polar auxin transport depends on the distribution of auxin transport proteins at the basal ends of cells. **Figure 39.13** No. Since the *ein* mutation renders the seedling “blind” to ethylene, enhancing ethylene production by adding an *eto* mutation would have no effect on phenotype compared with the *ein* mutation alone. **Figure 39.16** Yes. The white light, which contains red light, would stimulate seed germination in all treatments. **Figure 39.20** Since far-red light, like darkness, causes an accumulation of the red-absorbing form (P_r) of phytochrome, single flashes of far-red light at night would have no effect on flowering beyond what the dark periods alone would have. **Figure 39.21** If this were true, then florigen would be an inhibitor of flowering, not an inducer. **Figure 39.27** Photosynthetic adaptations can occur at the molecular level, as is apparent in the fact that C_3 plants use rubisco to fix carbon dioxide initially, whereas C_4 and CAM plants use PEP carboxylase. An adaptation at the tissue level is that plants have different stomatal densities based on their genotype and environmental conditions. At the organismal level, plants alter their shoot architectures to make photosynthesis more efficient. For example, self-pruning removes branches and leaves that respire more than they photosynthesize.

Concept Check 39.1

1. Dark-grown seedlings are etiolated: They have long stems, underdeveloped root systems, and unexpanded leaves, and their shoots lack chlorophyll. Etiolated growth is beneficial to seeds sprouting under the dark conditions they would encounter underground. By devoting more energy to stem elongation and less to leaf expansion and root growth, a plant increases the likelihood that the shoot will reach the sunlight before its stored foods run out.
2. Cycloheximide should inhibit de-etiolation by preventing the synthesis of new proteins necessary for de-etiolation.
3. No. Applying Viagra, like injecting cyclic GMP as described in the text, should cause only a partial de-etiolation response. Full de-etiolation would require activation of the calcium branch of the signal transduction pathway.

Concept Check 39.2

1. Fusicoccin's ability to cause an increase in plasma H^+ pump activity has an auxin-like effect and promotes stem cell elongation.
2. The plant will exhibit a constitutive triple response. Because the kinase that normally prevents the triple response is dysfunctional, the plant will undergo the triple response regardless of whether ethylene is present or the ethylene receptor is functional.
3. Since ethylene often stimulates its own synthesis, it is under positive-feedback regulation.

Concept Check 39.3

1. Not necessarily. Many environmental factors, such as temperature and light, change over a 24-hour period in the field. To determine whether the enzyme is under circadian control, a scientist would have to demonstrate that its activity oscillates even when environmental conditions are held constant.
2. It is impossible to say. To establish that this species is a short-day plant, it would be necessary to establish the critical night length for flowering and that this species only flowers when the night is longer than the critical night length.
3. According to the action spectrum of photosynthesis, red and blue light are the most effective in photosynthesis. Thus, it is not surprising that plants assess their light environment using blue- and red-light-absorbing photoreceptors.

Concept Check 39.4

1. A plant that overproduces ABA would undergo less evaporative cooling because its stomata would not open as widely.
2. Plants close to the aisles may be more subject to mechanical stresses caused by passing workers and air currents. The plants nearer the center of the bench may also be taller as a result of shading and less evaporative stress.
3. No. Because root caps are involved in sensing gravity, roots that have their root caps removed are almost completely insensitive to gravity.

Concept Check 39.5

1. An infection can trigger the hypersensitive response, which causes a ring of cell death around the infection site, thereby isolating the pathogen from living host cells and preventing systemic infection.
2. Mechanical damage breaches a plant's first line of defense against infection, its protective dermal tissue.
3. No. Pathogens that kill their hosts would soon run out of victims and might themselves go extinct.
4. Perhaps the breeze dilutes the local concentration of a volatile defense compound that the plants produce.

Summary of Key Concepts Questions

- 39.1** Signal transduction pathways often activate protein kinases, enzymes that phosphorylate other proteins. Protein kinases can directly activate certain preexisting enzymes by phosphorylating them, or they can regulate gene transcription (and enzyme production) by phosphorylating specific transcription factors.
- 39.2** Yes, there is truth to the old adage that one bad apple spoils the whole bunch. Ethylene, a gaseous hormone that stimulates ripening, is produced by damaged, infected, or overripe fruits. Ethylene can diffuse to healthy fruit in the “bunch” and stimulate their rapid ripening.
- 39.3** Plant physiologists proposed the existence of a floral-promoting factor (florigen) based on the fact that a plant induced to flower could induce flowering in a second plant to which it was grafted, even though the second plant was not in an environment that would normally induce flowering in that species.
- 39.4** Plants subjected to drought stress are often more resistant to freezing stress because the two types of stress are quite similar. Freezing of water in

the extracellular spaces causes free water concentrations outside the cell to decrease. This, in turn, causes free water to leave the cell by osmosis, leading to the dehydration of cytoplasm, much like what is seen in drought stress.

39.5 Chewing insects make plants more susceptible to pathogen invasion by disrupting the waxy cuticle of shoots, thereby creating an opening for infection. Moreover, substances released from damaged cells can serve as nutrients for the invading pathogens.

Test Your Understanding

1. B 2. C 3. D 4. C 5. B 6. B 7. C
8.

	Control	Ethylene added	Ethylene synthesis inhibitor
Wild-type	1	2	1
Ethylene insensitive (<i>ein</i>)	1	1	1
Ethylene overproducing (<i>eto</i>)	2	2	1
Constitutive triple response (<i>ctr</i>)	2	2	2

Chapter 40

Figure Questions

Figure 40.4 Such exchange surfaces are internal in the sense that they are inside the body. However, they are also continuous with openings on the external body surface that contact the environment. **Figure 40.6** Signals in the nervous system always travel on a direct route between the sending and receiving cell. In contrast, hormones that reach target cells can have an effect regardless of the path by which they arrive or how many times they travel through the circulatory system. **Figure 40.8** The stimuli (gray boxes) are the room temperature increasing in the top loop and decreasing in the bottom loop. The responses could include the heater turning off and the temperature decreasing in the top loop and the heater turning on and the temperature increasing in the bottom loop. The sensor/control center is the thermostat. The air conditioner would form a second control circuit, cooling the house when air temperature exceeded the set point. Such opposing, or antagonistic, pairs of control circuits increase the effectiveness of a homeostatic mechanism. **Figure 40.12** The conduction arrows would be in the opposite direction, transferring heat from the penguin to the ice because the penguin is warmer than the ice. **Figure 40.16** If a female Burmese python were not incubating eggs, her oxygen consumption would decrease with decreasing temperature, as for any other ectotherm. **Figure 40.17** The ice water would cool tissues in your head, including blood that would then circulate throughout your body. This effect would accelerate the return to a normal body temperature. If, however, the ice water reached the eardrum and cooled the blood vessel that supplies the hypothalamus, the hypothalamic thermostat would respond by inhibiting sweating and constricting blood vessels in the skin, slowing cooling elsewhere in the body. **Figure 40.18** The transport of nutrients across membranes and the synthesis of RNA and protein are coupled to ATP hydrolysis. These processes proceed spontaneously because there is an overall drop in free energy, with the excess energy given off as heat. Similarly, less than half of the free energy in glucose is captured in the coupled reactions of cellular respiration. The remainder of the energy is released as heat. **Figure 40.22** Nothing. Although genes that show a circadian variation in expression during euthermia exhibit constant RNA levels during hibernation, a gene that shows constant expression during hibernation might also show constant expression during euthermia. **Figure 40.23** In hot environments, both plants and animals experience evaporative cooling as a result of transpiration (in plants) or bathing, sweating, and panting (in animals); both plants and animals synthesize heat-shock proteins, which protect other proteins from heat stress; and animals also use various behavioral responses to minimize heat absorption. In cold environments, both plants and animals increase the proportion of unsaturated fatty acids in their membrane lipids and use antifreeze proteins that prevent or limit the formation of intracellular ice crystals; plants increase cytoplasmic levels of specific solutes that help reduce the loss of intracellular water during extracellular freezing; and animals increase metabolic heat production and use insulation, circulatory adaptations such as countercurrent exchange, and behavioral responses to minimize heat loss.

Concept Check 40.1

1. All types of epithelia consist of cells that line a surface, are tightly packed, are situated on top of a basal lamina, and form an active and protective interface with the external environment.
2. An oxygen molecule must cross a plasma membrane when entering the body at an exchange surface in the respiratory system, in both entering and exiting the circulatory system, and in moving from the interstitial fluid to the cytoplasm of the body cell.
3. You need the nervous system to perceive the danger and provoke a split-second muscular response to keep from falling. The nervous system, however, does not make a direct connection with blood vessels or glucose-storing cells in the liver. Instead, the nervous system triggers the release of a hormone (called epinephrine, or adrenaline) by the endocrine system, bringing about a change in these tissues in just a few seconds.

Concept Check 40.2

1. In thermoregulation, the product of the pathway (a change in temperature) decreases pathway activity by reducing the stimulus. In an enzyme-catalyzed biosynthetic process, the product of the pathway (in this case, isoleucine) inhibits the pathway that generated it.
2. You would want to put the thermostat close to

where you would be spending time, where it would be protected from environmental perturbations, such as direct sunshine, and not right in the path of the output of the heating system. Similarly, the sensors for homeostasis located in the human brain are separated from environmental influences and can monitor conditions in a vital and sensitive tissue. **3.** In convergent evolution, the same biological trait arises independently in two or more species. Gene analysis can provide evidence for an independent origin. In particular, if the genes responsible for the trait in one species lack significant sequence similarity to the corresponding genes in another species, scientists conclude that there is a separate genetic basis for the trait in the two species and thus an independent origin. In the case of circadian rhythms, the clock genes in cyanobacteria appear unrelated to those in humans.

Concept Check 40.3

1. “Wind chill” involves heat loss through convection, as the moving air contributes to heat loss from the skin surface. **2.** The hummingbird, being a very small endotherm, has a very high metabolic rate. If by absorbing sunlight certain flowers warm their nectar, a hummingbird feeding on these flowers is saved the metabolic expense of warming the nectar to its body temperature. **3.** To raise body temperature to the higher range of fever, the hypothalamus triggers heat generation by muscular contractions, or shivering. The person with a fever may in fact say that they feel cold, even though their body temperature is above normal.

Concept Check 40.4

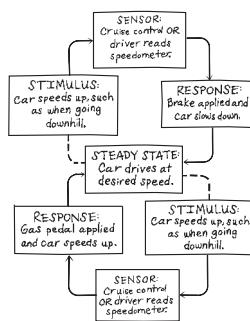
1. The mouse would consume oxygen at a higher rate because it is an endotherm, so its basal metabolic rate is higher than the ectothermic lizard’s standard metabolic rate. **2.** The house cat; smaller animals have a higher metabolic rate per unit body mass and a greater demand for food per unit body mass. **3.** The alligator’s body temperature would decrease along with the air temperature. Its metabolic rate would therefore also decrease as chemical reactions slowed. In contrast, the lion’s body temperature would not change. Its metabolic rate would increase as it shivered and produced heat to keep its body temperature constant.

Summary of Key Concepts Questions

40.1 Animals exchange materials with their environment across their body surface, and a spherical shape has the minimum surface area per unit volume. As body size increases, the ratio of surface area to body volume decreases. **40.2** No; an animal’s internal environment fluctuates slightly around set points or within normal ranges. Homeostasis is a dynamic state. Furthermore, there are sometimes programmed changes in set points, such as those resulting in radical increases in hormone levels at particular times in development. **40.3** Heat exchange across the skin is a primary mechanism for the regulation of body core temperature, with the result that the skin is cooler than the body core. **40.4** Small animals have a higher BMR per unit mass and therefore consume more oxygen per unit mass than large animals. A higher breathing rate is required to support this increased oxygen consumption.

Test Your Understanding

- 1.B 2.C 3.A 4.B 5.C 6.B 7.D
8.



Chapter 41

Figure Questions

Figure 41.6 Your diagram should show food entering through the hydra’s mouth and being digested into nutrients in the large portion of the gastrovascular cavity. The nutrients then diffuse into the extensions of that cavity that reach into the tentacles. There, nutrients would be absorbed by cells of the gastrodermis and transported to cells of the epidermis of a tentacle. **Figure 41.9** The airway must be open for exhaling to occur. If the epiglottis is up, water that entered the throat from the mouth encounters air forced out of the lungs and is carried along into the nasal cavity and out the nose. **Figure 41.11** Since enzymes are proteins, and proteins are hydrolyzed in the small intestine, the digestive enzymes in that compartment need to be resistant to enzymatic cleavage other than the cleavage required to activate them. **Figure 41.12** None. Since digestion is completed in the small intestine, tapeworms simply absorb predigested nutrients through their large body surface. **Figure 41.13** Yes. The exit of the chylomicrons involves exocytosis, an active process that consumes energy in the form of ATP. In contrast, the entry of monoglycerides and fatty acids into the cell by diffusion is a passive process that does not consume energy. **Figure 41.23** Both insulin and glucagon are involved in negative feedback circuits.

Concept Check 41.1

- 1.** The only essential amino acids are those that an animal cannot synthesize from other molecules. **2.** Many vitamins serve as enzyme cofactors, which, like enzymes themselves, are unchanged by the chemical reactions in which they participate. Therefore, only very small amounts of vitamins are needed. **3.** To

identify the essential nutrient missing from an animal’s diet, a researcher could supplement the diet with individual nutrients one at a time and determine which nutrient eliminates the signs of malnutrition.

Concept Check 41.2

1. A gastrovascular cavity is a digestive pouch with a single opening that functions in both ingestion and elimination; an alimentary canal is a digestive tube with a separate mouth and anus at opposite ends. **2.** As long as nutrients are within the cavity of the alimentary canal, they are in a compartment that is continuous with the outside environment via the mouth and anus and have not yet crossed a membrane to enter the body. **3.** In both cases, high-energy fuels are consumed, complex molecules are broken down into simpler ones, and waste products are eliminated. In addition, gasoline, like food, is broken down in a specialized compartment, so that surrounding structures are protected from disassembly. Finally, just as food and wastes remain outside the body in a digestive tract, neither gasoline nor its waste products enter the passenger compartment of the automobile.

Concept Check 41.3

1. Because parietal cells in the stomach pump hydrogen ions into the stomach lumen where they combine with chloride ions to form HCl, a proton pump inhibitor reduces the acidity of chyme and thus the irritation that occurs when chyme enters the esophagus. **2.** Bile acids act as emulsifiers, dispersing large fat globules into smaller fat droplets. The lipid-soluble surfaces of the bile acids bind to the fat droplets and the water-soluble surfaces of the bile acids interact with the digestive fluids. As a result, surface tension is reduced and the droplets are stabilized, facilitating enzymatic digestion of fats by lipases. **3.** Proteins would be denatured and digested into peptides. Further digestion, to individual amino acids, would require enzymatic secretions found in the small intestine. No digestion of carbohydrates or lipids would occur.

Concept Check 41.4

1. The increased time for transit through the alimentary canal allows for more extensive processing, and the increased surface area of the canal provides greater opportunity for absorption. **2.** A mammal’s digestive system provides mutualistic microorganisms with an environment that is protected against other microorganisms by saliva and gastric juice, that is held at a constant temperature conducive to enzyme action, and that provides a steady source of nutrients. **3.** For the yogurt treatment to be effective, the bacteria from yogurt would have to establish a mutualistic relationship with the small intestine, where disaccharides are broken down and sugars are absorbed. Conditions in the small intestine are likely to be very different from those in a yogurt culture. The bacteria might be killed before they reach the small intestine, or they might not be able to grow there in sufficient numbers to aid in digestion.

Concept Check 41.5

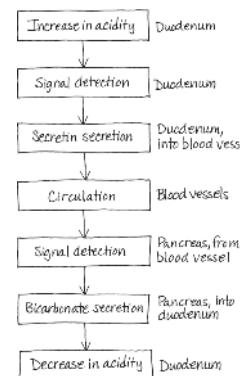
1. Over the long term, the body stores excess calories in fat, whether those calories come from fat, carbohydrate, or protein in food. **2.** In most individuals, leptin levels decline during fasting. Individuals in the group with low levels of leptin are likely to be unable to produce leptin, so leptin levels would remain low regardless of food intake. Individuals in the group with high leptin levels are likely to be unable to respond to leptin, but they still should shut off leptin production as fat stores are used up. **3.** Excess insulin production will cause the blood glucose level to decrease below normal physiological levels. It will also trigger glycogen synthesis in the liver, further decreasing the blood glucose level. However, a low blood glucose level will stimulate the release of glucagon from alpha cells in the pancreas, which will trigger glycogen breakdown. Thus, there will be antagonistic effects in the liver.

Summary of Key Concepts Questions

41.1 Since the cofactor is necessary in all animals, those animals that do not require it in their diet must be able to synthesize it from other organic molecules. **41.2** A liquid diet containing glucose, amino acids, and other building blocks could be ingested and absorbed without the need for mechanical or chemical digestion. **41.3** The small intestine has a much larger surface area than the stomach. **41.4** The assortment of teeth in our mouth and the short length of our cecum suggest that our ancestors’ digestive systems were not specialized for digesting plant material. **41.5** When mealtime arrives, nervous inputs from the brain signal the stomach to prepare to digest food through secretions and churning.

Test Your Understanding

- 1.B 2.A 3.B 4.B 5.B 6.D 7.B
8.



Chapter 42

Figure Questions

Figure 42.2 Although gas exchange might be improved by a steady, one-way flow of fluid, there would likely be inadequate time for food to be digested and nutrients absorbed if fluid flowed through the cavity in this manner.

Figure 42.5 Two capillary beds. The molecule of carbon dioxide would need to enter a capillary bed in the thumb before returning to the right atrium and ventricle, then travel to the lung and enter a capillary from which it could diffuse into an alveolus and be available to be exhaled. **Figure 42.8** Each feature of the ECG recording, such as the sharp upward spike, occurs once per cardiac cycle. Using the x-axis to measure the time in seconds between successive spikes and dividing that number by 60 would yield the heart rate as the number of cycles per minute. **Figure 42.25** The reduction in surface tension results from the presence of surfactant. Therefore, for all the infants who had died of RDS, you would expect the amount of surfactant to be near zero. For infants who had died of other causes, you would expect the amount of surfactant to be near zero for body masses less than 1,200 g but much greater than zero for body masses above 1,200 g.

Figure 42.27 Since exhalation is largely passive, the recoil of the elastic fibers in alveoli helps force air out of the lungs. When alveoli lose their elasticity, as occurs in the disease emphysema, less air is exhaled. Because more air is left in the lungs, less fresh air can be inhaled. With a smaller volume of air exchanged, there is a decrease in the partial pressure gradient that drives gas exchange.

Figure 42.28 Breathing at a rate greater than that needed to meet metabolic demand (hyperventilation) would lower the blood CO_2 level. Sensors in major blood vessels and the medulla would signal the breathing control center to decrease the rate of contraction of the diaphragm and rib muscles, decreasing the breathing rate and restoring normal CO_2 level in the blood and other tissues.

Figure 42.29 The resulting increase in tidal volume would enhance ventilation within the lungs, increasing P_{O_2} and decreasing P_{CO_2} in the alveoli.

Concept Check 42.1

1. In both an open circulatory system and a fountain, fluid is pumped through a tube and then returns to the pump after collecting in a pool. 2. The ability to shut off blood supply to the lungs when the animal is submerged 3. The O_2 content would be abnormally low because some oxygen-depleted blood returned to the right atrium from the systemic circuit would mix with the oxygen-rich blood in the left atrium.

Concept Check 42.2

1. The pulmonary veins carry blood that has just passed through capillary beds in the lungs, where it accumulated O_2 . The venae cavae carry blood that has just passed through capillary beds in the rest of the body, where it lost O_2 to the tissues. 2. The delay allows the atria to empty completely, filling ventricles fully before they contract. 3. The heart, like any other muscle, becomes stronger through regular exercise. You would expect a stronger heart to have a greater stroke volume, which would allow for the decrease in heart rate.

Concept Check 42.3

1. The large total cross-sectional area of the capillaries 2. An increase in blood pressure and cardiac output combined with the diversion of more blood to the skeletal muscles would increase the capacity for action by increasing the rate of blood circulation and delivering more O_2 and nutrients to the skeletal muscles. 3. Additional hearts could be used to improve blood return from the legs. However, it might be difficult to coordinate the activity of multiple hearts and to maintain adequate blood flow to hearts far from the gas exchange organs.

Concept Check 42.4

1. An increase in the number of white blood cells (leukocytes) may indicate that the person is combating an infection. 2. Clotting factors do not initiate clotting but are essential steps in the clotting process. 3. The chest pain results from inadequate blood flow in coronary arteries. Vasodilation promoted by nitric oxide from nitroglycerin increases blood flow, providing the heart muscle with additional oxygen and thus relieving the pain. 4. Embryonic stem cells are pluripotent rather than multipotent, meaning they can give rise to many rather than a few different cell types.

Concept Check 42.5

1. Their interior position helps gas exchange tissues stay moist. If the respiratory surfaces of lungs extended into the terrestrial environment, they would quickly dry out, and diffusion of O_2 and CO_2 across these surfaces would stop. 2. Earthworms need to keep their skin moist for gas exchange, but they need air outside this moist layer. If they stay in their waterlogged tunnels after a heavy rain, they will suffocate because they cannot get as much O_2 from water as from air. 3. In fish, water passes over the gills in the direction opposite to that of blood flowing through the gill capillaries, maximizing the extraction of oxygen from the water along the length of the exchange surface. Similarly, in the extremities of some vertebrates, blood flows in opposite directions in neighboring veins and arteries; this countercurrent arrangement maximizes the recapture of heat from blood leaving the body core in arteries, which is important for thermoregulation in cold environments.

Concept Check 42.6

1. An increase in blood CO_2 concentration causes an increase in the rate of CO_2 diffusion into the cerebrospinal fluid, where the CO_2 combines with water to form carbonic acid. Dissociation of carbonic acid releases hydrogen ions, decreasing the pH of the cerebrospinal fluid. 2. Increased heart rate increases the rate at which CO_2 -rich blood is delivered to the lungs, where CO_2 is removed. 3. A hole would allow air to enter the space between the inner and

outer layers of the double membrane, resulting in a condition called a pneumothorax. The two layers would no longer stick together, and the lung on the side with the hole would collapse and cease functioning.

Concept Check 42.7

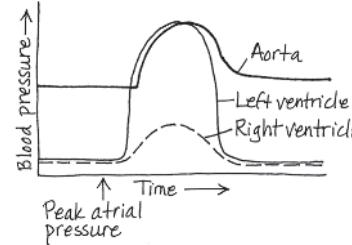
1. Differences in partial pressure between the capillaries and the surrounding tissues or medium; the net diffusion of a gas occurs from a region of higher partial pressure to a region of lower partial pressure. 2. The Bohr shift causes hemoglobin to release more O_2 at a lower pH, such as is found in the vicinity of tissues with high rates of cellular respiration and CO_2 release. 3. The doctor is assuming that the rapid breathing is the body's response to low blood pH. Metabolic acidosis, the lowering of blood pH as a result of metabolism, can have many causes, including complications of certain types of diabetes, shock (extremely low blood pressure), and poisoning.

Summary of Key Concepts Questions

42.1 In a closed circulatory system, an ATP-driven muscular pump generally moves fluids in one direction on a scale of millimeters to meters. Exchange between cells and their environment relies on diffusion, which involves random movements of molecules. Concentration gradients of molecules across exchange surfaces can drive rapid net diffusion on a scale of 1 mm or less. **42.2** Replacement of a defective valve should increase stroke volume. A lower heart rate would therefore be sufficient to maintain the same cardiac output. **42.3** Blood pressure in the arm would fall by 25–30 mm Hg, the same difference as is normally seen between your heart and your brain. **42.4** One microliter of blood contains about 5 million erythrocytes and 5,000 leukocytes, so leukocytes make up only about 0.1% of the cells in the absence of infection. **42.5** Because CO_2 is such a small fraction of atmospheric gas (0.29 mm Hg/760 mm Hg, or less than 0.04%), the partial pressure gradient of CO_2 between the respiratory surface and the environment always strongly favors the release of CO_2 to the atmosphere. **42.6** Because the lungs do not empty completely with each breath, incoming and outgoing air mix. Lungs thus contain a mixture of fresh and stale air. **42.7** An enzyme speeds up a reaction without changing the equilibrium and without being consumed. Similarly, a respiratory pigment speeds up the exchange of gases between the body and the external environment without changing the equilibrium state and without being consumed.

Test Your Understanding

1. C 2. A 3. D 4. C 5. C 6. A 7. A
8.



Chapter 43

Figure Questions

Figure 43.3 Dicer-2 binds double-stranded RNA without regard to size or sequence and then cuts that RNA into fragments, each 21 base pairs long. The Argo complex binds to double-stranded RNA fragments that are each 21 base pairs long, displaces one strand, and then uses the remaining strand to match to a particular target sequence in a single-stranded mRNA. **Figure 43.4** Cell-surface TLRs recognize molecules on the surface of pathogens, whereas TLRs in vesicles recognize internal molecules of pathogens after the pathogens are broken down.

Figure 43.5 Because the pain of a splinter stops almost immediately when you remove it from the skin, you can correctly deduce that the signals that mediate the inflammatory response are quite short-lived. **Figure 43.10** Part of the enzyme or antigen receptor provides a structural "backbone" that maintains overall shape, while interaction occurs at a surface with a close fit to the substrate or antigen. The combined effect of multiple noncovalent interactions at the active site or binding site is a high-affinity interaction of tremendous specificity.

Figure 43.14 After gene rearrangement, a lymphocyte and its daughter cells make a single version of the antigen receptor. In contrast, alternative splicing is not heritable and can give rise to diverse gene products in a single cell. **Figure 43.16** A single B cell has more than 100,000 identical antigen receptors on its surface, not four, and there are more than 1 million B cells differing in their antigen specificity, not three. **Figure 43.19** These receptors enable memory cells to present antigen on their cell surface to a helper T cell. This presentation of antigen is required to activate memory cells in a secondary immune response. **Figure 43.23** Primary response: arrows extending from Antigen (1st exposure), Antigen-presenting cell, Helper T cell, B cell, Plasma cells, Cytotoxic T cell, and Active cytotoxic T cells; secondary response: arrows extending from Antigen (2nd exposure), Memory helper T cells, Memory B cells, Memory cytotoxic T cells, Plasma cells, and Active cytotoxic T cells. **Figure 43.25** There would be no change in the results. Because the two antigen-binding sites of an antibody have identical specificity, the two bacteriophages bound would have to display the same viral peptide.

Concept Check 43.1

1. Because pus contains white blood cells, fluid, and cell debris, it indicates an active and at least partially successful inflammatory response against invading pathogens. 2. Whereas the ligand for the TLR receptor is a foreign molecule, the ligand for many signal transduction pathways is a molecule produced by the organism itself. 3. Mounting an immune response would require recognition of some molecular feature of the wasp egg not found in the host. It might be that only some potential hosts have a receptor with the necessary specificity.

Concept Check 43.2

1. See Figure 43.9. The transmembrane regions lie within the C regions, which also form the disulfide bridges. In contrast, the antigen-binding sites are in the V regions. 2. Generating memory cells ensures both that a receptor specific for a particular epitope will be present and that there will be more lymphocytes with this specificity than in a host that had never encountered the antigen. 3. If each B cell produced two different light and heavy chains for its antigen receptor, different combinations would make four different receptors. If any one were self-reactive, the lymphocyte would be eliminated in the generation of self-tolerance. For this reason, many more B cells would be eliminated, and those that could respond to a foreign antigen would be less effective at doing so due to the variety of receptors (and antibodies) they express.

Concept Check 43.3

1. A child lacking a thymus would have no functional T cells. Without helper T cells to help activate B cells, the child would be unable to produce antibodies against extracellular bacteria. Furthermore, without cytotoxic T cells or helper T cells, the child's immune system would be unable to kill virus-infected cells. 2. Since the antigen-binding site is intact, the antibody fragments could neutralize viruses and opsonize bacteria. 3. If the handler developed immunity to proteins in the antivenin, another injection could provoke a severe immune response.

Concept Check 43.4

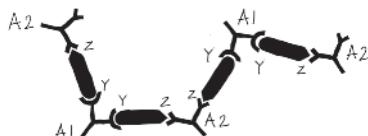
1. Myasthenia gravis is considered an autoimmune disease because the immune system produces antibodies against self molecules (certain receptors on muscle cells). 2. A person with a cold is likely to produce oral and nasal secretions that facilitate viral transfer. In addition, since sickness can cause incapacitation or death, a virus that is programmed to exit the host when there is a physiological stress has the opportunity to find a new host at a time when the current host may cease to function. 3. A person with a macrophage deficiency would have frequent infections. The causes would be poor innate responses, due to diminished phagocytosis and inflammation, and poor adaptive responses, due to the lack of macrophages to present antigens to helper T cells.

Summary of Key Concepts Questions

43.1 Lysozyme in saliva destroys bacterial cell walls; the viscosity of mucus helps trap bacteria; acidic pH in the stomach kills many bacteria; and the tight packing of cells lining the gut provides a physical barrier to infection. **43.2** Sufficient numbers of cells to mediate an innate immune response are always present, whereas an adaptive response requires selection and proliferation of an initially very small cell population specific for the infecting pathogen. **43.3** No. Immunological memory after a natural infection and that after vaccination are very similar. There may be minor differences in the particular antigens that can be recognized in a subsequent infection. **43.4** No. AIDS refers to a loss of immune function that can occur over time in an individual infected with HIV. However, certain multidrug combinations ("cocktails") or rare genetic variations usually prevent progression to AIDS in people infected with HIV.

Test Your Understanding

1. B 2. C 3. C 4. B 5. B 6. B 7. C
8. One possible answer:



9. Lamarck's discredited idea was that organisms changed their form to fit challenges and then somehow passed those changes on to their descendants. In clonal selection, heritable differences that give rise to variation arise prior to any challenge. An encounter with a particular antigen results in proliferation of the variants best suited to recognize and respond to that challenge.

Chapter 44**Figure Questions**

Figure 44.13 You would expect to find these cells lining tubules where they pass through the renal medulla. Because the extracellular fluid of the renal medulla has a very high osmolarity, production of organic solutes by tubule cells in this region keeps intracellular osmolarity high, with the result that these cells maintain normal volume. **Figure 44.14** Furosemide increases urine volume. The absence of ion transport in the ascending limb leaves the filtrate too concentrated for substantial volume reduction in the distal tubule and collecting duct. **Figure 44.17** When the concentration of an ion differs across a plasma membrane, the difference in the concentration of ions inside and outside represents chemical potential energy, while the resulting difference in charge inside and outside represents electrical potential energy. **Figure 44.20** The ADH levels would likely be elevated in both sets of patients with mutations because either

defect prevents the recapture of water that restores blood osmolarity to normal levels. **Figure 44.21** Arrows that would be labeled "secretion" are the arrows indicating secretion of aldosterone, angiotensinogen, and renin.

Concept Check 44.1

1. Because the salt is moved against its concentration gradient, from low concentration (fresh water) to high concentration (blood) 2. A freshwater osmoconformer would have body fluids too dilute to carry out life's processes. 3. Without a layer of insulating fur, the camel must use the cooling effect of evaporative water loss to maintain body temperature, thus linking thermoregulation and osmoregulation.

Concept Check 44.2

1. Because uric acid is largely insoluble in water, it can be excreted as a semisolid paste, thereby reducing an animal's water loss. 2. Humans produce uric acid from purine breakdown, and reducing purines in the diet often lessens the severity of gout. Birds, however, produce uric acid as a waste product of general nitrogen metabolism. They would therefore need a diet low in all nitrogen-containing compounds, not just purines.

Concept Check 44.3

1. In flatworms, ciliated cells draw interstitial fluids containing waste products into protonephridia. In earthworms, waste products pass from interstitial fluids into the coelom. From there, cilia move the wastes into metanephridia. In insects, the Malpighian tubules pump fluids from the hemolymph, which receives waste products during exchange with cells in the course of circulation. 2. Filtrate is formed when the glomerulus filters blood from the renal artery within Bowman's capsule. Some of the filtrate contents are recovered, enter capillaries, and exit in the renal vein; the rest remain in the filtrate and pass out of the kidney in the ureter. 3. The presence of Na^+ and other ions (electrolytes) in the dialysate would limit the extent to which they would be removed from the filtrate during dialysis. Adjusting the electrolyte concentrations in the starting dialysate can thus lead to the restoration of proper electrolyte concentrations in the plasma. Similarly, the absence of urea and other waste products in the starting dialysate facilitates their removal from the filtrate.

Concept Check 44.4

1. The numerous nephrons and well-developed glomeruli of freshwater fishes produce urine at a high rate, while the small numbers of nephrons and smaller glomeruli of marine fishes produce urine at a low rate. 2. The kidney medulla would absorb less water; thus, the drug would increase the amount of water lost in the urine. 3. A decline in blood pressure in the afferent arteriole would reduce the rate of filtration by moving less material through the vessels.

Concept Check 44.5

1. Alcohol inhibits the release of ADH, causing an increase in urinary water loss and increasing the chance of dehydration. 2. The consumption of a very large amount of water in a short period of time, coupled with an absence of solute intake, can reduce sodium levels in the blood below tolerable levels. This condition, called hyponatremia, leads to disorientation and, sometimes, respiratory distress. It has occurred in some marathon runners who drink water rather than sports drinks. (It has also caused the death of a fraternity pledge as a consequence of a water hazing ritual and the death of a contestant in a water-drinking competition.) 3. High blood pressure

Summary of Key Concepts Questions

44.1 Water moves into a cell by osmosis when the fluid outside the cells is hypotonic (has a lower solute concentration than the cytosol). **44.2** As cofactors for the enzymes that catalyze metabolism, nitrogen-containing molecules such as NAD^+/NADH are "recycled" during cellular respiration. They thus are not broken down and their components are not absorbed or excreted. **44.3** Filtration produces a fluid for exchange processes that is free of cells and large molecules, which are of benefit to the animal and could not readily be reabsorbed. **44.4** Both types of nephrons have proximal tubules that can reabsorb nutrients, but only juxtaglomerular nephrons have loops of Henle that extend deep into the renal medulla. Thus, only kidneys containing juxtaglomerular nephrons can produce urine that is more concentrated than the blood. **44.5** Patients who don't produce ADH have symptoms relieved by treatment with the hormone, but many patients with diabetes insipidus lack functional receptors for ADH.

Test Your Understanding

1. C 2. A 3. C 4. D 5. C 6. B

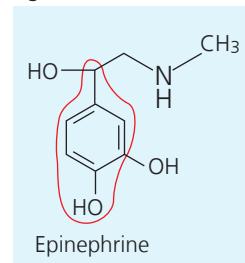
Chapter 45**Figure Questions****Figure 45.4**

Figure 45.5 The hormone is water-soluble and has a cell-surface receptor. Such receptors, unlike those for lipid-soluble hormones, can cause observable changes in cells without hormone-dependent gene transcription.

Figure 45.6 ATP is enzymatically converted to cAMP. The other steps represent binding reactions. **Figure 45.21** The embryonic gonad can become either a testis or an ovary. In contrast, the ducts either form a particular structure or degenerate, and the bladder forms in both males and females.

Concept Check 45.1

1. Water-soluble hormones, which cannot penetrate the plasma membrane, bind to cell-surface receptors. This interaction triggers an intracellular signal transduction pathway that ultimately alters the activity of a preexisting protein in the cytoplasm and/or changes transcription of specific genes in the nucleus. Steroid hormones are lipid-soluble and can cross the plasma membrane into the cell interior, where they bind to receptors located in the cytosol or nucleus. The hormone-receptor complex then functions directly as a transcription factor that changes transcription of specific genes. **2.** An exocrine gland, because pheromones are not secreted into interstitial fluid but instead are typically released onto a body surface or into the environment. **3.** Because receptors for water-soluble hormones are located on the cell surface, facing the extracellular space, injecting the hormone into the cytosol would not trigger a response.

Concept Check 45.2

1. Prolactin regulates milk production, and oxytocin regulates milk release. **2.** The posterior pituitary, an extension of the hypothalamus that contains the axons of neurosecretory cells, is the storage and release site for two neurohormones, oxytocin and antidiuretic hormone (ADH). The anterior pituitary contains endocrine cells that make at least six different hormones. Secretion of anterior pituitary hormones is controlled by hypothalamic hormones that travel via blood vessels to the anterior pituitary. **3.** The hypothalamus and pituitary glands function in many different endocrine pathways. Many defects in these glands, such as those affecting growth or organization, would therefore disrupt many hormone pathways. Only a very specific defect, such as a mutation affecting a particular hormone receptor, would alter just one endocrine pathway. The situation is quite different for the final gland in a pathway, such as the thyroid gland. In this case, a wide range of defects that disrupt gland function would disrupt only the one pathway or small set of pathways in which that gland functions. **4.** Both diagnoses could be correct. In one case, the thyroid gland may produce excess thyroid hormone despite normal hormonal input from the hypothalamus and anterior pituitary. In the other, abnormally elevated hormonal input (an elevated TSH level) may be the cause of the overactive thyroid gland.

Concept Check 45.3

1. If the function of the pathway is to provide a transient response, a short-lived stimulus would be less dependent on negative feedback. **2.** You would be exploiting the anti-inflammatory activity of glucocorticoids. Local injection avoids the effects on glucose metabolism that would occur if glucocorticoids were taken orally and transported throughout the body in the bloodstream. **3.** Both hormones produce opposite effects in different target tissues. In the fight-or-flight response, epinephrine increases blood flow to skeletal muscles and reduces blood flow to smooth muscles in the digestive system. In establishing apical dominance, auxin promotes the growth of apical buds and inhibits the growth of lateral buds.

Summary of Key Concepts Questions

45.1 As shown in Figure 43.18, helper T cell activation by cytokines acting as local regulators involves both autocrine and paracrine signaling. **45.2** The pancreas, parathyroid glands, and pineal gland. **45.3** Both the pituitary and the adrenal glands are formed by fusion of neural and nonneuronal tissue. ADH is secreted by the neurosecretory portion of the pituitary gland, and epinephrine is secreted by the neurosecretory portion of the adrenal gland.

Test Your Understanding

1. C 2. D 3. D 4. A 5. B 6. B 7. A
8.

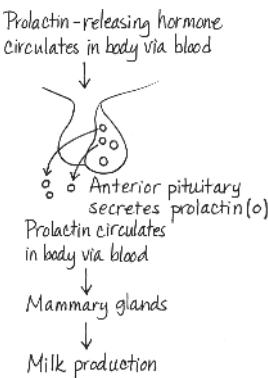
**Chapter 46****Figure Questions**

Figure 46.7 Newly formed sperm enter the seminal vesicle from the testis and exit via the ejaculatory duct during intercourse. Sperm enter the spermatheca after intercourse and, after storage, are released into the oviduct to fertilize an egg moving into the uterus. **Figure 46.8** When successfully courted by a second male, regardless of his genotype, about one-third of the females rid themselves of all sperm from the first mating. Thus, two-thirds retained some sperm from the first mating. We would therefore predict that two-thirds of those females would have some offspring exhibiting the small-eye phenotype of the dominant mutation carried by the males with which the females mated first. **Figure 46.11** The

analysis would be informative because the polar bodies contain all of the maternal chromosomes that don't end up in the mature egg. For example, finding two copies of the disease gene in the polar bodies would indicate its absence in the egg. This method of genetic testing is sometimes carried out when oocytes collected from a female are fertilized with sperm in a laboratory dish.

Figure 46.15 The embryo normally implants about a week after conception, but it spends several days in the uterus before implanting, receiving nutrients from the endometrium. Therefore, the fertilized egg should be cultured for several days in liquid that is at normal body temperature and contains the same nutrients as those provided by the endometrium before implantation. **Figure 46.16** Testosterone can pass from fetal blood to maternal blood via the placental circulation, temporarily upsetting the hormonal balance in the mother. **Figure 46.18** Oxytocin would most likely induce labor, starting a positive-feedback loop that would direct labor to completion. Synthetic oxytocin is in fact frequently used to induce labor when prolonged pregnancy might endanger the mother or fetus.

Concept Check 46.1

1. The offspring of sexual reproduction are more genetically diverse. However, asexual reproduction can produce more offspring over multiple generations. **2.** Unlike other forms of asexual reproduction, parthenogenesis involves gamete production. By controlling whether or not haploid eggs are fertilized, species such as honeybees can readily switch between asexual and sexual reproduction. **3.** No. Owing to random assortment of chromosomes during meiosis, the offspring may receive the same copy or different copies of a particular parental chromosome from the sperm and the egg. Furthermore, genetic recombination during meiosis will result in reassortment of genes between pairs of parental chromosomes. **4.** Fragmentation occurs in both plants and animals. Also, budding in animals and the growth of adventitious plant roots both involve emergence of new individuals from outgrowths of the parent.

Concept Check 46.2

1. Internal fertilization allows sperm to reach the egg without either gamete drying out. **2.** (a) Animals with external fertilization tend to release many gametes at once, resulting in the production of enormous numbers of zygotes. This increases the chances that some will survive to adulthood. (b) Animals with internal fertilization produce fewer offspring but generally exhibit greater care of the embryos and the young. **3.** Like the uterus of an insect, the ovary of a plant is the site of fertilization. Unlike the plant ovary, the uterus is not the site of egg production, which occurs in the insect ovary. In addition, the fertilized insect egg is expelled from the uterus, whereas the plant embryo develops within a seed in the ovary.

Concept Check 46.3

1. Spermatogenesis occurs normally only when the testicles are cooler than normal body temperature. Extensive use of a hot tub (or of very tight-fitting underwear) can cause a decrease in sperm quality and number. **2.** In humans, the secondary oocyte combines with a sperm before it finishes the second meiotic division. Thus, oogenesis is completed after, not before, fertilization. **3.** The only effect of sealing off each vas deferens is an absence of sperm in the ejaculate. Sexual response and ejaculate volume are unchanged. The cutting and sealing off of these ducts, a *vasectomy*, is a common surgical procedure for men who do not wish to produce any (more) offspring.

Concept Check 46.4

1. In the testis, FSH stimulates the Sertoli cells, which nourish developing sperm. LH stimulates the production of androgens (mainly testosterone), which in turn stimulate sperm production. In both females and males, FSH encourages the growth of cells that support and nourish developing gametes (follicle cells in females and Sertoli cells in males), and LH stimulates the production of sex hormones that promote gametogenesis (estrogens, primarily estradiol, in females and androgens, especially testosterone, in males). **2.** In estrous cycles, which occur in most female mammals, the endometrium is reabsorbed (rather than shed) if fertilization does not occur. Estrous cycles often occur just once or a few times a year, and the female is usually receptive to copulation only during the period around ovulation. Menstrual cycles are found only in humans and some other primates. They control the buildup and breakdown of the uterine lining, but not sexual receptivity. **3.** The combination of estradiol and progesterone would have a negative-feedback effect on the hypothalamus, blocking release of GnRH. This would interfere with LH secretion by the pituitary, thus preventing ovulation. This is in fact one basis of action of the most common hormonal contraceptives. **4.** In the viral replicative cycle, the production of new viral genomes is coordinated with capsid protein expression and with the production of phospholipids for viral coats. In the reproductive cycle of a human female, there is hormonally based coordination of egg maturation with the development of support tissues of the uterus.

Concept Check 46.5

1. The secretion of hCG by the early embryo stimulates the corpus luteum to make progesterone, which helps maintain the pregnancy. During the second trimester, however, hCG production drops, the corpus luteum disintegrates, and the placenta completely takes over progesterone production. **2.** Both tubal ligation and vasectomy block the movement of gametes from the gonads to a site where fertilization could take place. **3.** The introduction of a sperm nucleus directly into an oocyte bypasses the sperm's acquisition of motility in the epididymis, its swimming to meet the egg in the oviduct, and its fusion with the egg.

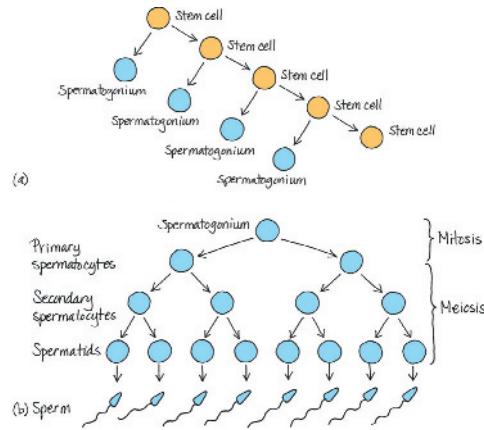
Summary of Key Concepts Questions

46.1 No. Because parthenogenesis involves meiosis, the mother would pass on to each offspring a random and therefore typically distinct combination of the chromosomes she inherited from her mother and father. **46.2** None **46.3** The

small size and lack of cytoplasm characteristic of a sperm are adaptations well suited to its function as a delivery vehicle for DNA. The large size and rich cytoplasmic contents of eggs support the growth and development of the embryo. **46.4** Circulating anabolic steroids mimic the feedback regulation of testosterone, turning off pituitary signaling to the testes and thereby blocking the release of signals required for spermatogenesis. **46.5** Oxygen in maternal blood diffuses from pools in the endometrium into fetal capillaries in the chorionic villi of the placenta and from there travels throughout the circulatory system of the fetus.

Test Your Understanding

1. D 2. B 3. B 4. C 5. A 6. B 7. C 8. C
9.



(c) The supply of stem cells would be used up, and spermatogenesis would not be able to continue.

Chapter 47

Figure Questions

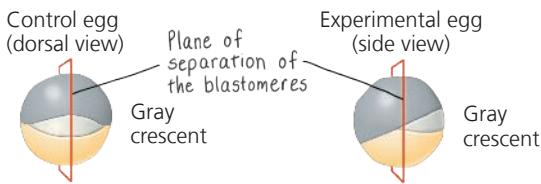
Figure 47.3 You could inject the compound into an unfertilized egg, expose the egg to sperm, and see whether the fertilization envelope forms.

Figure 47.6 There would be fewer cells, and they would be closer together.

Figure 47.8 (1) The blastocoel forms a single compartment that surrounds the gut, much like a doughnut surrounds a hole. (2) Ectoderm forms the outer covering of the animal, and endoderm lines the internal organs, such as the digestive tract. Mesoderm fills much of the space between these two layers.

Figure 47.19 Eight cell divisions are required to give rise to the intestinal cell closest to the mouth. **Figure 47.22** When the researchers allowed normal cortical rotation to occur, the “back-forming” determinants were activated. When they then forced the opposite rotation to occur, the back was established on the opposite side as well. Because the molecules on the normal side were already activated, forcing the opposite rotation apparently did not “cancel out” the establishment of the back side by the first rotation.

Figure 47.23 Draw It



What If? In Spemann’s control, the two blastomeres were physically separated, and each grew into a whole embryo. In Roux’s experiment, remnants of the dead blastomere were still contacting the live blastomere, which developed into a half-embryo. Therefore, molecules present in the dead cell’s remnants may have been signaling to the live cell, inhibiting it from making all the embryonic structures.

Figure 47.24 You could inject the isolated protein (or an mRNA encoding it) into ventral cells of an earlier gastrula. If dorsal structures form on the ventral side, that would support the idea that the protein is the signaling molecule secreted or presented by the dorsal lip. You should also do a control experiment to make sure the injection process alone did not cause dorsal structures to form. **Figure 47.26** Either Sonic hedgehog mRNA or protein can serve as a marker of the zone of polarizing activity (ZPA). The absence of either one after removal of the apical ectodermal ridge would support your hypothesis. You could also block fibroblast growth factor function and see whether the ZPA formed (by looking for Sonic hedgehog).

Concept Check 47.1

- The fertilization envelope forms after cortical granules release their contents outside the egg, causing the vitelline membrane to rise and harden. The fertilization envelope serves as a barrier to fertilization by more than one sperm.
- The increased Ca^{2+} concentration in the egg would cause the cortical granules to fuse with the plasma membrane, releasing their contents and causing a fertilization envelope to form, even though no sperm had entered. This would prevent fertilization.
- You would expect it to fluctuate. The fluctuation of MPF drives the transition between DNA replication (S phase) and mitosis (M phase), which is still required in the abbreviated cleavage cell cycle.

Concept Check 47.2

- The cells of the notochord migrate toward the midline of the embryo (converge), rearranging themselves so there are fewer cells across the notochord, which thus becomes longer overall (extends; see Figure 47.17).
- Because microfilaments would not be able to contract and decrease the size of one end of the cell, both the inward bending in the middle of the neural tube and the outward bending of the hinge regions at the edges would be blocked. Therefore, the neural tube probably would not form.
- Dietary intake of the vitamin folic acid dramatically reduces the frequency of neural tube defects.

Concept Check 47.3

- Axis formation establishes the location and polarity of the three axes that provide the coordinates for development. Pattern formation positions particular tissues and organs in the three-dimensional space defined by those coordinates.
- Morphogen gradients act by specifying cell fates across a field of cells through variation in the level of a determinant. Morphogen gradients thus act more globally than cytoplasmic determinants or inductive interactions between pairs of cells.
- Yes, a second embryo could develop because inhibiting BMP-4 activity would have the same effect as transplanting an organizer.
- The limb that developed probably would have a mirror-image duplication, with the most posterior digits in the middle and the most anterior digits at either end.

Summary of Key Concepts Questions

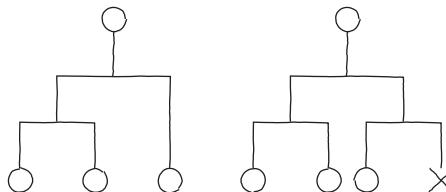
47.1 The binding of a sperm to a receptor on the egg surface is very specific and likely would not occur if the two gametes were from different species. Without sperm binding, the sperm and egg membranes would not fuse.

47.2 Apoptosis functions to eliminate structures required only in an immature form, nonfunctional cells from a pool larger than the number required, and tissues formed by a developmental program that is not adaptive for the organism as it has evolved.

47.3 Mutations that affected both limb and kidney development would be more likely to alter the function of cilia because these organelles are important in several signaling pathways. Mutations that affected limb development but not kidney development would more likely alter a single pathway, such as Hedgehog signaling.

Test Your Understanding

1. A 2. B 3. D 4. A 5. D 6. C 7. B
8.



Chapter 48

Figure Questions

Figure 48.7 Potassium and sodium channels must differ in the structure of the channel through which the ions pass. The channel could differ in the size of the opening, the distribution of charge, or other properties that would allow one type of ion but not others to diffuse through the channel. **Figure 48.8** Adding chloride channels would make the membrane potential less positive. Adding potassium channels would have no effect because there are no potassium ions present. **Figure 48.10** In the absence of other forces, chemical concentration gradients govern net diffusion. In this case, ions are more concentrated outside of the cell and move in when the channel opens.

Figure 48.11

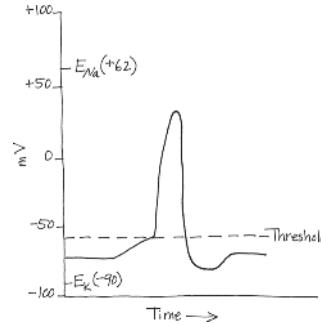


Figure 48.12

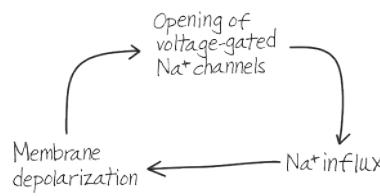


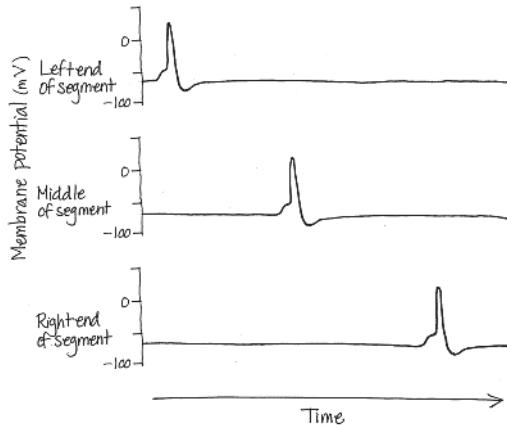
Figure 48.13

Figure 48.16 The production and transmission of action potentials would be unaffected. However, action potentials arriving at chemical synapses would be unable to trigger release of neurotransmitter. Signaling at such synapses would thus be blocked. **Figure 48.17** Summation only occurs if inputs occur simultaneously or nearly so. Thus, spatial summation, in which input is received from two different sources, is in effect also temporal summation.

Concept Check 48.1

1. A typical neuron has multiple dendrites and one axon. Dendrites transfer information to the cell body, whereas axons transmit information from the cell body. Both axons and dendrites extend from the cell body and function in information flow. 2. Sensors in your ear transmit information to your brain. There, the activity of interneurons in processing centers enables you to recognize your name. In response, signals transmitted via motor neurons cause contraction of muscles that turn your neck. 3. Increased branching would allow control of a greater number of postsynaptic cells, enhancing coordination of responses to nervous system signals.

Concept Check 48.2

1. Ions can flow against a chemical concentration gradient if there is an opposing electrical gradient of greater magnitude. 2. A decrease in permeability to K^+ , an increase in permeability to Na^+ , or both 3. Charged dye molecules could equilibrate only if other charged molecules could also cross the membrane. If not, a membrane potential would develop that would counterbalance the chemical gradient.

Concept Check 48.3

1. A graded potential has a magnitude that varies with stimulus strength, whereas an action potential has an all-or-none magnitude that is independent of stimulus strength. 2. Loss of the insulation provided by myelin sheaths leads to a disruption of action potential propagation along axons. Voltage-gated sodium channels are restricted to the nodes of Ranvier, and without the insulating effect of myelin, the inward current produced at one node during an action potential cannot depolarize the membrane to the threshold at the next node. 3. Positive feedback is responsible for the rapid opening of many voltage-gated sodium channels, causing the rapid outflow of sodium ions responsible for the rising phase of the action potential. As the membrane potential becomes positive, voltage-gated potassium channels open in a form of negative feedback that helps bring about the falling phase of the action potential. 4. The maximum frequency would decrease because the refractory period would be extended.

Concept Check 48.4

1. It can bind to different types of receptors, each triggering a specific response in postsynaptic cells. 2. These toxins would prolong the EPSPs that acetylcholine produces because the neurotransmitter would remain longer in the synaptic cleft. 3. Membrane depolarization, exocytosis, and membrane fusion each occur in fertilization and in neurotransmission.

Summary of Key Concepts Questions

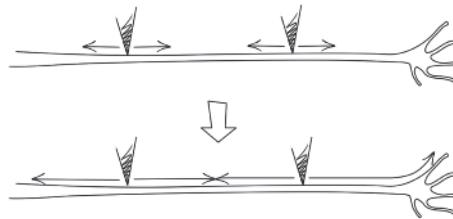
48.1 It would prevent information from being transmitted away from the cell body along the axon. **48.2** There are very few open sodium channels in a resting neuron, so the resting potential either would not change or would become slightly more negative (hyperpolarization). **48.4** A given neurotransmitter can have many receptors that differ in their location and activity. Drugs that target receptor activity rather than neurotransmitter release or stability are therefore likely to exhibit greater specificity and potentially have fewer undesirable side effects.

Test Your Understanding

1.C 2.C 3.C 4.B 5.A 6.D

7. The activity of the sodium-potassium pump is essential to maintain the resting potential. With the pump inactivated, the sodium and potassium concentration gradients would gradually disappear, resulting in a greatly reduced resting potential. 8. Since GABA is an inhibitory neurotransmitter in the CNS, this drug would be expected to decrease brain activity. A decrease in brain activity

might be expected to slow down or reduce behavioral activity. Many sedative drugs act in this fashion. 9. As shown in this pair of drawings, a pair of action potentials would move outward in both directions from each electrode. (Action potentials are unidirectional only if they begin at one end of an axon.) However, because of the refractory period, the two action potentials between the electrodes both stop where they meet. Thus, only one action potential reaches the synaptic terminals.



Chapter 49

Figure Questions

Figure 49.5 During swallowing, muscles along the esophagus alternately contract and relax, resulting in peristalsis. One model to explain this alternation is that each section of muscle receives nerve impulses that alternate between excitation and inhibition, just as the quadriceps and hamstring receive opposing signals in the knee-jerk reflex. **Figure 49.15** The gray areas have a different shape and pattern, indicating different planes through the brain. This fact indicates that the nucleus accumbens and the amygdala are in different planes. **Figure 49.17** The hand is shown larger than the forearm because the hand receives more innervation than the forearm for sensory input to the brain and motor output from the brain. **Figure 49.24** If the depolarization brings the membrane potential to or past threshold, it should initiate action potentials that cause dopamine release from the VTA neurons. This should mimic natural stimulation of the brain reward system, resulting in positive and perhaps pleasurable sensations.

Concept Check 49.1

- The sympathetic division would likely be activated. It mediates the “fight-or-flight” response in stressful situations.
- Nerves contain bundles of axons, some that belong to motor neurons, which send signals outward from the CNS, and some that belong to sensory neurons, which bring signals into the CNS. Therefore, you would expect effects on both motor control and sensation.
- Neurosecretory cells of the adrenal medulla secrete the hormones epinephrine and norepinephrine in response to preganglionic input from sympathetic neurons. These hormones travel in the circulation throughout the body, triggering responses in many tissues.

Concept Check 49.2

- The cerebral cortex on the left side of the brain initiates voluntary movement of the right side of the body.
- Alcohol diminishes function of the cerebellum.
- A coma reflects a disruption in the cycles of sleep and arousal regulated by communication between the midbrain and pons (reticular formation) and the cerebrum. You would expect this group to have damage to the midbrain, the pons, the cerebrum, or any part of the brain between these structures. Paralysis reflects an inability to carry out motor commands transmitted from the cerebrum to the spinal cord. You would expect this group to have damage to the portion of the CNS extending from the spinal cord up to but not including the midbrain and pons.

Concept Check 49.3

- Brain damage that disrupts behavior, cognition, memory, or other functions provides evidence that the portion of the brain affected by the damage is important for the normal activity that is blocked or altered.
- Broca’s area, which is active during the generation of speech, is located near the motor cortex, which controls skeletal muscles, including those in the face. Wernicke’s area, which is active when speech is heard, is located in the posterior part of the temporal lobe, which is involved in hearing.
- Each cerebral hemisphere is specialized for different parts of this task—the right for face recognition and the left for language. Without an intact corpus callosum, neither hemisphere can take advantage of the other’s processing abilities.

Concept Check 49.4

- There can be an increase in the number of synapses between the neurons or an increase in the strength of existing synaptic connections.
- If consciousness is an emergent property resulting from the interaction of many different regions of the brain, then it is unlikely that localized brain damage will have a discrete effect on consciousness.
- The hippocampus is responsible for organizing newly acquired information. Without hippocampal function, the links necessary to retrieve information from the cerebral cortex will be lacking, and no functional memory, short- or long-term, will be formed.

Concept Check 49.5

- Both are progressive brain diseases whose risk increases with advancing age. Both result from the death of brain neurons and are associated with the accumulation of peptide or protein aggregates.
- The symptoms of schizophrenia can be mimicked by a drug that stimulates dopamine-releasing neurons. The brain’s reward system, which is involved in drug addiction, is composed of dopamine-releasing neurons that connect the ventral tegmental area to regions in the cerebrum. Parkinson’s disease results from the death of dopamine-releasing neurons.
- Not

necessarily. It might be that the plaques, tangles, and missing regions of the brain seen at death reflect secondary effects, the consequence of other unseen changes that are actually responsible for the alterations in brain function.

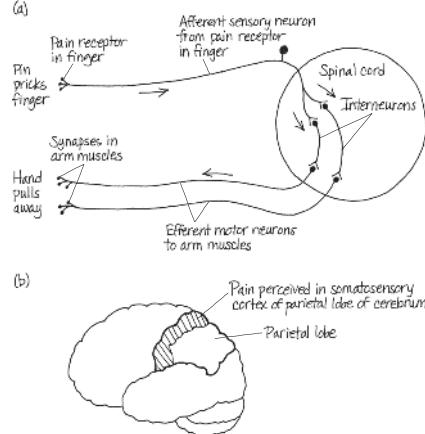
Summary of Key Concepts Questions

49.1 Because reflex circuits involve only a few neurons—the simplest consist of a sensory neuron and a motor neuron—the path for information transfer is short and simple, increasing the speed of the response. **49.2** The midbrain coordinates visual reflexes; the cerebellum controls coordination of movement that depends on visual input; the thalamus serves as a routing center for visual information; and the cerebrum is essential for converting visual input to a visual image. **49.3** You would expect the right side of the body to be paralyzed because it is controlled by the left cerebral hemisphere, where language generation and interpretation are localized. **49.4** Learning a new language likely requires the maintenance of synapses that are formed during early development but are otherwise lost prior to adulthood. **49.5** Whereas amphetamine stimulates dopamine release, PCP blocks glutamate receptors, suggesting that schizophrenia does not reflect a defect in the function of just one neurotransmitter.

Test Your Understanding

1. B 2. A 3. D 4. D 5. C 6. A

7.



Chapter 50

Figure Questions

Figure 50.17

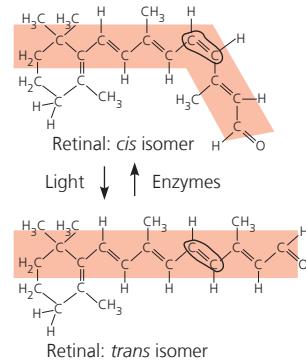


Figure 50.19 Each of the three types of cones is most sensitive to a different wavelength of light. A cone might be fully depolarized when there is light present if the light is of a wavelength far from its optimum. **Figure 50.21** In humans, an X chromosome with a defect in the red or green opsin gene is much less common than a wild-type X chromosome. Color blindness therefore typically skips a generation as the defective allele passes from an affected male to a carrier daughter and back to an affected grandson. In squirrel monkeys, no X chromosome can confer full color vision. As a result, all males are color-blind and no unusual inheritance pattern is observed. **Figure 50.23** The results of the experiment would have been identical. What matters is the activation of particular sets of neurons, not the manner in which they are activated. Any signal from a bitter cell will be interpreted by the brain as a bitter taste, regardless of the nature of the compound and the receptor involved. **Figure 50.25** Only perception. Binding of an odorant to its receptor will cause action potentials to be sent to the brain. Although an excess of that odorant might cause a diminished response through adaptation, another odorant can mask the first only at the level of perception in the brain. **Figure 50.26** Both. A muscle fiber contains many myofibrils bundled together and divided lengthwise into many sarcomeres. A sarcomere is a contractile unit made up of portions of many myofibrils, and each myofibril is a part of many sarcomeres. **Figure 50.28** Hundreds of myosin heads participate in sliding each pair of thick and thin filaments past each other. Because cross-bridge formation and breakdown are not synchronized, many myosin heads are exerting force on the thin filaments at all times during muscle contraction. **Figure 50.33** By causing all of the motor neurons that control the muscle to generate action potentials at a rate high enough to produce tetanus in all of the muscle fibers.

been identical. What matters is the activation of particular sets of neurons, not the manner in which they are activated. Any signal from a bitter cell will be interpreted by the brain as a bitter taste, regardless of the nature of the compound and the receptor involved. **Figure 50.25** Only perception. Binding of an odorant to its receptor will cause action potentials to be sent to the brain. Although an excess of that odorant might cause a diminished response through adaptation, another odorant can mask the first only at the level of perception in the brain. **Figure 50.26** Both. A muscle fiber contains many myofibrils bundled together and divided lengthwise into many sarcomeres. A sarcomere is a contractile unit made up of portions of many myofibrils, and each myofibril is a part of many sarcomeres. **Figure 50.28** Hundreds of myosin heads participate in sliding each pair of thick and thin filaments past each other. Because cross-bridge formation and breakdown are not synchronized, many myosin heads are exerting force on the thin filaments at all times during muscle contraction. **Figure 50.33** By causing all of the motor neurons that control the muscle to generate action potentials at a rate high enough to produce tetanus in all of the muscle fibers.

Concept Check 50.1

- Electromagnetic receptors in general detect only external stimuli. Nonelectromagnetic receptors, such as chemoreceptors or mechanoreceptors, can act as either internal or external sensors.
- The capsaicin present in the peppers

activates the thermoreceptor for high temperatures. In response to the perceived high temperature, the nervous system triggers sweating to achieve evaporative cooling.

- You would perceive the electrical stimulus as if the sensory receptors that regulate that neuron had been activated. For example, electrical stimulation of the sensory neuron controlled by the thermoreceptor activated by menthol would likely be perceived as a local cooling.

Concept Check 50.2

1. Otoliths detect the animal's orientation with respect to gravity, providing information that is essential in environments such as the tunnel habitat of the star-nosed mole, where light cues are absent. **2**. As a sound that changes gradually from a very low to a very high pitch. **3**. The stapes and the other middle ear bones transmit vibrations from the tympanic membrane to the oval window. Fusion of these bones (as occurs in a disease called otosclerosis) would block this transmission and result in hearing loss. **4**. In animals, the statoliths are extracellular. In contrast, the statoliths of plants are found within an intracellular organelle. The methods for detecting their location also differ. In animals, detection is by means of mechanoreceptors on ciliated cells. In plants, the mechanism appears to involve calcium signaling.

Concept Check 50.3

1. Planarians have ocelli that cannot form images but can sense the intensity and direction of light, providing enough information to enable the animals to find protection in shaded places. Flies have compound eyes that form images and excel at detecting movement. **2**. The person can focus on distant objects but not close objects (without glasses) because close focusing requires the lens to become almost spherical. This problem is common after age 50. **3**. The signal produced by rod and cone cells is glutamate, and their release of glutamate decreases upon exposure to light. However, a decrease in glutamate production causes other retinal cells to increase the rate at which action potentials are sent to the brain, so that the brain receives more action potentials in light than in dark. **4**. Absorption of light by retinal converts retinal from its *cis* isomer to its *trans* isomer, initiating the process of light detection. In contrast, a photon absorbed by chlorophyll does not bring about isomerization, but instead boosts an electron to a higher energy orbital, initiating the electron flow that generates ATP and NADPH.

Concept Check 50.4

1. Both taste cells and olfactory cells have receptor proteins in their plasma membrane that bind certain substances, leading to membrane depolarization through a signal transduction pathway involving a G protein. However, olfactory cells are sensory neurons, whereas taste cells are not. **2**. Since animals rely on chemical signals for behaviors that include finding mates, marking territories, and avoiding dangerous substances, it is adaptive for the olfactory system to have a robust response to a very small number of molecules of a particular odorant. **3**. Because the sweet, bitter, and umami tastes involve GPCR proteins but the sour taste does not, you might predict that the mutation is in a molecule that acts in the signal transduction pathway common to the different GPCRs.

Concept Check 50.5

1. In a skeletal muscle fiber, Ca^{2+} binds to the troponin complex, which moves tropomyosin away from the myosin-binding sites on actin and allows cross-bridges to form. In a smooth muscle cell, Ca^{2+} binds to calmodulin, which activates an enzyme that phosphorylates the myosin head and thus enables cross-bridge formation. **2**. *Rigor mortis*, a Latin phrase meaning "stiffness of death," results from the complete depletion of ATP in skeletal muscle. Since ATP is required to release myosin from actin and to pump Ca^{2+} out of the cytosol, muscles become chronically contracted beginning about 3–4 hours after death. **3**. A competitive inhibitor binds to the same site as the substrate for the enzyme. In contrast, the troponin and tropomyosin complex masks, but does not bind to, the myosin-binding sites on actin.

Concept Check 50.6

1. The main problem in swimming is drag; a fusiform body minimizes drag. The main problem in flying is overcoming gravity; wings shaped like airfoils provide lift, and adaptations such as air-filled bones reduce body mass. **2**. In modeling peristalsis you would constrict the toothpaste tube at different points along its length, using your hand to encircle the tube and squeeze concentrically. To demonstrate movement of food through the digestive tract you would want the cap off the toothpaste tube, whereas you would want the cap on to show how peristalsis contributes to worm locomotion. **3**. When you grasp the sides of the chair, you are using a contraction of the triceps to keep your arms extended against the pull of gravity on your body. As you lower yourself slowly into the chair, you gradually decrease the number of motor units in the triceps that are contracted. Contracting your biceps would jerk you down, since you would no longer be opposing gravity.

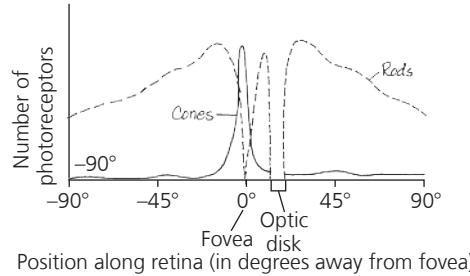
Summary of Key Concepts Questions

50.1 Nociceptors overlap with other classes of receptors in the type of stimulus they detect. They differ from other receptors only in how a particular stimulus is perceived. **50.2** Volume is encoded by the frequency of action potentials transmitted to the brain; pitch is encoded by which axons are transmitting action potentials. **50.3** The major difference is that neurons in the retina integrate information from multiple sensory receptors (photoreceptors) before transmitting information to the central nervous system. **50.4** Our olfactory sense is responsible for most of what we describe as distinct tastes. A head cold or other source of congestion blocks odorant access to receptors lining portions of the nasal cavity. **50.5** Hydrolysis of ATP is required to convert myosin to a high-energy configuration for binding to actin and to power the Ca^{2+} pump that removes cytosolic Ca^{2+} during muscle relaxation. **50.6** Human body movements rely on the contraction of muscles anchored to a rigid endoskeleton. Tendons attach muscles to

bones, which in turn are composed of fibers built up from a basic organizational unit, the sarcomere. The thin and thick filaments have separate points of attachment within the sarcomere. In response to nervous system motor output, the formation and breakdown of cross-bridges between myosin heads and actin ratchet the thin and thick filaments past each other. Because the filaments are anchored, this sliding movement shortens the muscle fibers. Furthermore, because the fibers themselves are part of the muscles attached at each end to bones, muscle contraction moves bones of the body relative to each other. In this way, the structural anchoring of muscles and filaments enables muscle function, such as the bending of an elbow by contraction of the biceps.

Test Your Understanding

- 1.C 2.A 3.B 4.C 5.B 6.D
7.



The answer shows the actual distribution of rods and cones in the human eye. Your graph may differ, but should have the following properties: only cones at the fovea; fewer cones and more rods at both ends of the x-axis; no photoreceptors in the optic disk.

Chapter 51

Figure Questions

Figure 51.2 The fixed action pattern based on the sign stimulus of a red belly ensures that the male will chase away any invading males of his species. By chasing away such males, the defender decreases the chance that another male will fertilize eggs laid in his nesting territory. **Figure 51.5** The straight-run portion conveys two pieces of information: direction, via the angle of that run relative to the wall of the hive, and distance, via the number of waggles performed during the straight run. At a minimum, the portions between the straight runs identify the activity as a waggle dance. Since they also provide contact with workers to one side and then the other, they may ensure transmission of information to a larger number of other bees. **Figure 51.7** There should be no effect. Imprinting is an innate behavior that is carried out anew in each generation. Assuming the nest was not disturbed, the offspring of the geese imprinted on a human would imprint on the mother goose. **Figure 51.8** Perhaps the wasp doesn't use visual cues. It might also be that wasps recognize objects native to their environment, but not foreign objects, such as the pinecones. Tinbergen addressed these ideas before carrying out the pinecone study. When he swept away the pebbles and sticks around the nest, the wasps could no longer find their nests. If he shifted the natural objects in their natural arrangement, the shift in the landmarks caused a shift in the site to which the wasps returned. Finally, if natural objects around the nest site were replaced with pinecones while the wasp was in the burrow, the wasp nevertheless found her way back to the nest site. **Figure 51.10** Switching the orientations of all three grids would control for an inherent preference for or against a particular orientation. If there were no inherent preference or bias, the experiment should work equally well after the switch. **Figure 51.24** It might be that the birds require stimuli during flight to exhibit their migratory preference. If this were true, the birds would show the same orientation in the funnel experiment despite their distinct genetic programming. **Figure 51.26** It holds true for some, but not all individuals. If a parent has more than one reproductive partner, the offspring of different partners will have a coefficient of relatedness less than 0.5.

Concept Check 51.1

1. The proximate explanation for this fixed action pattern might be that nudging and rolling are released by the sign stimulus of an object outside the nest, and the behavior is carried to completion once initiated. The ultimate explanation might be that ensuring that eggs remain in the nest increases the chance of producing healthy offspring. 2. There might be selective pressure for other prey fish to detect an injured fish because the source of the injury might threaten them as well. Among predators, there might be selection for those that are attracted to the alarm substance because they would be more likely to encounter crippled prey. Fish with adequate defenses might show no change because they have a selective advantage if they do not waste energy responding to the alarm substance. 3. In both cases, the detection of periodic variation in the environment results in a reproductive cycle timed to environmental conditions that optimize the opportunity for success.

Concept Check 51.2

1. Natural selection would tend to favor convergence in color pattern because a predator learning to associate a pattern with a sting or bad taste would avoid all other individuals with that same color pattern, regardless of species. 2. You might move objects around to establish an abstract rule, such as "past landmark A, the same distance as A is from the starting point," while maintaining a minimum of fixed metric relationships, that is, avoiding having the food directly

adjacent to or a set distance from a landmark. As you might surmise, designing an informative experiment of this kind is not easy. 3. Learned behavior, just like innate behavior, can contribute to reproductive isolation and thus to speciation. For example, learned bird songs contribute to species recognition during courtship, thereby helping ensure that only members of the same species mate.

Concept Check 51.3

1. Certainty of paternity is higher with external fertilization. 2. Balancing selection could maintain the two alleles at the *forager* locus if population density fluctuated from one generation to another. At times of low population density, the energy-conserving sitter larvae (carrying the *for^s* allele) would be favored, while at higher population density, the more mobile Rover larvae (*for^R* allele) would have a selective advantage. 3. Because females would now be present in much larger numbers than males, all three types of males should have some reproductive success. Nevertheless, since the advantage that the blue-throats rely on—a limited number of females in their territory—will be absent, the yellow-throats are likely to increase in frequency in the short term.

Concept Check 51.4

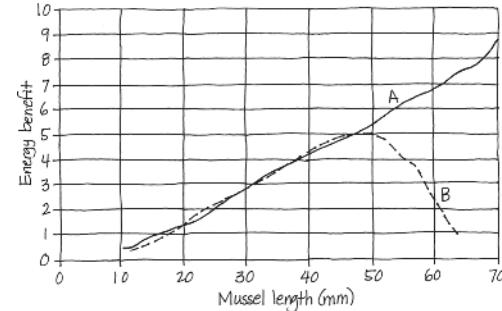
1. Because this geographic variation corresponds to differences in prey availability between two garter snake habitats, it seems likely that snakes with characteristics enabling them to feed on the abundant prey in their locale would have had increased survival and reproductive success. In this way, natural selection would have resulted in the divergent foraging behaviors. 2. The fact that the individual shares some genes with the offspring of its sibling (in the case of humans, with the individual's niece or nephew) means that the reproductive success of that niece or nephew increases the representation of those genes in the population (selects for them). 3. The older individual cannot be the beneficiary because he or she cannot have extra offspring. However, the cost is low for an older individual performing the altruistic act because that individual has already reproduced (but perhaps is still caring for a child or grandchild). There can therefore be selection for an altruistic act by a postreproductive individual that benefits a young relative.

Summary of Key Concepts Questions

51.1 Circannual rhythms are typically based on the cycles of light and dark in the environment. As the global climate changes, animals that migrate in response to these rhythms may shift to a location before or after local environmental conditions are optimal for reproduction and survival. **51.2** For the goose, all that is acquired is an object at which the behavior is directed. In the case of the sparrow, learning takes place that will give shape to the behavior itself. **51.3** Because feeding the female is likely to improve her reproductive success, the genes from the sacrificed male are likely to appear in a greater number of progeny. **51.4** Studying the genetic basis of these behaviors reveals that changes in a single gene can have large-scale effects on even complex behaviors.

Test Your Understanding

- 1.C 2.B 3.B 4.A 5.C 6.A
7.



You could measure the size of mussels that oystercatchers successfully open and compare that with the size distribution in the habitat.

Chapter 52

Figure Questions

Figure 52.8 The species' distribution could be altered by dispersal limitations, the activities of people (such as a broad-scale conversion of forests to agriculture or selective harvesting), or many other factors, including those discussed later in the chapter (see Figure 52.18). **Figure 52.18** Some factors, such as fire, are relevant only for terrestrial systems. At first glance, water availability is primarily a terrestrial factor, too. However, species living along the intertidal zone of oceans or along the edge of lakes also suffer desiccation. Salinity stress is important for species in some aquatic and terrestrial systems. Oxygen availability is an important factor primarily for species in some aquatic systems and in soils and sediments.

Concept Check 52.1

1. In the tropics, high temperatures evaporate water and cause warm, moist air to rise. The rising air cools and releases much of its water as rain over the tropics. The remaining dry air descends at approximately 30° north and south, causing deserts to occur in those regions. 2. The microclimate around the stream will be cooler, moister, and shadier than that around the unplanted agricultural field. 3. Trees that require a long time to reach reproductive age are likely to evolve more slowly than annual plants in

response to climate change, constraining the potential ability of such trees to respond to rapid climate change. **4.** Plants with C₄ photosynthesis are likely to expand their range globally as Earth's climate warms. C₄ photosynthesis minimizes photorespiration and enhances sugar production, an advantage that is especially useful in warmer regions where C₄ plants are found today.

Concept Check 52.2

1. The biggest difference between the two biomes is the higher amounts of precipitation that the forest receives. **2.** Answers will vary by location but should be based on the information and maps in Figure 52.13. How much your local area has been altered from its natural state will influence how much it reflects the expected characteristics of your biome, particularly the expected plants and animals. **3.** Northern coniferous forest is likely to replace tundra along the boundary between these biomes. To see why, note that northern coniferous forest is adjacent to tundra throughout North America, northern Europe, and Asia (see Figure 52.10) and that the temperature range for northern coniferous forest is just above that for tundra (see Figure 52.11).

Concept Check 52.3

1. In the oceanic pelagic zone, the ocean bottom lies below the photic zone, so there is too little light to support benthic algae or rooted plants. **2.** Aquatic organisms either gain or lose water by osmosis if the osmolarity of their environment differs from their internal osmolarity. Water gain can cause cells to swell, and water loss can cause them to shrink. To avoid excessive changes in cell volume, organisms that live in estuaries must be able to compensate for both water gain (under freshwater conditions) and water loss (under saltwater conditions). **3.** Oxygen serves as a reactant when decomposers break down the bodies of dead algae using aerobic respiration. Following an algal bloom, there are many dead algae; hence, decomposers may use a lot of oxygen to break down the bodies of dead algae, causing the lake's oxygen levels to drop.

Concept Check 52.4

1. (a) Humans might transplant a species to a new area that it could not previously reach because of a geographic barrier. (b) Humans might eliminate a predator or herbivore species, such as sea urchins, from an area. **2.** One test would be to build a fence around a plot of land in an area that has trees of that species, excluding all deer from the plot. You could then compare the abundance of tree seedlings inside and outside the fenced plot over time. **3.** Because the ancestor of the silverswords reached isolated Hawaii early in the islands' existence, it likely faced little competition and was able to occupy many unfilled niches. The cattle egret, in contrast, arrived in the Americas only recently and has to compete with a well-established group of species. Thus, its opportunities for adaptive radiation have probably been much more limited.

Concept Check 52.5

1. Changes in how organisms interact with one another and their environment can cause evolutionary change. In turn, an evolutionary change, such as an improvement in the ability of a predator to detect its prey, can alter ecological interactions. **2.** As cod adapt to the pressure of commercial fishing by reproducing at younger ages and smaller sizes, the number of offspring they produce each year will be lower. This may cause the population to decline as time goes on, thereby further reducing the population's ability to recover. If that happened, as the population becomes smaller over time, effects of genetic drift might become increasingly important. Drift could, for example, lead to the fixation of harmful alleles, which would further hinder the ability of the cod population to recover from overfishing.

Summary of Key Concepts Questions

52.1 Because dry air would descend at the equator instead of at 30° north and south latitude (where deserts exist today), deserts would be more likely to exist along the equator (see Figure 52.3). **52.2** The dominant plants in savanna ecosystems tend to be adapted to fire and tolerant of seasonal droughts. The savanna biome is maintained by periodic fires, both natural and set by humans, but humans are also clearing savannas for agriculture and other uses. **52.3** An aphotic zone is most likely to be found in the deep waters of a lake, the oceanic pelagic zone, or the marine benthic zone.

52.4 You might arrange a flowchart that begins with abiotic limitations—first determining the physical and chemical conditions under which a species could survive—and then moves through the other factors listed in the flowchart. **52.5** Because the introduced species had few predators or parasites, it might outcompete native species and thereby increase in number and expand its range in the new location. As the introduced species increased in abundance, natural selection might cause evolution in populations of competing species, favoring individuals with traits that made them more effective competitors with the introduced species. Selection could also cause evolution in populations of potential predator or parasite species, in this case favoring individuals with traits that enabled them to take advantage of this new potential source of food. Such evolutionary changes could modify the outcome of ecological interactions, potentially leading to further evolutionary changes, and so on.

Test Your Understanding

1.B 2.B 3.C 4.D 5.C 6.A 7.A 8.B

Chapter 53

Figure Questions

Figure 53.3 The dispersion of the penguins would likely appear clumped as you flew over densely populated islands and sparsely populated ocean.

Figure 53.4 Ten percent (100/1,000) of the females survive to be 3 years old.

Figure 53.6 #109 **Figure 53.7** The population with $r = 1.0$ (blue curve) reaches 1,500 individuals in about 7.5 generations, whereas the population with $r = 0.5$ (red curve) reaches 1,500 individuals in about 14.5 generations.

Figure 53.15

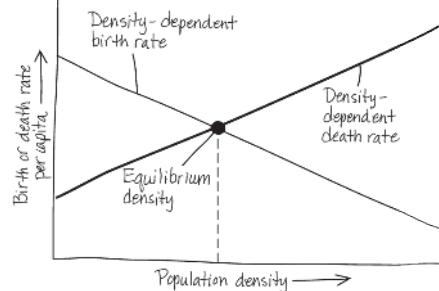
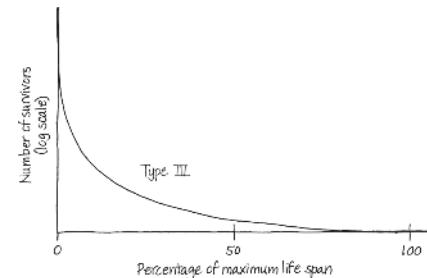


Figure 53.22 Based on Figure 53.21, which highlights the long-term, explosive growth of the human population, one might conclude (mistakenly) that the growth rate of the human population has not decreased in recent decades. However, the growth rate of the human population *has* decreased in recent decades—a slowdown that is evident in the blue curve shown in Figure 53.22. Both curves are accurate, but they convey different messages because they differ in the time scale over which human population size is represented. The time period covered by Figure 53.21 is so long (over 6,000 years in the “unbroken” portion of the x-axis lying to the right of the hatch mark) that the recent slowdown in how fast the human population is growing is not visually apparent. In contrast, Figure 53.22 covers only 100 years, a time period that is short enough to show the recent decrease in the growth rate of the human population.

Figure 53.24 If the average ecological footprint were 8 gha per person, Earth could support about 1.5 billion people in a sustainable fashion. This estimate is obtained by dividing the total amount of Earth's productive land (11.9 billion gha) by the number of global hectares used per person (8 gha/person), which yields 1.49 billion people.

Concept Check 53.1

1.



A Type III survivorship curve is most likely because very few of the young probably survive.

2. The proportion alive at the start of year 0–1 is $485/485 = 1.0$. The proportion alive at the start of year 1–2 is $218/485 = 0.449$. **3.** Male sticklebacks would likely have a uniform pattern of dispersion, with antagonistic interactions maintaining a relatively constant spacing between them.

Concept Check 53.2

1. Although r is constant, the population size (N) is increasing. As r is applied to an increasingly large N , population growth (rN) accelerates, producing the J-shaped curve. **2.** Exponential growth is more likely in the area where a forest was destroyed by fire. The first plants that found suitable habitat there would encounter an abundance of space, nutrients, and light. In the undisturbed forest, competition among plants for these resources would be intense. **3.** The equation for the number of people added to the population each year is $\Delta N/\Delta t = r\Delta N$. Therefore, the net population growth in 2018 was

$$\Delta N/\Delta t = 0.005 \times 327,000,000 = 1,635,000$$

or roughly 1.6 million people. To determine whether the population is growing exponentially, you would need to determine whether $r > 0$ and if it is constant through time (across multiple years).

Concept Check 53.3

1. When N (population size) is small, there are relatively few individuals producing offspring. When N is large, near the carrying capacity, the per capita growth rate is relatively small because it is limited by available resources. The steepest part of the logistic growth curve corresponds to a population with a number of reproducing individuals that is substantial but not yet near carrying capacity.

2. All else being equal, you would expect a plant species to have a larger carrying capacity at the equator than at high latitudes because there is more incident sunlight near the equator. **3.** The sudden change in environmental conditions might alter the phenotypic traits favored by natural selection. Assuming the newly favored traits were encoded at least in part by genes, natural selection might alter gene frequencies in this population. In addition, a substantial drop in the carrying capacity of the population could cause the size of the population to drop considerably. If this occurred, effects of genetic drift could become more pronounced—and that in turn could lead to the fixation of harmful alleles, hindering the ability of the population to rebound in size.

Concept Check 53.4

1. Three key life history traits are when reproduction begins, how often reproduction occurs, and how many offspring are produced per reproductive episode. Organisms differ widely for each of these traits. For example, the age of first reproduction is typically 3–4 years in coho salmon compared to 30 years in loggerhead turtles. Similarly, an agave reproduces only once during its lifetime, whereas an oak tree reproduces many times. Finally, the white rhinoceros produces a single calf when it reproduces, while most insects produce many offspring each time they reproduce. **2.** By preferentially investing in the eggs it lays in the nest, the peacock wrasse increases the chance those eggs will survive. The eggs it disperses widely and does not provide care for are less likely to survive, at least some of the time, but require a lower investment by the adults. (In this sense, the adults avoid the risk of placing all their eggs in one basket.) **3.** If a parent's survival is compromised greatly by bearing young during times of stress, the animal's fitness may increase if it abandons its current young and survives to produce healthier young at a later time.

Concept Check 53.5

1. Three attributes are the size, quality, and isolation of patches. A patch that is larger or of higher quality is more likely to attract individuals and to be a source of individuals for other patches. A patch that is relatively isolated will undergo fewer exchanges of individuals with other patches. **2.** You should have circled the portion of the curve where it is close to K (after generation 10). **3.** You would need to study the population for more than one cycle (longer than 10 years and probably at least 20) before having sufficient data to examine changes through time. Otherwise, it would be impossible to know whether an observed decrease in the population size reflected a long-term trend or was part of the normal cycle. **4.** In negative feedback, the output, or product, of a process slows that process. In populations that have a density-dependent birth rate, such as dune fescue grass, an accumulation of product (more individuals, resulting in a higher population density) slows the process (population growth) by decreasing the birth rate.

Concept Check 53.6

1. A bottom-heavy age structure, with a disproportionate number of young people, portends continuing growth of the population as these young people begin reproducing. In contrast, a more evenly distributed age structure predicts a more stable population size, and a top-heavy age structure predicts a decrease in population size because relatively fewer young people are reproducing. **2.** The growth rate of Earth's human population has dropped by half since the 1960s, from 2.2% in 1962 to 1.1% today. Nonetheless, the yearly increase in population size has not slowed as much because the smaller growth rate is counterbalanced by increased population size; hence, the number of additional people on Earth each year remains enormous—approximately 80 million. **3.** Each student will calculate his or her own ecological footprint. Each of us influences our ecological footprint by how we live—what we eat, how much energy we use, and the amount of waste we generate—as well as by how many children we have. Making choices that reduce our demand for resources makes our ecological footprint smaller.

Summary of Key Concepts Questions

53.1 Ecologists can potentially estimate birth rates by counting the number of young born each year, and they can estimate death rates by seeing how the number of adults changes each year. **53.2** Under the exponential model, both populations will continue to grow to infinite size, regardless of the specific value of r (see Figure 53.7). **53.3** There are many things you can do to increase the carrying capacity of the species, including increasing its food supply, protecting it from predators, and providing more sites for nesting or reproduction. **53.4** Ecological trade-offs are common because organisms do not have access to unlimited amounts of energy and resources. As a result, the use of energy or resources for one function (such as reproduction) can decrease the energy or resources available to support other functions (such as growth or survival). **53.5** An example of a biotic factor is disease caused by a pathogen; natural disasters, such as earthquakes and floods, are examples of abiotic factors. **53.6** Humans are unique in our potential ability to reduce global population through contraception and family planning. Humans also are capable of consciously choosing their diet and personal lifestyle, and these choices influence the number of people Earth can support.

Test Your Understanding

1.B 2.A 3.A 4.D 5.C 6.B 7.C 8.A 9.C

Chapter 54

Figure Questions

Figure 54.3 Its realized and fundamental niches would be similar, unlike those of *Chthamalus*. Figure 54.5 Beak depths in the *G. fortis* population would likely decrease over time. With the extinction of *G. fuliginosa*, the small seeds eaten by that species would increase in abundance. As a result, natural selection would favor *G. fortis* individuals with smaller beaks because those individuals can eat small seeds more efficiently than could *G. fortis* individuals with larger beaks. Figure 54.6 Individuals of a harmless species that resembled a distantly related harmful species might be attacked by predators less often than were other individuals that did not resemble the harmful species. As a result, individuals of the harmless species that resembled a harmful species would tend to contribute more offspring to the next generation than would other individuals of the harmless species. Over time, as natural selection by predators continued to favor those individuals of the harmless species that most closely resembled the harmful species, the resemblance of the harmless species to the harmful species would increase. However, selection is not the only process that could cause

a harmless species to resemble a closely related harmful species. In this case, the two species could also resemble each other because they descended from a recent common ancestor and hence share many traits (including a resemblance to one another). **Figure 54.16** An increase in the abundance of carnivores that eat zooplankton might cause zooplankton abundance to drop, thereby causing phytoplankton abundance to increase. **Figure 54.17** The number of types of organisms eaten is zero for phytoplankton; one for copepods, crab-eater seals, and baleen whales; two for krill, carnivorous plankton, elephant seals, and sperm whales; three for squids, fishes, and leopard seals; and five for birds and smaller toothed whales. The two groups that both consume and are consumed by each other are fishes and squids. **Figure 54.18** Zooplankton are primary consumers of phytoplankton. Fish larvae are secondary consumers of zooplankton. Sea nettles function as secondary consumers when they eat zooplankton, but as tertiary consumers when they eat fish larvae. Juvenile striped bass are tertiary consumers of fish larvae. **Figure 54.20** The death of individuals of *Mytilus*, a competitively dominant species, should open up space for individuals of other species and thereby increase species richness even in the absence of *Pisaster*. **Figure 54.27** At the earliest stages of primary succession, free-living prokaryotes in the soil would reduce atmospheric N_2 to NH_3 . Symbiotic nitrogen fixation could not occur until plants were present at the site. **Figure 54.31** We would expect that (a) population sizes would decrease because there would be fewer resources and less suitable habitat; (b) the extinction curve would rise more rapidly as the number of species on the island increased because small islands generally have fewer resources, less diverse habitats, and smaller population sizes; and (c) the predicted equilibrium species number would be smaller than shown in Figure 54.31. **Figure 54.34** Shrew populations in different locations and habitats might show substantial genetic variation in their susceptibility to the Lyme pathogen. As a result, there might be fewer infected ticks where shrew populations are less susceptible to the Lyme pathogen and more infected ticks where shrews are more susceptible.

Concept Check 54.1

- Competition has negative effects on individuals of both species (−/−). In predation, members of the predator population benefit by killing and eating members of the prey population; this is an example of exploitation (+/−). Mutualism is an interaction in which individuals of both species benefit (+/+).
- One of the competing species will become locally extinct because of the greater reproductive success of the more efficient competitor. **3.** By specializing in eating seeds of different plant species, individuals of the two finch species may be less likely to come into contact in the separate habitats, thereby reinforcing a reproductive barrier to hybridization.

Concept Check 54.2

1. Species richness, the number of species in the community, and relative abundance, the proportions of the community represented by the various species, both contribute to species diversity. Compared to a community with a very high proportion of one species, one with a more even proportion of species is considered more diverse. **2.** A food chain presents a set of one-way transfers of food energy up to successively higher trophic levels. A food web documents how food chains are linked together, with many species weaving into the web at more than one trophic level. **3.** In bottom-up control, adding extra predators would have little effect on lower trophic levels, particularly vegetation. If top-down control applied, increased bobcat numbers would decrease raccoon numbers, increase snake numbers, decrease mouse numbers, and increase grass biomass. **4.** A decrease in krill abundance might increase the abundance of organisms that krill eat (phytoplankton and copepods), while decreasing the abundance of organisms that eat krill (baleen whales, crabeater seals, birds, fishes, and carnivorous plankton); baleen whales and crabeater seals might be particularly at risk because they eat only krill. However, many of these possible changes could lead to other changes as well, making the overall outcome hard to predict. For example, a decrease in krill abundance could cause an increase in copepod abundance—but an increase in copepod abundance could counteract some of the other effects of decreased krill abundance (since like krill, copepods eat phytoplankton and are eaten by carnivorous plankton and fishes).

Concept Check 54.3

- High levels of disturbance are generally so disruptive that they eliminate many species from communities, leaving the community dominated by a few tolerant species. Low levels of disturbance permit competitively dominant species to exclude other species from the community. On the other hand, moderate levels of disturbance can facilitate coexistence of a greater number of species in a community by preventing competitively dominant species from becoming abundant enough to eliminate other species from the community. **2.** Early successional species can facilitate the arrival of other species in many ways, including increasing the fertility or water-holding capacity of soils or providing shelter to seedlings from wind and intense sunlight. **3.** The absence of fire for 100 years would represent a change to a low level of disturbance. According to the intermediate disturbance hypothesis, this change should cause diversity to decline as competitively dominant species gain sufficient time to exclude less competitive species.

Concept Check 54.4

- Ecologists propose that the greater species richness of tropical regions is the result of their longer evolutionary history and the greater solar energy input and water availability in tropical regions. **2.** Immigration of species to islands declines with distance from the mainland and increases with island area. Extinction of species is lower on larger islands and on less isolated islands. Since the number of species on islands is largely determined by the difference between rates of immigration and extinction, the number of species will be highest on

large islands near the mainland and lowest on small islands far from the mainland. **3.** Because of their greater mobility, birds disperse to islands more often than snakes and lizards, so birds should have greater richness.

Concept Check 54.5

- Pathogens are microorganisms, viruses, viroids, or prions that cause disease.
- To keep the rabies virus out, you could ban imports of all mammals, including pets. Potentially, you could also attempt to vaccinate all dogs in the British Isles against the virus. A more practical approach might be to quarantine all pets brought into the country that are potential carriers of the disease, the approach the British government actually takes.

Summary of Key Concepts Questions

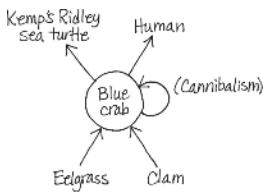
54.1 Note: Sample answers follow; other answers could also be correct. Competition: a fox and a bobcat competing for prey. Predation: an orca eating a sea otter. Herbivory: a bison eating grass. Parasitism: a parasitoid wasp that lays its eggs on a caterpillar. Mutualism: a fungus and an alga that make up a lichen. Commensalism: a wildflower that grows in a maple forest and a maple tree. **54.2** Not necessarily if the more species-rich community is dominated by only one or a few species.

54.3 Similar to clear-cutting a forest or plowing a field, some species would be present initially. As a result, the disturbance would initiate secondary succession in spite of its severe appearance. **54.4** Glaciations are major disturbances that can completely destroy communities found in temperate and polar regions. As a result, tropical communities may be older than temperate or polar communities. This can cause species diversity to be high in the tropics simply because there has been more time for speciation to occur. **54.5** A keystone species is one with a pivotal ecological role. Hence, a pathogen that reduces the abundance of (or otherwise harms) a keystone species could greatly alter the structure of the community. For example, if a novel pathogen drove a keystone species to local extinction, drastic changes in species diversity could occur.

Test Your Understanding

1. D 2. C 3. C 4. C 5. B 6. C 7. D 8. B

9. Community 1: $H = -(0.05 \ln 0.05 + 0.05 \ln 0.05 + 0.85 \ln 0.85 + 0.05 \ln 0.05) = 0.59$. Community 2: $H = -(0.30 \ln 0.30 + 0.40 \ln 0.40 + 0.30 \ln 0.30) = 1.1$. Community 2 is more diverse. 10. Crab numbers should increase, reducing the abundance of eelgrass.



Chapter 55

Figure Questions

Figure 55.4 The blue arrow leading to *Primary consumers* could represent a grasshopper feeding on a plant. The blue arrow leading from *Primary consumers* to *Detritus* could represent the remains of a dead primary consumer (such as a grasshopper) becoming part of the detritus found in the ecosystem. The blue arrow leading from *Primary consumers* to *Secondary and tertiary consumers* could represent a bird (the secondary consumer) eating a grasshopper (the primary consumer). Finally, the blue arrow leading from *Primary consumers* to *Primary producers* could represent CO₂ released by a grasshopper in cellular respiration. **Figure 55.5** The map does not accurately reflect the productivity of wetlands, coral reefs, and coastal zones because these habitats cover areas that are too small to show up clearly on global maps. **Figure 55.6** New duck farms would add extra nitrogen and phosphorus to the water samples used in the experiment. We would expect that the extra phosphorus from these new duck farms would not alter the results (because in the original experiment, phosphorus levels were already so high that adding phosphorus did not increase phytoplankton growth). However, the new duck farms might increase nitrogen levels to the point where adding extra nitrogen in an experiment would not increase phytoplankton density. **Figure 55.12** The availability of water and exposure to light are other factors that may have varied across the sites. Factors such as those that are not included in the experimental design could make the results more difficult to interpret. Multiple factors can also be correlated to each other in nature, so ecologists must be careful that the factor they are studying is actually causing the observed response and is not just correlated with it. **Figure 55.13** (1) If the rate of decomposition slowed, more organic materials would be transferred from reservoir A to reservoir B; eventually, this might lead to more organic material becoming fossilized into fossil fuels. In addition, a decrease in decomposition rate would cause fewer inorganic materials to become available as nutrients in reservoir C, which would ultimately slow the rates of nutrient uptake and photosynthesis by living organisms. (2) Materials move into and out of reservoir A on a much shorter time scale than they move into reservoir B. Materials may remain in reservoir B for a very long time, or humans may remove them at a rapid pace by excavating and burning fossil fuels. **Figure 55.15** If the y-axis had a consistent scale with no break, the change in nitrate concentration in runoff from one tick mark to the next would remain constant throughout the entire axis. For example, if the y-axis were redrawn to have a consistent scale that ran from 0 to 80 mg/L with nine evenly spaced tick marks, the nitrate concentration would increase by 10 mg/L from each tick mark to the next. Drawing the graph with a consistent scale would emphasize the dramatic increase in nitrate concentration that occurred in 1966,

but it would be harder to see other, comparatively small changes that occurred from 1965 to 1968 in both control and deforested areas. **Figure 55.19** Populations evolve as organisms interact with each other and with the physical and chemical conditions of their environment. As a result, any human action that alters the environment has the potential to cause evolutionary change. In particular, since climate change has greatly affected arctic ecosystems, we would expect that climate change will cause evolution in arctic tundra populations.

Concept Check 55.1

- Energy passes through an ecosystem, entering as sunlight and leaving as heat. It is not recycled within the ecosystem.
- You would need to know how much biomass the wildebeests ate from your plot and how much nitrogen was contained in that biomass. You would also need to know how much nitrogen they deposited in urine or feces.
- The second law states that in any energy transfer or transformation, some of the energy is dissipated to the surroundings as heat. For the ecosystem to remain intact, this "escape" of energy from the ecosystem must be offset by the continuous influx of solar radiation.

Concept Check 55.2

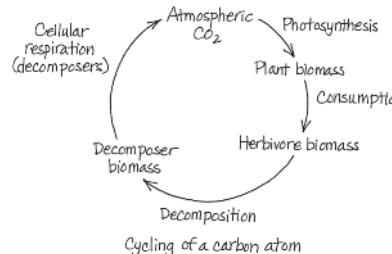
- Only a fraction of solar radiation strikes plants or algae, only a portion of that fraction is of wavelengths suitable for photosynthesis, and much energy is reflected or lost as heat.
- By manipulating the level of the factors of interest, such as phosphorus availability or soil moisture, and measuring responses by primary producers
- It is likely that NEP would decline after the fire. To see why, recall that NEP = GPP - R_T, where GPP is gross primary production and R_T is the total amount of cellular respiration in the ecosystem. By killing trees and other plants, the fire would cause GPP to decline from its pre-fire level. In addition, as decomposers broke down the remains of trees killed by fire, the overall amount of cellular respiration (R_T) in the ecosystem could increase (because of increased cellular respiration by decomposers).
- The enzyme rubisco, which catalyzes the first step in the Calvin cycle, is the most abundant protein on Earth. Like all proteins, rubisco contains nitrogen, and because photosynthetic organisms require so much rubisco, they also require considerable nitrogen to make it. Phosphorus is also needed as a component of several metabolites in the Calvin cycle and as a component of both ATP and NADPH (see Figure 10.19).

Concept Check 55.3

- 20 J; 40%
- Nicotine protects the plant from herbivores.
- Total net primary production is 10,000 + 1,000 + 100 + 10 J = 11,110 J. This is the amount of energy theoretically available to decomposers.

Concept Check 55.4

- For example, for the carbon cycle:



- Removal of the trees stops nitrogen uptake from the soil, allowing nitrate to accumulate in the soil. The nitrate is washed away by precipitation and enters the streams.
- Most of the nutrients in a tropical rain forest are contained in the trees, so removing the trees by logging rapidly depletes nutrients from the ecosystem. The nutrients that remain in the soil are quickly carried away into streams and groundwater by the abundant precipitation.

Concept Check 55.5

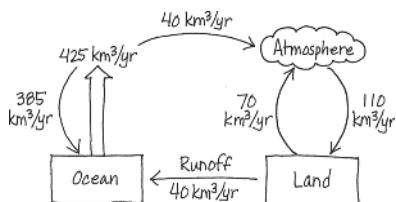
- The main goal is to restore degraded ecosystems to a more natural state.
- Bioremediation uses organisms—generally prokaryotes, fungi, or plants—to detoxify or remove pollutants from ecosystems. Biological augmentation uses organisms, such as nitrogen-fixing plants, to add essential materials to degraded ecosystems.
- The Kissimmee River project returns the flow of water to the original channel and restores natural flow, a self-sustaining outcome. Ecologists at the Maungatautari reserve will need to maintain the integrity of the fence indefinitely, an outcome that is not self-sustaining in the long term.

Summary of Key Concepts Questions

55.1 Because energy conversions are inefficient, with some energy inevitably lost as heat, you would expect that a given mass of primary producers would support a smaller biomass of consumers. **55.2** If you know NPP and want to estimate NEP, you must be able to determine how much of the total respiration (R_T) results from heterotrophs and how much results from autotrophs. In a sample of ocean water, primary producers and other organisms are usually mixed together, making their respective respirations hard to separate. **55.3** Runners use much more energy in respiration when they are running than when they are sedentary, reducing their production efficiency. **55.4** Factors other than temperature, including a shortage of water and nutrients, slow decomposition in hot deserts. **55.5** If the topsoil and deeper soil are kept separate, the engineers could return the deeper soil to the site first and then apply the more fertile topsoil to improve the success of revegetation and other restoration efforts.

Test Your Understanding

- 1.B 2.B 3.A 4.C 5.A 6.D 7.D 8.D
9.(a)



(b) On average, the ratio is 1, with equal amounts of water moving from the ocean to land as precipitation and moving from land to ocean in runoff. (c) During an ice age, the amount of ocean evaporation falling on land as precipitation would be greater than the amount returning to the oceans in runoff; thus, the ratio would be 71. The difference would build up on land as ice.

Chapter 56

Figure Questions

Figure 56.3 You would need to know the complete range of the species and that it is missing across all of that range. You would also need to be certain that the species isn't hidden, as might be the case for an animal that is hibernating underground or a plant that is present in the form of seeds or spores. **Figure 56.8** The two examples are similar in that segments of DNA from the harvested samples were analyzed and compared with segments from specimens of known origin. One difference is that the whale researchers investigated relatedness at species and population levels to determine whether illegal activity had occurred, whereas the elephant investigators determined relatedness at the population level to determine the precise location of the poaching. Another difference is that mtDNA was used for the whale study, whereas nuclear DNA was used for the elephant study. The primary limitations of such approaches are the need to have (or generate) a reference database and the requirement that the organisms have sufficient variation in their DNA to reveal the relatedness of samples.

Figure 56.10 The higher the pH, the lower the acidity. Thus, the precipitation in this forest is becoming less acidic. **Figure 56.12** Answers may vary, but there are two reasons not to support transplanting additional birds. First, the Illinois population has a different genetic makeup than birds in other regions, and you would want to maintain to the greatest extent possible the frequency of beneficial genes or alleles found only in the Illinois population. Second, the translocation of birds from other states already caused the percentage of hatched eggs to increase dramatically, indicating that the transplantation of additional birds is not necessary. **Figure 56.14** The natural disturbance regime in this habitat includes frequent fires that clear undergrowth but do not kill mature pine trees. Without these fires, the undergrowth quickly fills in and the habitat becomes unsuitable for red-cockaded woodpeckers. **Figure 56.16** The photo shows edges between forest and grassland ecosystems, and grassland and river ecosystems. **Figure 56.24** The PCB concentration increased by a factor of 4.9 from phytoplankton to zooplankton, 41.6 from phytoplankton to smelt, 8.5 from zooplankton to smelt, 4.6 from smelt to lake trout, 119.2 from smelt to herring gull eggs, and 25.7 from lake trout to herring gull eggs. **Figure 56.31** Ocean acidification reduces the availability of carbonate ions (CO_3^{2-}). Corals and many other marine organisms require carbonate ions to build their shells. Since shell-building organisms depend upon their shells for survival, scientists have predicted that ocean acidification will cause many shell-building organisms to die. In turn, increased mortality rates of organisms that build shells would cause many other changes to ecological communities. For example, increased mortality rates of corals would harm the many other species that seek protection in coral reefs or that feed upon the species living there. **Figure 56.32** The model results in the blue curve (natural factors only) and the results in the purple curve (natural and human factors) both provide a good match to observed temperature changes until about 1960. After 1960, however, the results in the blue curve are a poor match to observed temperature changes, whereas the results in the purple curve continue to provide a good match. These results suggest that human activities such as burning fossil fuels have contributed to the observed rise in global temperatures, especially for the period 1960 to the present.

Concept Check 56.1

1. In addition to species loss, the biodiversity crisis includes the loss of genetic diversity within populations and species and the degradation of entire ecosystems. 2. Habitat destruction, such as deforestation, channelizing of rivers, or conversion of natural ecosystems to agriculture or cities, deprives species of places to live. Introduced species, which are transported by humans to regions outside their native range, often reduce the population sizes of native species through competition or by feeding on them (as predators, herbivores, or pathogens). Overharvesting has reduced populations of plants and animals or driven them to extinction. Finally, global change is altering the environment to the extent that it reduces the capacity of Earth to sustain life. 3. If both populations breed separately, then gene flow between the populations would not occur and genetic differences between them would be greater. As a result, the loss of genetic diversity would be greater than if the populations interbreed.

Concept Check 56.2

1. Reduced genetic variation decreases the capacity of a population to evolve in the face of change. 2. The effective population size, N_e , would be

$4(30 \times 10)/(30 + 10) = 30$ birds. 3. Because millions of people use the greater Yellowstone ecosystem each year, it would be impossible to eliminate all contact between people and bears. Instead, you might try to reduce the kinds of encounters where bears are killed. You might recommend lower speed limits on roads in the park, adjust the timing or location of hunting seasons (where hunting is allowed outside the park) to minimize contact with mother bears and cubs, and provide financial incentives for livestock owners to try alternative means of protecting livestock, such as using guard dogs.

Concept Check 56.3

1. A small area supporting numerous endemic species as well as a large number of endangered and threatened species 2. Zoned reserves may provide sustained supplies of forest products, water, hydroelectric power, educational opportunities, and income from tourism. 3. Habitat corridors can increase the rate of movement or dispersal of organisms between habitat patches and thus the rate of gene flow between subpopulations. They thus help prevent a decrease in fitness attributable to inbreeding. They can also minimize interactions between organisms and humans as the organisms disperse; in cases involving potential predators, such as bears or large cats, minimizing such interactions is desirable.

Concept Check 56.4

1. Adding nutrients causes population explosions of algae and the organisms that feed on them. Increased respiration by algae and consumers, including decomposers, depletes the lake's oxygen, which the fish require. 2. Decomposers are consumers that use nonliving organic matter as fuel for cellular respiration, which releases CO_2 as a by-product. Because higher temperatures lead to faster decomposition, organic matter in these soils could be decomposed to CO_2 more rapidly, thereby speeding up global warming. 3. Reduced concentrations of ozone in the atmosphere increase the amount of UV radiation that reaches Earth's surface and the organisms living there. UV radiation can cause mutations by producing disruptive thymine dimers in DNA.

Concept Check 56.5

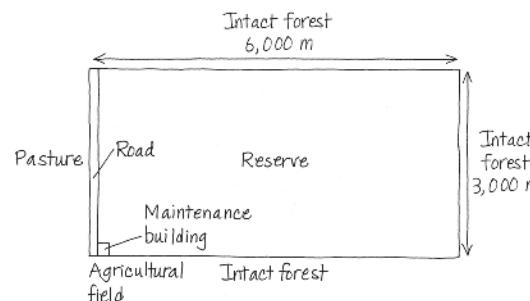
1. Sustainable development is an approach to development that works toward the long-term prosperity of human societies and the ecosystems that support them, which requires linking the biological sciences with the social sciences, economics, and humanities. 2. Biophilia, our sense of connection to nature and all forms of life, may act as a significant motivation for the development of an environmental ethic that resolves not to allow species to become extinct or ecosystems to be destroyed. Such an ethic is necessary if we are to become more attentive and effective custodians of the environment. 3. At a minimum, you would want to know the size of the population and the average reproductive rate of the individuals in it. To develop the fishery sustainably, you would seek a harvest rate that maintains the population near its original size and maximizes its harvest in the long term rather than the short term.

Summary of Key Concepts Questions

56.1 Nature provides us with many beneficial services, including a supply of reliable, clean water, the production of food and fiber, and the dilution and detoxification of our pollutants. **56.2** A more genetically diverse population is better able to withstand pressures from disease or environmental change, making it less likely to become extinct over a given period of time. **56.3** Habitat fragmentation can isolate populations, leading to inbreeding and genetic drift, and it can make populations more susceptible to local extinctions resulting from edge effects, including a change in physical conditions and an increase in competition or predation with edge-adapted species. **56.4** It's healthier to feed at a lower trophic level because biological magnification increases the concentration of toxins at higher levels. **56.5** One goal of conservation biology is to preserve as many species as possible. Sustainable approaches that maintain the quality of habitats are required for the long-term survival of organisms.

Test Your Understanding

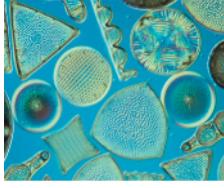
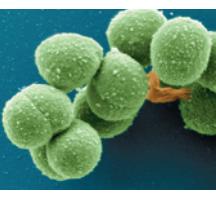
- 1.C 2.D 3.B 4.A 5.B 6.D
7.



To minimize the area of forest into which the cowbirds penetrate, you should locate the road along the west edge of the reserve (since that edge abuts deforested pasture and an agricultural field). Any other location would increase the area of affected habitat. Similarly, the maintenance building should be in the southwest corner of the reserve to minimize the area susceptible to cowbirds.

APPENDIX B Classification of Life

This appendix presents a taxonomic classification for the major extant groups of organisms discussed in this text; not all phyla are included. The classification presented here is based on the three-domain system, which assigns the two major groups of prokaryotes, bacteria and archaea, to separate domains (with eukaryotes making up the third domain).

DOMAIN BACTERIA	DOMAIN EUKARYA
<ul style="list-style-type: none">▪ Proteobacteria▪ Chlamydia▪ Spirochetes▪ Cyanobacteria▪ Gram-positive Bacteria 	<p>In the phylogenetic hypothesis we present in Chapter 28, major clades of eukaryotes are grouped together in the four “supergroups” listed in blue type. Formerly, all the eukaryotes generally called protists were assigned to a single kingdom, Protista. However, advances in systematics have made it clear that some protists are more closely related to plants, fungi, or animals than they are to other protists. As a result, the kingdom Protista has been abandoned.</p> <p>Excavata</p> <ul style="list-style-type: none">▪ Diplomonadida (diplomonads)▪ Parabasala (parabasalids)▪ Euglenozoa (euglenozoans)<ul style="list-style-type: none">Kinetoplastida (kinetoplastids)Euglenophyta (euglenids) <p>SAR</p> <ul style="list-style-type: none">▪ Stramenopila (stramenopiles)<ul style="list-style-type: none">Oomycota (oomycetes)Phaeophyta (brown algae)Bacillariophyta (diatoms)  <p>Archaeplastida</p> <ul style="list-style-type: none">▪ Rhodophyta (red algae)▪ Chlorophyta (green algae: chlorophytes)▪ Charophyta (green algae: charophytes)▪ Plantae<ul style="list-style-type: none">Phylum Hepatophyta (liverworts)Phylum Bryophyta (mosses)Phylum Anthocerophyta (hornworts)Phylum Lycophyta (lycophytes)Phylum Monilophyta (ferns, horsetails, whisk ferns)▪ Ginkgophyta (ginkgo)▪ Cycadophyta (cycads)▪ Gnetophyta (gnetophytes)▪ Coniferophyta (conifers)▪ Anthophyta (flowering plants)  <p>Nonvascular plants (bryophytes) Seed plants</p> <p>Gymnosperms Angiosperms</p>
DOMAIN ARCHAEA	
<ul style="list-style-type: none">▪ Euryarchaeota▪ Thaumarchaeota▪ Aigarchaeota▪ Crenarchaeota▪ Korarchaeota 	<ul style="list-style-type: none">▪ Alveolata (alveolates)<ul style="list-style-type: none">Dinoflagellata (dinoflagellates)Apicomplexa (apicomplexans)Ciliophora (ciliates)▪ Rhizaria (rhizarians)<ul style="list-style-type: none">Radiolaria (radiolarians)Foraminifera (forams)Cercozoa (cercozoans)

Various alternative classification schemes are discussed in Unit Five of the text. The taxonomic turmoil includes debates about the number and boundaries of kingdoms and about the alignment of the Linnaean classification hierarchy with the findings of modern cladistic analysis.

DOMAIN EUKARYA, continued

Unikonta (also called Amorphea)

- Amoebozoa (amoebozoans)
 - Tubulinida (tubulinids)
 - Myxogastrida (plasmodial slime molds)
 - Dictyostelida (cellular slime molds)
 - Entamoeba (entamoebas)
- Nucleariida (nucleariids)
- Fungi
 - Phylum Cryptomycota (cryptomycetes)
 - Phylum Microsporidia (microsporidians)
 - Phylum Chytridiomycota (chytrids)
 - Phylum Zoopagomycota (zoopagomycetes)
 - Phylum Mucoromycota (mucoromycetes)
 - Phylum Ascomycota (ascomycetes)
 - Phylum Basidiomycota (basidiomycetes)



- Choanoflagellata (choanoflagellates)
- Animalia
 - Phylum Porifera (sponges)
 - Phylum Ctenophora (comb jellies)
 - Phylum Cnidaria (cnidarians)
 - Medusozoa (hydrozoans, jellies, box jellies)
 - Anthozoa (sea anemones and most corals)
 - Phylum Acoela (acoel flatworms)
 - Phylum Placozoa (placozoans)
- Lophotrochozoa (lophotrochozoans)
 - Phylum Platyhelminthes (flatworms)
 - Catenulida (chain worms)
 - Rhabditophora (planarians, flukes, tapeworms)
 - Phylum Nemertea (ribbon worms)
 - Phylum Ectoprocta (ectoprocts)
 - Phylum Brachiopoda (brachiopods)
 - Phylum Syndermata (rotifers and spiny-headed worms)
 - Phylum Gastrotricha (gastrotrichs)
 - Phylum Cycliophora (cycliophorans)
 - Phylum Mollusca (molluscs)
 - Polyplacophora (chitons)
 - Gastropoda (gastropods)
 - Bivalvia (bivalves)
 - Cephalopoda (cephalopods)

Phylum Annelida (segmented worms)

Errantia (errantians)

Sedentaria (sedentarians)

Ecdysozoa (ecdysozoans)

Phylum Loricifera (loriciferans)

Phylum Priapula (priapulans)

Phylum Nematoda (roundworms)

Phylum Arthropoda (This survey groups arthropods into a single phylum, but some zoologists now split the arthropods into multiple phyla.)

Chelicerata (horseshoe crabs, arachnids)

Myriapoda (millipedes, centipedes)

Pancrustacea (crustaceans, insects)

Phylum Tardigrada (tardigrades)

Phylum Onychophora (velvet worms)

Deuterostomia (deuterostomes)

Phylum Hemichordata (hemichordates)

Phylum Echinodermata (echinoderms)

Asteroidea (sea stars, sea daisies)

Ophiuroidea (brittle stars)

Echinoidea (sea urchins, sand dollars)

Crinoidea (sea lilies)

Holothuroidea (sea cucumbers)

Phylum Chordata (chordates)

Cephalochordata (cephalochordates: lancelets)

Urochordata (urochordates: tunicates)

Cyclostomata (cyclostomes)

Myxini (hagfishes)

Petromyzontida (lampreys)

Gnathostomata (gnathostomes)

Chondrichthyes (sharks, rays, chimaeras)

Actinopterygii (ray-finned fishes)

Actinistia (coelacanths)

Diplopoda (lungfishes)

Amphibia (amphibians: frogs,

salamanders, caecilians)

Reptilia (reptiles: tuataras, lizards,

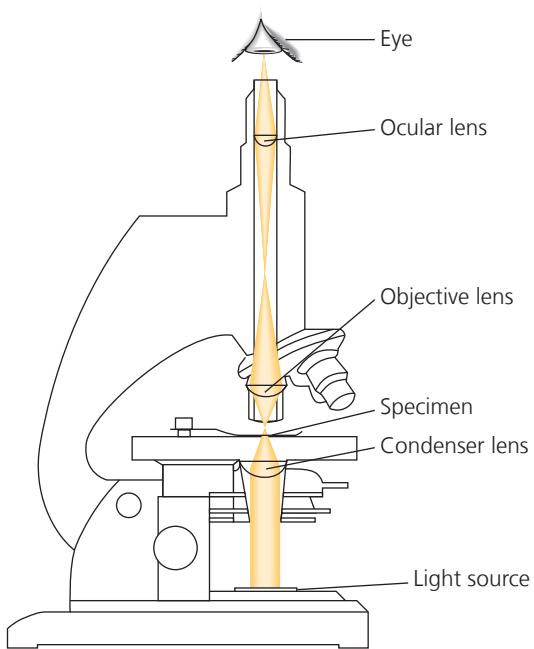
snakes, turtles, crocodilians, birds)

Mammalia (mammals)

Vertebrates

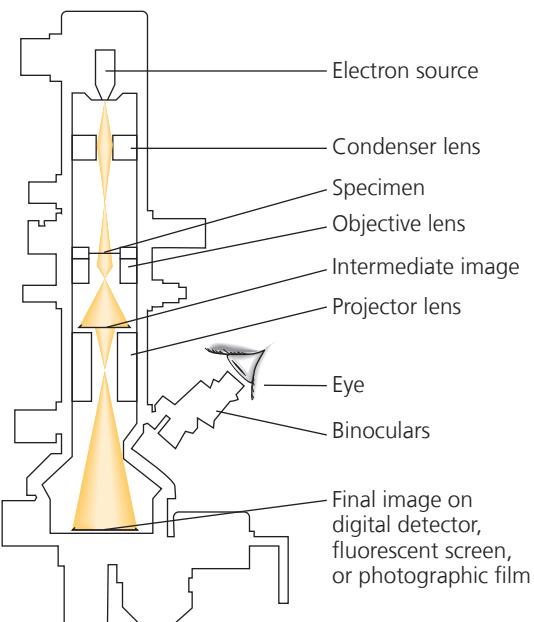


A Comparison of the Light Microscope and the Electron Microscope



Light Microscope

In light microscopy, light is focused on a specimen by a glass condenser lens; the image is then magnified by an objective lens and an ocular lens for projection on the eye, digital camera, digital video camera, or photographic film.



Electron Microscope

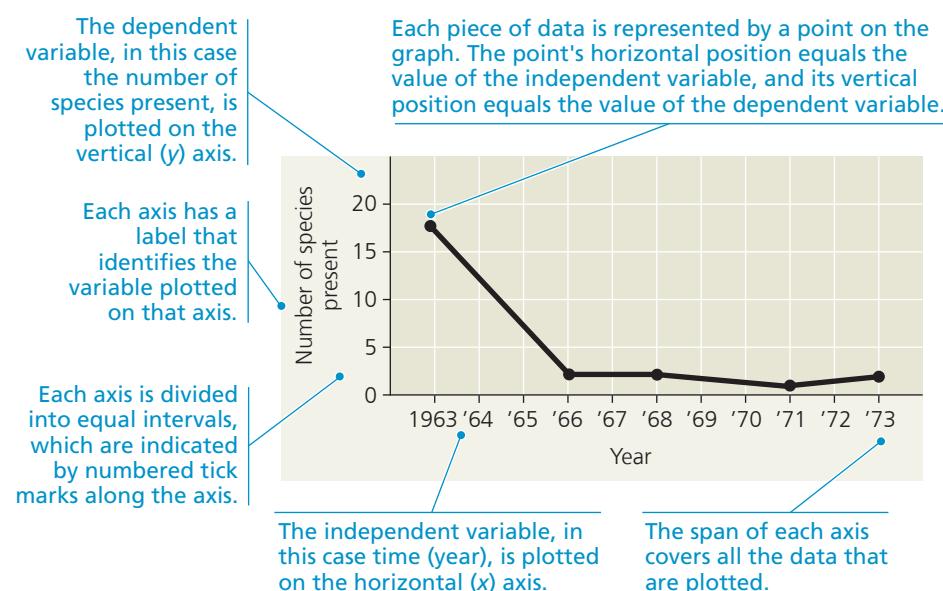
In electron microscopy, a beam of electrons (top of the microscope) is used instead of light, and electromagnets are used instead of glass lenses. The electron beam is focused on the specimen by a condenser lens; the image is magnified by an objective lens and a projector lens for projection on a digital detector, fluorescent screen, or photographic film.

APPENDIX D Scientific Skills Review

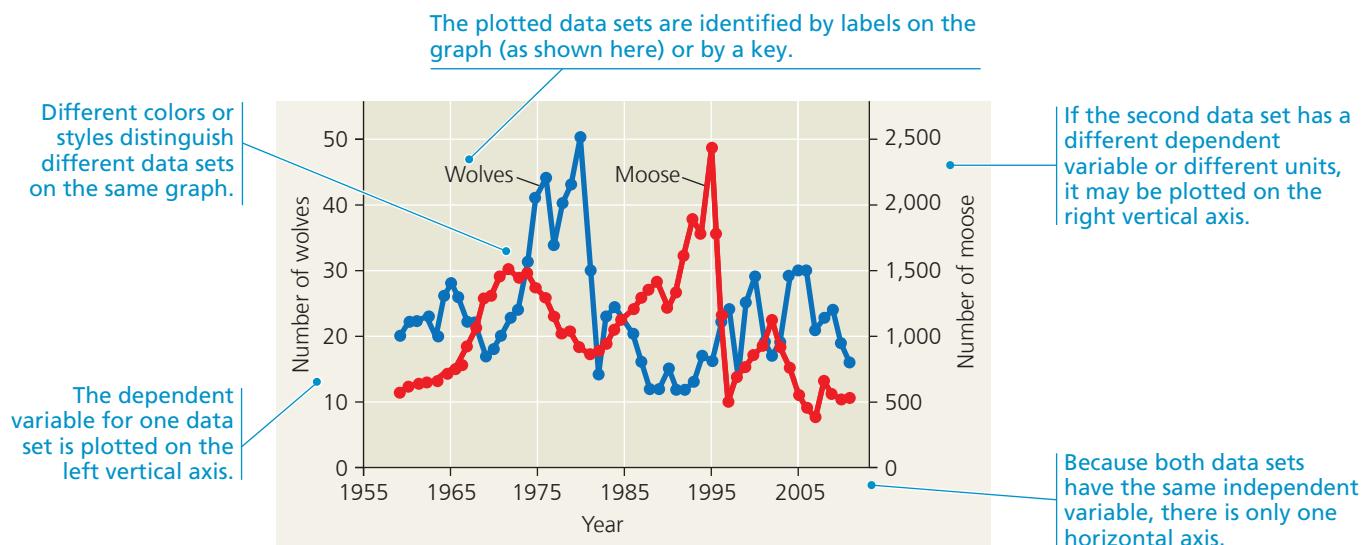
Graphs

Graphs provide a visual representation of numerical data. They may reveal patterns or trends in the data that are not easy to recognize in a table. A graph is a diagram that shows how one variable in a data set is related (or perhaps not related) to another variable. The **independent variable** is the factor that is manipulated or changed by the researchers. The **dependent variable** is the factor that the researchers are measuring in relation to the independent variable. The independent variable is typically plotted on the *x*-axis and the dependent variable on the *y*-axis. Types of graphs that are frequently used in biology include scatter plots, line graphs, bar graphs, and histograms.

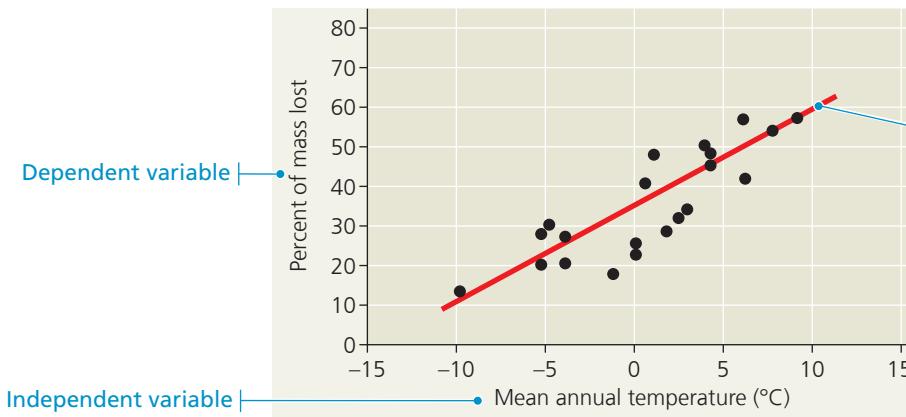
- A **scatter plot** is used when the data for all variables are numerical and continuous. Each piece of data is represented by a point. In a **line graph**, each data point is connected to the next point in the data set with a straight line, as in the graph to the right. (To practice making and interpreting scatter plots and line graphs, see the Scientific Skills Exercises in Chapters 2, 3, 7, 8, 10, 13, 19, 24, 34, 43, 47, 49, 50, 52, 54, and 56.)



- ▼ Two or more data sets can be plotted on the same line graph to show how two dependent variables are related to the same independent variable. (To practice making and interpreting line graphs with two or more data sets, see the Scientific Skills Exercises in Chapters 7, 43, 47, 49, 50, 52, and 56.)

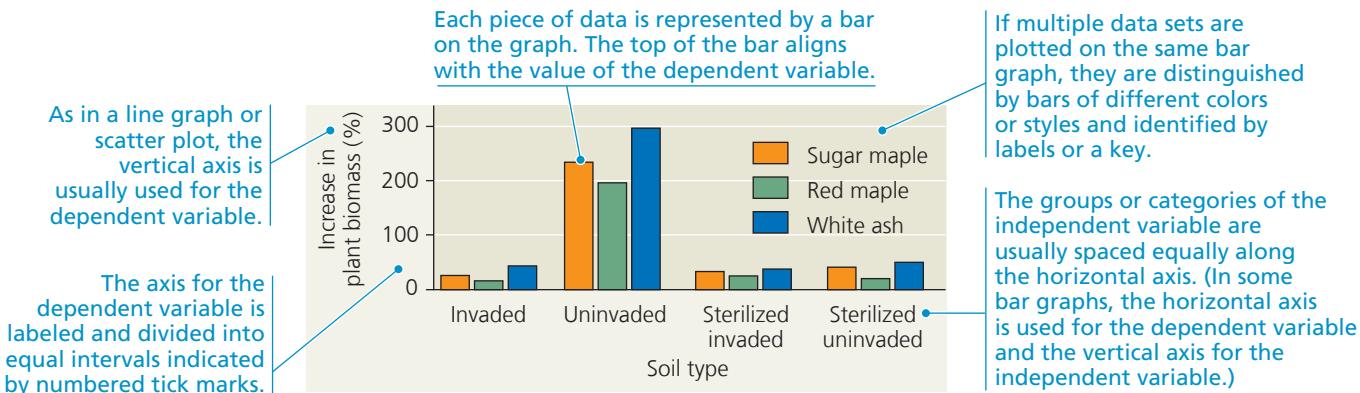


- ▼ In some scatter plot graphs, a straight or curved line is drawn through the entire data set to show the general trend in the data. A straight line that mathematically best fits the data is called a *regression line*. Alternatively, a mathematical function that best fits the data may describe a curved line, often termed a *best-fit curve*. (To practice making and interpreting regression lines, see the Scientific Skills Exercises in Chapters 3, 10, and 34.)



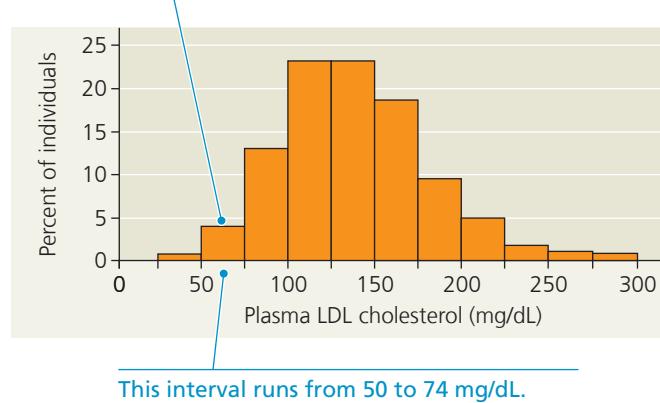
The regression line can be expressed as a mathematical equation. It allows you to predict the value of the dependent variable for any value of the independent variable within the span of the data set and, less commonly, beyond the span of the data.

- ▼ A **bar graph** is a kind of graph in which the independent variable represents groups or nonnumerical categories and the values of the dependent variable(s) are shown by bars. (To practice making and interpreting bar graphs, see the Scientific Skills Exercises in Chapters 1, 9, 18, 22, 25, 29, 33, 35, 39, 51, 52, and 54.)



- A variant of a bar graph called a **histogram** can be made for numeric data by first grouping, or “binning,” the variable plotted on the x-axis into intervals of equal width. The “bins” may be integers or spans of numbers. In the histogram at right, the intervals are 25 mg/dL wide. The height of each bar shows the percent (or, alternatively, the number) of experimental subjects whose characteristics can be described by one of the intervals plotted on the x-axis. (To practice making and interpreting histograms, see the Scientific Skills Exercises in Chapters 12, 14, and 42.)

The height of this bar shows the percent of individuals (about 4%) whose plasma LDL cholesterol levels are in the interval indicated on the x-axis.



Glossary of Scientific Inquiry Terms

See Concept 1.3 for more discussion of the process of scientific inquiry.

control group In a controlled experiment, a set of subjects that lacks (or does not receive) the specific factor being tested. Ideally, the control group is identical to the experimental group in other respects.

controlled experiment An experiment designed to compare an experimental group with a control group; ideally, the two groups differ only in the factor being tested.

data Recorded observations.

deductive reasoning A type of logic in which specific results are predicted from a general premise.

dependent variable A factor whose value is measured during an experiment to see whether it is influenced by changes in another factor (the independent variable).

experiment A scientific test. Often carried out under controlled conditions that involve manipulating one factor in a system in order to see the effects of changing that factor.

experimental group A set of subjects that has (or receives) the specific factor being tested in a controlled experiment. Ideally, the

experimental group is identical to the control group for all other factors.

hypothesis A testable explanation for a set of observations based on the available data and guided by inductive reasoning. A hypothesis is narrower in scope than a theory.

independent variable A factor whose value is manipulated or changed during an experiment to reveal possible effects on another factor (the dependent variable).

inductive reasoning A type of logic in which generalizations are based on a large number of specific observations.

inquiry The search for information and explanation, often focusing on specific questions.

model A physical or conceptual representation of a natural phenomenon.

prediction In deductive reasoning, a forecast that follows logically from a hypothesis. By testing predictions, experiments may allow certain hypotheses to be rejected.

theory An explanation that is broader in scope than a hypothesis, generates new hypotheses, and is supported by a large body of evidence.

variable A factor that varies during an experiment.

Chi-Square (χ^2) Distribution Table

To use the table, find the row that corresponds to the degrees of freedom in your data set. (The degrees of freedom is the number of categories of data minus 1.) Move along that row to the pair of

values that your calculated χ^2 value lies between. Move up from those numbers to the probabilities at the top of the columns to find the probability range for your χ^2 value. A probability of 0.05 or less is generally considered significant. (To practice using the chi-square test, see the Scientific Skills Exercise in Chapter 15.)

Degrees of Freedom (df)	Probability										
	0.95	0.90	0.80	0.70	0.50	0.30	0.20	0.10	0.05	0.01	0.001
1	0.004	0.02	0.06	0.15	0.45	1.07	1.64	2.71	3.84	6.64	10.83
2	0.10	0.21	0.45	0.71	1.39	2.41	3.22	4.61	5.99	9.21	13.82
3	0.35	0.58	1.01	1.42	2.37	3.66	4.64	6.25	7.82	11.34	16.27
4	0.71	1.06	1.65	2.19	3.36	4.88	5.99	7.78	9.49	13.28	18.47
5	1.15	1.61	2.34	3.00	4.35	6.06	7.29	9.24	11.07	15.09	20.52
6	1.64	2.20	3.07	3.83	5.35	7.23	8.56	10.64	12.59	16.81	22.46
7	2.17	2.83	3.82	4.67	6.35	8.38	9.80	12.02	14.07	18.48	24.32
8	2.73	3.49	4.59	5.53	7.34	9.52	11.03	13.36	15.51	20.09	26.12
9	3.33	4.17	5.38	6.39	8.34	10.66	12.24	14.68	16.92	21.67	27.88
10	3.94	4.87	6.18	7.27	9.34	11.78	13.44	15.99	18.31	23.21	29.59

Mean and Standard Deviation

The **mean** is the sum of all data points in a data set divided by the number of data points. The mean (or average) represents a “typical” or central value around which the data points are clustered. The mean of a variable x (denoted by \bar{x}) is calculated from the following equation:

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

In this formula, n is the number of observations, and x_i is the value of the i th observation of variable x ; the “ Σ ” symbol indicates that the n values of x_i are to be summed. (To practice calculating the mean, see the Scientific Skills Exercises in Chapters 27, 32, and 34.)

The **standard deviation** provides a measure of the variation found in a set of data points. The standard deviation (s) of a variable x is calculated from the following equation:

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$$

In this formula, n is the number of observations, x_i is the value of the i th observation of variable x , and \bar{x} is the mean of x ; the “ Σ ” symbol indicates that the n values of $(x_i - \bar{x})^2$ are to be summed. (To practice calculating standard deviation, see the Scientific Skills Exercises in Chapters 27, 32, and 34.)

Performing a *t*-Test

One way to assess whether the results of an experiment are statistically significant is to perform a *t*-test. Consider an experiment in which one group of bean plants was treated with fertilizer, whereas a control group was not. Before beginning the experiment, the researchers hypothesized that fertilizer would not affect plant height (the fertilizer would neither increase plant height nor decrease it).

When the experiment was completed, the fertilized plants appeared overall to have grown taller than the unfertilized ones—that is, the mean height of the fertilized plants was greater than the mean height of the unfertilized ones. This result suggests that the fertilizer did, in fact, have an effect and, hence, that the two means are not equal. However, it is also possible that the different means in the two study groups resulted from natural variation of plant heights within the two groups, particularly if the total number of plants is small. How can we determine the likelihood that the observed differences are meaningful and therefore indicate that the fertilizer had an effect? The *t*-test provides a standardized way to decide whether the fertilizer had a significant effect on mean plant height.

To perform a *t*-test, the first step is to calculate the value *T* (named for “*t*-test”):

$$T = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(s_1^2 + s_2^2)}{n}}}$$

In this equation, \bar{x}_1 is the mean for the experimental group (fertilized plants), \bar{x}_2 is the mean for the control group (unfertilized plants), s_1 is the standard deviation for the experimental group, and s_2 is the standard deviation for the control group. Finally, n is the number of observations in each of the groups. [Note: The formula shown here is valid when the experimental and control groups have the same number of observations (n). A different formula would be used if the two groups had different numbers of observations.]

To calculate *T*, plug in the values for \bar{x}_1 , \bar{x}_2 , s_1 , s_2 , and n . *T* will be close to zero when the means \bar{x}_1 and \bar{x}_2 are nearly equal, and *T* will be farther from zero (will differ more greatly from zero) when the means are considerably different.

Is the calculated value *T* different enough from zero to reject the hypothesis that the two means are equal? This decision is based on the probability (*p*) that an observed difference between two means could have occurred simply by chance (assuming the initial hypothesis was correct, that is, that the two means are equal). The value of *p* can be determined using a *t* distribution that has $2(n - 1)$ degrees of freedom, where n is the number of observations. When *p* is small (typically, when it is less than 0.05), we reject the hypothesis that the means \bar{x}_1 and \bar{x}_2 are equal. The value of *p* can be obtained from an online calculator or looked up in tables for *t* distributions in a statistics textbook.

Credits

Photo Credits

Front Endpapers and Front Matter **laptop** Lemberg Vector studio/Shutterstock; **iPhone, iPad** Pixedon; **Brief Contents, Students page, pp. I, iii, xiv, xvi** **water lily** Rohrbaugh Photography; **p. iv donkeys** AFP/Getty Images; **p. v sunflowers** Christopher Ison/Alamy Stock Photo Image; **p. vi CRISPR video** HHMI BioInteractive; **breathing animation** BioFlix® 3-D Animation; **p. xii human lanych**/Shutterstock; **monkey** David Bagnall/Alamy Stock Photo; **gibbon** Eric Isselee/Shutterstock; **frogs** Joel Sartore/Getty Images; **p. xiii students** YanLev/Shutterstock; **p. xv authors** Josh Frost, Pearson Education, **Neil Campbell** Pearson Education; **p. xvii bioluminescence** Biosphoto/Alamy Stock Photo; **mice** Permission for use granted by Randy Jirtle, Professor of Epigenetics, NC State University, Raleigh, NC; **Dutch Hunger Winter** History and Art Collection/Alamy Stock Photo; **p. xix snowshoe hares (a)** From: Camouflage mismatch in seasonal coat color due to decreased snow duration. L. S. Mills, et al. *Proc Natl Acad Sci U S A.* 2013 Apr 30;110(18):7360-5. Fig. 1; **(b)** L. Scott Mills; **p. xix graph** Data from K. Kupferschmidt, Resistance Fighters. *Science* 352(6287):758-761. 13 May 2016; **p. xxii space-filling model, ribbon model** Data from PDB ID 2LYZ. R. Diamond. Real-Space Refinement of the Structure of Hen Egg-white Lysozyme. *Journal of Molecular Biology* 82(3):371-91 (Jan. 25, 1974); **wireframe model** Clive Freeman, The Royal Institution/Science Source; **p. xxiv sunflower** © Radius Images/Getty Images; **p. xxv seal** Hemis Morales/agefotostock; **cryo-EM** Veronica Falconieri and Siriam Subramaniam, National Cancer Institute; **students** Pearson Education; **p. xxvi Olden** CUNY; **Bautista** Mark Joseph Hanson; **Mojica** University of Alicante; **Extavour** Kris Snibbe; **Chisholm** Gretchen Ertl; **Gonsalves** Courtesy of Dennis Gonsalves; **Stratdee** UCSD Health; **Rochman** Courtesy of Chelsea Rochman; **p. xxxii seal** Hemis Morales/agefotostock; **p. xxxiii researchers** CDC; **p. xxxiv marmot** Tierfotagentur/Alamy Stock Photo; **caterpillar** blickwinkel/Alamy Stock Photo Image; **p. xxxv impala** Nature Picture Library/Alamy Stock Photo; **pea blossom** John Swithinbank/Agefotostock; **p. xxxvi DNA** 4X-image/E+/Getty Images; **p. xxxvii cell** Thomas Deerinck, NCMIR/Science Source; **sea horse** Rich Cary/Shutterstock; **p. xxxviii hare** L. Scott Mills; **amber** Iolanda Astor/AGE fotostock/Alamy Stock Photo; **p. xxxix dulce** Andrew J. Martinez/Science Source; **p. xl seed** Howard Sandler/shutterstock; **fungi** Sava Krstic; **p. xli ladybug** André Skonieczny/F1online digitale Bildagentur GmbH/Alamy Stock Photo; **shark** Gino Santa Maria/shutterstock; **tree** Raimund Linke/Photodisc/Getty Images; **p. xlii farmer** Visuals Stock/Alamy Stock Photo; **pollen** Dartmouth College Electron Microscope Facility; **p. xliii penguins** Paul Nicklen/National Geographic Image Collection/Getty Images; **p. xliv virus** Kateryna Kon/Shutterstock; **p. xlvi zebras** Mike Taylor/Alamy Stock Photo; **p. xlvi plover** Joel Sartore/National Geographic Images; **p. xlvi reef** Matthew Banks/Alamy Stock Photo Image; **tiger** Edwin Giesbers/Nature Picture Library.

Chapter 1 **1.1 top** J.B. Miller/Florida Department of Environmental Protection; **bottom left** Hopi Hoekstra/Harvard University; **bottom right** Shawn P. Carey/Migration Productions; **1.2 sunflower** John Foxx/ImageState Media Partners; **seahorse** R. Dirscherl/OceanPhoto/Frank Lane Picture Agency; **rabbit** Joe McDonald/Encyclopædia/Corbis; **butterfly** Louise Docker Sydney Australia/Moment/Getty Images; **seedling** Frederic Dillon/Garden Picture Library/Getty Images; **venus flytrap** Maximilian Weinzierl/Alamy Stock Photo; **giraffe** Malcolm Schuyl/Frank Lane Picture Agency; **1.3 biosphere** Leonello Calvetti/Stocktrek Images/Getty Images; **ecosystems** Terry Donnelly/Alamy Stock Photo; **communities, populations** Floris van Breugel/naturepl.com; **organisms** Greg Vaughn/Alamy Stock Photo; **organs** Pat Burner/Pearson Education; **tissues** Photo Researchers/Science Source; **cells** Andreas Holzenburg, University of Texas Rio Grande Valley; **organelles** Jeremy Burgess/Science Source; **p. 6 hummingbird** Jim Zipp/Science Source; **1.4 left** Steve Gschmeissner/Science Source; **1.5** Conly L. Rieder, Wadsworth Center, Albany, NY; **1.6 Gelpi**/Fotolia; **1.8a** Carol Yipes/Moment/Getty Images; **inset** Ralf Dahm/Max Planck Institute of Neurobiology; **1.11** James Balog/Aurora/Getty Images; **1.12 Kefca**/Shutterstock; **1.13a, b** Eye of Science/Science Source; **1.13c plantae** John Delapp/Design Pics/Getty Images; **fungi** daksel/Fotolia; **animalia** Anup Shah/naturepl.com; **protists** M. I. Walker/Science Source; **1.14 lake** Basel101658/Shutterstock; **paramecium** SPL/Science Source; **cilium** Dartmouth College Electron Microscope Facility; **cilia** Steve Gschmeissner/Science Source; **1.15** Robert Clark/National Geographic Image Collection; **1.16 left** G. Richmond/FineArt/Alamy Stock Photo; **1.16 right** Origin of Species/Charles Darwin, 1859. Murray edition; **1.17 hawk** jhayes44/E+/Getty Images; **robin** Sebastian Knight/Shutterstock; **flamingo** zhaoyan/Shutterstock; **penguin** Volodymyr Goinyk/Shutterstock; **1.19** Dorling Kindersley Ltd/Alamy Stock Photo; **1.21** Michael Nichols/National Geographic Image Collection; **p. 17 Goodall** Jim Dallas/Alamy Stock Photo; **1.23 top** Martin Shields/Alamy Stock Photo; **center** xpacifica/Getty Images; **bottom left** Rolf Hicker Photography/All Canada Photos/Alamy Stock Photo; **bottom right** Maureen Spuhler/Pearson Education; **1.24 left** HildeAnna/Shutterstock; **inset** Courtesy of Hopi Hoekstra/Harvard University; **right** Sacha Vignieri; **inset** Shawn P. Carey, Migration Productions; **1.25** From: The selective advantage of cryptic coloration in mice. Vignieri, S. N., J. Larson, and H. E. Hoekstra. 2010. *Evolution* 64:2153-2158. Fig. 1; **p. 21 Hoekstra** Josh Frost/Pearson Education; **Scientific Skills Exercise** Rolf Nussbaumer Photography/Alamy Stock Photo; **1.26 left** John Amis/AP Images; **top** Don Heupel/AP Images; **right** LBJ Presidential Library/Alamy Stock Photo; **bottom** McClatchy-Tribune/Tribune Content Agency LLC/Alamy Stock Photo; **p. 26 gecko** Chris Mattison/Alamy Stock Photo.

Unit One Interview CUNY.

Chapter 2 **2.1 top** www.pqpictures.co.uk/Alamy Stock Photo; **bottom** Nature Picture Library/Alamy Stock Photo; **2.2 left** sciencephotos/Alamy Stock Photo; **center, right** Stephen Frisch/Pearson Education; **p. 29 Olden** CUNY; **2.3 community** Richard Wong/Alamy Stock Photo; **lily** Tom Hilton; **rock** Andrew Alden; **2.5 National Library of Medicine; Scientific Skills Exercise** Pascal Goetgheluck/Science Source; **2.13** Stephen

Frisch/Pearson Education; **p. 39 gecko** nico99/Shutterstock; **hairs** Andrew Syred/Science Source; **p. 40 Pert** Photo 12/Alamy Stock Photo; **2.17** Nigel Cattlin/Science Source; **p. 43 top** Rolf Nussbaumer Photography/Alamy Stock Photo; **bottom** From: Spray aiming in the bombardier beetle: photographic evidence. T. Eisner et al. *Proc Natl Acad Sci U S A* 1999 Aug 17;96(17):9705-9. Fig. 1.

Chapter 3 **3.1 top** Hemis Morales/agefotostock; **bottom** Paul Nicklen/National Geographic Image Collection; **3.3** Alasdair James/E+/Getty Images; **3.4** N.C Brown Center for Ultrastructure Studies, SUNY-ESF, Syracuse, NY; **3.6** Four Oaks/Shutterstock; **p. 48 Solomon** Justina Thorsen; **3.10** JPL/University of Arizona/NASA; **3.11 lemon** Paulista/Fotolia; **ant** Nature Picture Library/Alamy Stock Photo; **blood cells** SCIEPRO/SPL/AGE Fotostock; **bleach** Beth Van Trees/Shutterstock; **Scientific Skills Exercise** Vlad61/Shutterstock; **p. 55 cat** Eric Guilloret/Biosphoto/Science Source.

Chapter 4 **4.1** Florian Möllers/Nature Picture Library; **p. 57 Miller** Robin Heyden, Pearson Education; **Scientific Skills Exercise** Mandeville Special Collections Library; **vials** Jeffrey Bada/Scripps Institution of Oceanography/University of California San Diego; **p. 60 Gordon** Stuart Brinrin; **4.6a** David M. Phillips/Science Source; **p. 65 lions** George Sanker/Nature Picture Library.

Chapter 5 **5.1** Mark J. Winter/Science Source; **5.6a arm** Dougal Waters/Getty Images; **plastids** Omikron/Science Source; **5.6b** Mediscan/Alamy Stock Photo; **5.6c cell** John Durham/Science Source; **microfibrils** Biophoto Associates/Science Source; **5.8** blickwinkel/Alamy Stock Photo; **5.10a** Vincent Giordano Photo/Shutterstock; **5.10b** Bamorgan91/Shutterstock; **p. 75 Jones** Courtesy of Lovell Jones; **5.13 eggs** Andrey Stratilatov/Shutterstock; **muscle, collagen** Nina Zanetti/Pearson Education; **5.16 wireframe model** Clive Freeman, The Royal Institution/Science Source; **5.17** Peter M. Colman; **5.18 spider** Dieter Hopf/imageBROKER/AGE Fotostock; **blood cells** SCIEPRO/SPL/AGE Fotostock; **5.19** Eye of Science/Science Source; **p. 82 Pauling** James W. Behnke/Pearson Education; **5.21 top** Dsrsjr; **bottom** Laguna Design/Science Source; **5.25** Centers for Disease Control and Prevention (CDC); **5.26 DNA** Alfred Pasieka/Science Source; **neanderthal** Mark Thiessen/National Geographic/Alamy Stock Photo; **hippo** Frontline Photography/Alamy Stock Photo; **whale** WaterFrame_mus/Alamy Stock Photo; **5.26 doctor** Chassenet/BSIP/Alamy Stock Photo; **elephants** Villiers Steyn/Shutterstock; **roots** D.J. Read, Department of Animal and Plant Sciences, University of Sheffield; **Scientific Skills Exercise** human lanych/Shutterstock; **monkey** David Bagnall/Alamy Stock Photo; **gibbon** Eric Isselee/Shutterstock; **Problem-Solving Exercise** Cindy Hopkins/Alamy Stock Photo; **p. 91 chick** Africa Studio/Shutterstock.

Unit Two Interview **top** Mark Joseph Hansen; **bottom** Robin Heyden.

Chapter 6 **6.1** M. I. Walker/Science Source; **6.3 brightfield, phase-contrast, Nomarski** Elisabeth Pierson/Pearson Education; **fluorescence** Michael W. Davidson/The Florida State University Research Foundation; **confocal** Karl Garsha; **deconvolution** Hans van der Voort SVI; **super-resolution** Muthugapatti K. Kandasamy, Biomedical Microscopy Core, University of Georgia; **SEM, TEM** Steve Gschmeissner/Science Source; **cryo-EM** Veronica Falconieri and Siriam Subramaniam, National Cancer Institute; **6.5b** CNRI/Science Source; **6.6a** Don W. Fawcett/Science Source; **Scientific Skills Exercise** Kelly Tatchell; **6.8 human cells** S. Cinti/Science Source; **yeast SEM** SPL/Science Source; **yeast TEM** A. Barry Dowsett/Science Source; **duckweed** Biophoto Associates/Science Source; **alga SEM** SPL/Science Source; **alga TEM** From: Flagellar microtubule dynamics in *Chlamydomonas*: cytochalasin D induces periods of microtubule shortening and elongation; and colchicine induces disassembly of the distal, but not proximal, half of the flagellum. W. L. Dentler et al. *J Cell Biol.* 1992 Jun;117(6):1289-98. Fig. 10d; **p. 102 nucleus** Thomas Deerinck/Mark Elsismann/NCMIR; **6.9 nuclear envelope** Biophoto Associates/Science Source; **pore complex** Don W. Fawcett/Science Source; **nuclear lamina** Ueli Aebi; **6.10 left** Don W. Fawcett/Science Source; **right** Harry Noller; **p. 103 Ramakrishnan** Courtesy of Venki Ramakrishnan; **6.11** R. W. Bolender; Don W. Fawcett/Science Source; **6.12** Don W. Fawcett/Science Source; **6.13a** Steve Gschmeissner/Science Source; **6.13b** Don W. Fawcett/Science Source; **6.14** Eldon H. Newcomb; **6.17a** Keith R. Porter/Science Source; **6.17c** From: The shape of mitochondria and the number of mitochondrial nucleoids during the cell cycle of *Euglena gracilis*. Y. Hayashi and K. Ueda. *Journal of Cell Science*, 93:565-570, fig. 3. Copyright © 1989 by Company of Biologists; **6.18a** Jeremy Burgess/Mary Martin/Science Source; **6.18b** Ed Reschke/Photolibrary/Getty Images; **6.19** Eldon H. Newcomb; **6.20** Albert Tousson; **p. 113 Langford** Syracuse University; **6.21b** Bruce J. Schnapp; **Table 6.1 left to right** Gopal Murti/Science Source, Nikon MicroscopyU (www.microscopyu.com), Mark Ladinsky; **6.22** Kent L. McDonald; **6.23a** Biophoto Associates/Science Source; **6.23b** Oliver Meckes, Nicole Ottawa/Eye of Science/Science Source; **6.24a** Omikron/Science Source; **6.24b** Dartmouth College Electron Microscope Facility; **6.24c** Richard W. Linck; **6.25** From: Organization of actin, myosin, and intermediate filaments in the brush border of intestinal epithelial cells. Hirokawa et al. *J Cell Biol.* 1982 Aug;94(2):425-43. Fig. 1. The Rockefeller University Press; **6.26a** Clara Franzini-Armstrong/University of Pennsylvania; **6.26b** M. I. Walker/Science Source; **6.26c** Michael Clayton/University of Wisconsin; **6.27** G. F. Leedale/Science Source; **6.29** Eldon H. Newcomb, University of Wisconsin, Department of Botany; **6.30 top** Reproduced with permission from: *Freeze-Etch Histology*, by L. Orci and A. Perrelet, Springer-Verlag, Heidelberg, 1975. Plate 32. Page 68. Copyright 1975 by Springer-Verlag GmbH & Co KG; **6.30 center** From: Fine structure of desmosomes, hemidesmosomes, and an epidermal globular layer in developing newt epidermis. DE Kelly. *J Cell Biol.* 1966 Jan; 28(1):51-72. Fig. 7. Reproduced by permission of Rockefeller University Press; **bottom** From: Low resistance junctions in crayfish. Structural changes with functional uncoupling. C. Peracchia and A. F. Dulhunty, *The Journal of Cell Biology*. 1976 Aug; 70(2 pt 1):419-39. Fig. 6. Reproduced by permission of Rockefeller University Press; **6.31** Eye of Science/Science Source; **p. 125 epithelial cell** Susumu Nishinaga/Science Source.

Chapter 7 **7.1** David Goodsell; **p. 129 mosaic** camerawithlegs/Fotolia; **7.10** Used by permission of B. L. de Groot. Related to work done for: Water Permeation Across Biological Membranes: Mechanism and Dynamics of Aquaporin-1 and GlpF. B. L. de Groot, H. Grubmüller. *Science* 294:2353-2357 (2001); **p. 132 Agre** Sam Kittner, Pearson Education; **7.14** Michael Abbey/Science Source; **p. 135 ion channel** From: Crystal structure of a mammalian voltage-dependent Shaker family K⁺ channel. S. B. Long et al. *Science*. 2005 Aug 5;309(5736):897-903. Epub 2005 Jul 7. Cover image; **p. 135 Serrano** Darren Phillips/New Mexico State University; **Scientific Skills Exercise** Photo Fun/Shutterstock; **7.21 left** Biophoto Associates/Science Source; **center** Don W. Fawcett/Science Source; **right** From: M. M. Perry and A. B. Gilbert, *Journal of Cell Science* 39: 257-272, Figs. 11 and 13 (1979). © 1979 The Company of Biologists Ltd.; **p. 142 spray** Kristoffer Trippal/Alamy Stock Photo.

Chapter 8 **8.1** Biosphoto/Alamy Stock Photo; **8.2** Stephen Simpson/Getty Images; **8.3** Robert N. Johnson/RnJ Photography; **8.4a** From: Micromechanical properties of biological silica in skeletons of deep-sea sponges. Alexander Woesz et al. *J. Mat. Res.* Volume 21, Issue 8, August 2006, pp. 2068-2078. Fig. 1; **8.4b** Neale Clark Agency/robertharding/Alamy Stock Photo; **8.15** Thomas Steitz; **Scientific Skills Exercise** Fer Gregory/Shutterstock; **8.17** Jack Dykinga/Nature Picture Library/Alamy Stock Photo; **8.22** Keith R. Porter/Science Source; **p. 163 penguins** Flickr/Getty Images.

Chapter 9 **9.1** Tierfotoagentur/Alamy Stock Photo; **9.3** Dionisvera/Fotolia; **9.9 Z.** Hong Zhou, University of California, Los Angeles; **Scientific Skills Exercise** Thomas Kitchin & Victoria Hurst/Design Pics/Alamy Stock Photo; **p. 180 cacao** Aedka Studio/Shutterstock; **p. 186 model** Medical Research Council; **CoQ10** Stephen Rees/Shutterstock.

Chapter 10 **10.1 tree** Rolf Roeckl/mauritius images GmbH/Alamy Stock Photo; **caterpillar** blickwinkel/Alamy Stock Photo; **10.2a STILLFX**/Shutterstock; **10.2b** NatalieJean/Shutterstock; **10.2c** M. I. Walker/Science Source; **10.2d** Michael Abbey/Science Source; **10.2e** Heide N. Schulz-Vogt, Leibniz Institute for Baltic Sea Research Warnemuende; **10.3 top**, **10.21** Andreas Holzenburg, University of Texas Rio Grande Valley; **bottom** Jeremy Burgess/Science Source; **p. 194 C. thermalis** Dennis Nürnberg; **10.11b** Christine L. Case; **Scientific Skills Exercise** The Ohio State University; **10.20a** Doukdouk/Alamy Stock Photo; **10.20b** Keysurfing/Shutterstock; **p. 211 snow** gary yim/Shutterstock.

Chapter 11 **11.1 top**, **11.5c** Federico Veronesi/Gallo Images/Alamy Stock Photo; **bottom** Nature Picture Library/Alamy Stock Photo; **11.2a–c** A. Dale Kaiser/Stanford University; **11.2d** Michiel Vos; **Problem-Solving Exercise** Bruno Coignard and Jeff Hageman, CDC; **p. 214 Bassler** Alena Soboleva; **11.7** From: High-resolution crystal structure of an engineered human beta2-adrenergic G protein-coupled receptor. V. Cherezov, et al. *Science*. 2007 Nov 23;318(5854):1258-65. Epub 2007 Oct 25; **p. 220 Bautista** Mark Joseph Hanson; **11.19** Gopal Murti/Science Source; **11.21** William Wood; **p. 233 chips** Maureen Spuhler/Seellevel.com.

Chapter 12 **12.1** George von Dassow; **12.2a, c** Biophoto/Science Source; **12.2b** Biology Pics/Science Source; **12.3** Andrew S. Bajer, University of Oregon, Eugene; **12.4, 12.5** Biophoto/Science Source; **12.7** Conly L. Rieder, Wadsworth Center, Albany, NY; **12.8 left** Jane Stout and Claire Walczak, Indiana University; **right** Matthew J. Schibler; **12.10a** Don W. Fawcett/Science Source; **12.10b** B. A. Palevitz and E. H. Newcomb, University of Wisconsin; **12.11** Elizabeth Pierson, Pearson Education; **p. 246 Nurse** Zach Veilleux, Rockefeller University; **12.18** Guenter Albrecht-Buehler; **12.19** Lan Bo Chen; **12.20** Nature's Geometry/Science Source; **Scientific Skills Exercise** Molecular Expressions; **p. 250 Alberts** Photo by Tom Kochel, courtesy of the Department of Biochemistry and Biophysics, The University of California San Francisco, Gitschier J. (2012) "Scientist Citizen: An Interview with Bruce Alberts". *PLoS Genetics* 8(5): e1002743. doi:10.1371/journal.pgen.1002743. Figure 1; **p. 252 onion cells** Scenics & Science/Alamy Stock Photo; **HeLa cells** Steve Gschmeissner/Science Source.

Unit Three Interview Mojica, flask, petri dish University of Alicante; lake Richard Brown/Alamy Stock Photo.

Chapter 13 **13.1** PeopleImages/DigitalVision/Getty Images; **p. 255 sperm** Don W. Fawcett/Science Source; **13.2a** Roland Birke/Okapia/Science Source; **13.2b** George Ostertag/Alamy Stock Photo; **13.3 top** Ermakoff/Science Source; **bottom** CNRI/Science Source; **Scientific Skills Exercise** SciMAT/Science Source; **13.12** Mark Petronczki and Maria Siomos; **13.13** John Walsh, Micrographia.com; **p. 268 bananas** Randy Ploetz.

Chapter 14 **14.1** John Swithinbank/Agefotostock; **14.14a** Maximilian Weinzierl/Alamy Stock Photo; **14.14b** Paul Dymond/Alamy Stock Photo; **Scientific Skills Exercise** Apomares/E+/Getty Images; **14.15** Barbara Bowman, Pearson Education; **14.16** Patricia Willocq; **14.18** Michael Ciesielski Photography; **p. 287 Wexler** Ron Galella, Ltd./Getty Images; **14.19** CNRI/Science Source; **p. 293 cat** Arco Images GmbH/Alamy Stock Photo; **family** Rene MALTETE/Gamma-Rapho/Getty Images.

Chapter 15 **15.1** Courtesy of Peter Lichter; **15.2** Martin Shields/Alamy Stock Photo; **15.5** Andrew Syred/Science Source; **15.6b** Li Jingwang/E+/Getty Images; **15.6c** Kosam/Shutterstock; **15.6d** Creative images/Fotolia; **15.8** Jagodka/Shutterstock; **Scientific Skills Exercise** Oliver91119/Shutterstock; **p. 306 Orr-Weaver** Maria Nemchuk; **15.15 left** CNRI/Science Source; **right** Denys_Kuvaiev/Fotolia; **p. 311 Tilghman** Denise Applewhite, Office of Communications, Princeton University; **15.18** Phomphan/Shutterstock; **p. 313 butterfly** James K Adams.

Chapter 16 **16.1** 4X-image/E+/Getty Images; **16.3** Oliver Meckes/Eye of Science/Science Source; **Scientific Skills Exercise** Marevision Agency/AGE Fotostock/Alamy Stock Photo; **16.6a** Library of Congress; **16.6b** Science Source; **16.13a** Jerome Vinograd; **16.13b** From: Enrichment and visualization of small replication units from cultured mammalian cells. D. J. Burks et al. *J Cell Biol.* 1978 Jun;77(3):762-73. Fig. 6A; **16.22** Peter Lansdorp; **16.23 DNA strand** Gopal Murti/Science Source; **nucleosome** Victoria E. Foe; **chromosome** Biophoto/Science Source; **16.24a** Thomas Reid, Genetics Branch/CCR/NCI/NIH; **16.24b** Michael R. Speicher/Medical University of Graz; **p. 334 models** Thomas A. Steitz/Yale University.

Chapter 17 **17.1** AFP/Getty Images; **17.7a** Keith V. Wood; **17.7b** Sinclair Stammers/Science Source; **p. 346 Steitz** National Science Foundation; **17.18** Joachim Frank; **17.23b** Barbara Hamkalo; **17.24** Oscar Miller/Science Source; **17.26** Eye of Science/

Science Source; **Problem-Solving Exercise** Duplass/Shutterstock; **p. 360 Mojica** University of Alicante; **p. 364 cat** Vasilii Koval/Shutterstock.

Chapter 18 **18.1 top** gallimaufry/Shutterstock; **18.1 bottom** Andreas Werth; **18.8a** Permission for use granted by Randy Jirtle, Professor of Epigenetics, NC State University, Raleigh, NC; **18.8b** History and Art Collection/Alamy Stock Photo; **Scientific Skills Exercise** hidese/E+/Getty Images; **18.13** Michael Speicher and Nigel Carter, Medical University of Graz; **p. 381 Lin** Courtesy of Haifan Lin; **18.16** Mike Wu; **18.20** F. Rudolf Turner, Indiana University; **18.21** Wolfgang Driever, University of Freiburg, Freiburg, Germany; **p. 387 Hopkins** Courtesy of the Cold Spring Harbor Laboratory Archives; **18.22** Ruth Lahmann, The Whitehead Institution; **18.27** Bloomberg/Getty Images; **p. 394 King** © University of Washington; **p. 397 fish** Peter Herring/Image Quest Marine.

Chapter 19 **19.1** Thomas Deerinck, NCMIR/Science Source; **19.2** Peter von Sengbusch, Botanik; **19.3a** Science Source; **19.3b** Linda M. Stannard, University of Cape Town/Science Source; **19.3c** Hazel Appleton, Health Protection Agency Centre for Infection/Science Source; **19.3d** Ami Images/Science Source; **19.7 molekuul.be**/Fotolia; **p. 404 Mojica** University of Alicante; **19.9 top** Charles Dauguet/Science Source; **bottom** Petit Format/Science Source; **19.10a** CDC; **19.10b** Kuhn and Rossman research groups, Purdue University; **19.10c** Cynthia Goldsmith, CDC; **p. 410 Satcher** Courtesy of David Satcher; **Scientific Skills Exercise** Dong yanjun/Imaginechina/AP Images; **19.11** Olivier Asselin/Alamy Stock Photo; **inset** James Gathany, CDC; **19.12** Nigel Cattlin/Alamy Stock Photo; **p. 414 Tamiflu** Nelson Hale/Shutterstock.

Chapter 20 **20.1** Ian Derrington; **20.2** P. Morris, Garvan Institute of Medical Research; **20.6b** Scott Sinklier/Alamy Stock Photo; **20.9** Ethan Bier; **20.13** George S. Watts and Bernard W. Futscher, University of Arizona Cancer Center; **20.14** Stephen McNally, UC Berkeley; **p. 427 Rotimi** National Human Genome Research Institute; **20.17** Roslin Institute; **20.18** Pat Sullivan/AP Images; **20.19** Steve Gschmeissner/Science Photo Library/Alamy Stock Photo; **20.23** Brad DeCecco/Redux; **20.24** Steve Helber/AP Images; **p. 439 Suzuki** dpa picture alliance archive/Alamy Stock Photo; **p. 441 hot spring** Galyna Andrushko/Shutterstock.

Chapter 21 **21.1 elephant shark** Image Quest Marine; **sea horse** Rich Cary/Shutterstock; **21.4** University of Toronto Lab; **21.5 Affymetrix** *Recherches sur les ossements fossiles*. G. Cuvier. Atlas, pl. 17 (1836); **iguana** Wayne Lynch/All Canada Photos/AGE Fotostock; **frog** The Natural History Museum, London/Alamy Stock Photo; **Alfred Russel Wallace** The Natural History Museum/Alamy Stock Photo; **The Origin of Species** 1859 Murray edition of *The Origin of Species* by Charles Darwin; **22.4** Karen Moskowitz/Stone/Getty Images; **22.5 left** Derek Bayes/Lebrecht Music and Arts Photo Library/Alamy Stock Photo; **right** Photo Researchers/Science History Images/Alamy Stock Photo; **22.6a** Michel Gunther/Science Source; **22.6b** David Hosking/Frank Lane Picture Agency; **22.6c** David Hosking/Alamy Stock Photo; **22.7** Darwin, C. R. *Notebook B: Transmutation of species* (1837-1838), p. 36. CUL-DAR121; **22.9 Brussels sprouts** Arena Photo UK/Fotolia; **kale** Željko Radojko/Fotolia; **cabbage** Guy Shapira/Shutterstock; **wild mustard** Martin Fowler/Alamy Stock Photo; **broccoli** YinYang/E+/Getty Images; **kohlrabi** Motorolka/Shutterstock; **22.10** Robert Hamilton/Alamy Stock Photo; **22.11** Kichigin/Shutterstock; **22.12a** William Mullins/Alamy Stock Photo; **22.12b** Chris Mattison/Alamy Stock Photo; **22.13** Scott P. Carroll; **22.16 left** Keith Wheeler/Science Source; **right** Omikron/Science Source; **22.18 left** ANT Photo Library/Science Source; **right** Joe McDonald/Steve Bloom Images/Alamy Stock Photo; **22.19** Chris Linz, Thewissen lab, Northeastern Ohio Universities College of Medicine (NEOUCOM); **p. 485 honeypot ant** © Joel Sartore/National Geographic Image Collection.

Chapter 23 **23.1** Sylvain Cordier/Science Source; **p. 487 Grants** Robin Heyden; **23.3** Juniors Bildarchiv GmbH/Alamy Stock Photo; **23.5** Erick Greene; **23.6 left** Edward Bennett Agency/Design Pics Inc/Alamy Stock Photo; **right** Patrick Valkenburg/Alaska Department of Fish and Game; **Scientific Skills Exercise** DLewis/Fotolia; **23.11** Bruce Montagne/Dembinsky Photo Associates/Alamy Stock Photo; **23.12 top** Kristin Stanford, Stone Laboratory, Ohio State University; **bottom** Kent Bekker, United States Fish and Wildlife Service; **23.14** Anthony Bannister/NHPA/Photoshot/Newscom; **23.15** Dave Blackley Agency/All Canada Photos/Alamy Stock Photo; **23.18 blood cells** Eye of Science/Science Source; **doctor with child** Caroline Penn/Alamy Stock Photo; **mosquito** James Gathany and Frank Collins, University of Notre Dame, CDC; **23.19a** From: Camouflage mismatch in seasonal coat color due to decreased snow duration. L. S. Mills, et al. *Proc Natl Acad Sci U S A.* 2013 Apr 30;110(18):7360-5. Fig. 1; **23.19b** L. Scott Mills; **p. 505 lake** Thomas/Pat Leeson/Science Source.

Chapter 24 **24.1** Joel Sartore/National Geographic Image Collection; **24.2a left** Malcolm Schuyler/Alamy Stock Photo; **right** Wave RF/Getty Images; **24.2b top left** Robert Kneschke/Kaliuum/AGE Fotostock; **top center** Justin Horrocks/E+/Getty Images; **top right** Ryan Mcvay/Getty Images; **bottom left** Dragon Images/Shutterstock; **bottom center** arek_malang/Shutterstock; **bottom right** Jaki good photography - celebrating the art of life/Moment Open/Getty Images; **24.3a** Phil Huntley-Franck; **24.3b** Jerry A. Payne, USDA Agricultural Research Service, Bugwood.org; **24.3c** Hogle Zoo; **24.3d** USDA; **24.3e** Imagebroker/Alamy Stock Photo; **24.3f, g** Takahiro Asami; **24.3h** Larry Geddis/Alamy Stock Photo; **24.3i** Chuck Brown/Science Source; **24.3j** mivod/Shutterstock; **24.3k** Bagicat/Fotolia; **24.3l** FreeReinDesigns/Fotolia; **24.3m** Kazutoshi Okuno; **24.4 top** CLFProductions/Shutterstock; **right** Boris Karpinski/Alamy Stock Photo; **bottom** Troy Maben/AP Images; **24.6a** Courtesy of Brian Langerhans; **24.8 maps** NASA EOS Earth Observing System; **shrimp** Arthur Anker, Florida Museum of Natural History; **Scientific Skills Exercise** John Shaw/Avalon/Photoshot/Alamy Stock Photo; **24.11** Pam and Doug Soltis; **24.12** Ole Seehausen; **24.13** Jeroen Speybroeck, Research

Institute for Nature and Forest; **24.14a** Steve Byland/Shutterstock; **24.14b** Bonnie Taylor Barry/Shutterstock; **Problem-Solving Exercise** Philimon Bulawayo/Reuters; **24.16** Ole Seehausen; **p. 521 Gould** Ulf Andersen/Hulton Archive/Getty Images; **24.18** Jason Rick and Loren Rieseberg; **24.20** Reprinted by permission from *Nature*. From: Allele substitution at a flower colour locus produces a pollinator shift in monkeyflowers. H. D. Bradshaw et al. *Nature*. 2003 November 12; 426(6963):176-8. Fig. 1. © 2003. Macmillan Magazines Limited; **p. 524 frog** Rolf Nussbaumer Photography/Alamy Stock Photo.

Chapter 25 **25.1** Juergen Ritterbach/Alamy Stock Photo; **25.2** Stringer/Chile/Reuters/Newscom; **25.3 left** NASA; **right** Deborah S. Kelley; **25.4b** From: Chemically-Induced Birthing and Foraging in Viscel Systems. F. M. Menger, and Kurt Gabrielson. *J. Am. Chem. Soc.*, February 1994, 116 (4), pp 1567-1568. Fig. 1; **25.4c** Jack W. Szostak; **p. 528 Szostak** Li Huang/Courtesy of Jack Szostak; **25.5a** John Cancalosi/Alamy Stock Photo Image; **25.5b** Jerome Gorin/PhotoAlto/sas/Alamy Stock Photo; **25.5c** Michael Lockley; **25.5d** Iolanda Astor/AGE Fotostock/Alamy Stock Photo; **25.5e** Government of Yukon; **25.8 stromatolites** Biosphoto/Alamy Stock Photo; **stromatolite (inset)** Sinclair Stammers/Science Source; **microfossil** David Lamb; **coccosteus** Roger Jones; **Tiktaalik** Ted Daeschler/Academy of Natural Sciences; **Archaefrutus** David L. Dilcher and Ge Sun; **25.11a** Xunlai Yuan; **25.11b** From: The most probable Eumetazoa among late Precambrian macrofossils. A.Y. Ivantsov. *Invertebrate Zoology*. Vol.14. No.2: 127-133 [in English], 2017. Fig 2; **25.13a** From: Four hundred-million-year-old vesicular arbuscular mycorrhizae. W. Remy et al. *Proc Natl Acad Sci USA*. 1994 Dec 6;91(25):11841-3. Figure 1; **inset** From: Fou hundred-million-year-old vesicular arbuscular mycorrhizae. Remy W1, Taylor TN, Hass H, Kerp H. *Proc Natl Acad Sci U.S.A.* 1994 Dec 6;91(25):11841-3. Figure 4; **p. 537 Vermeij** Courtesy of Geerat J. Vermeij; **Scientific Skills Exercise** Biophoto Associates/Science Source; **25.23 Dubautia laxa, Argyroxiphium sandwicense, Dubautia waialealea, Dubautia scabra, Dubautia linearis** Gerald D. Carr; **Carlquistia muiii** Bruce G. Baldwin; **25.24** Jean Kern; **25.25** Juniors Bildarchiv GmbH/Alamy Stock Photo; **25.27 top** David Horsley; **bottom** From: Genetic and developmental basis of evolutionary pelvic reduction in threespine sticklebacks. MD Shapiro et al. *Nature*. Erratum. 2006 February 23; 439(7079):1014; **25.28** Sinclair Stammers/Science Source; **p. 547 Extavour** Kris Snibbe; **p. 551 volcano** Solent News/Splash News/Newscom.

Unit Five Interview **top** Gretchen Ertl; **bottom** Steven J. Biller.

Chapter 26 **26.1** blickwinkel/Alamy Stock Photo; **26.17a** Mick Ellison; **26.17b** Julius T. Csontoy/Science Source; **26.22** Gary Crabbe/Enlightened Images/Alamy Stock Photo; **inset** Gerald Schoenknecht; **Scientific Skills Exercise** Nigel Cattlin/Alamy Stock Photo; **p. 570 Moran** Courtesy of Nancy Moran; **p. 572 manatee** David Fleetham/Alamy Stock Photo.

Chapter 27 **27.1 top** Zastolskiy Viktor/Shutterstock; **center right** Janice Haney Carr, CDC; **bottom left** Irina Sen/Shutterstock; **bottom right** Oliver Meckes/Eye of Science/Science Source; **27.2a** Janice Haney Carr, CDC; **27.2b** CDC; **27.2c** Stem Jems/Science Source; **27.3 L** Brent Selinger/Pearson; **27.4** Immo Rantala/SPL/Science Source; **27.5** Oliver Meckes/Eye of Science/Science Source; **27.6** Kwangshin Kim/Science Source; **27.7** David DeRosier; **27.8a** From: Taxonomic Considerations of the Family Nitrobacteraceae Buchanan: Requests for Opinions. Stanley W. Watson, *IJSEM (International Journal of Systematic and Evolutionary Microbiology)* formerly (in 1971) *Intl. Journal of Systematic Bacteriology*, July 1971 vol. 21 no. 3, 254-270. Flg. 14; **27.8b** From: Light-dependent governance of cell shape dimensions in cyanobacteria. B. L. Montgomery. *Front Microbiol*. 2015 May 26;6:514. doi: 10.3389/fmicb.2015.00514. eCollection 2015. Fig. 1. CC BY 4.0; **27.9** Huntington Potter; **27.12** Charles C. Brinton, Jr.; **27.14** John Walsh/Science Source; **27.15** Paul Gunning/Science Source; **27.17** *spirochetes* Cnri/SPL/Science Source; **proteobacteria** Yuichi Suwa; **cyanobacteria** Michael Abbey/Science Source; **chlamydia** Moredon Animal Health/SPL/Science Source; **gram-positive bacteria** Paul Alan Hoskisson; **27.18** Irina Sen/Shutterstock; **27.19** Pascale Frey-Klett; **27.20** WaterFrame/Alamy Stock Photo; **p. 587 Chisholm** Gretchen Ertl **27.21 left** Steve Heap Agency/Zoonar GmbH/Alamy Stock Photo; **center** David M. Phillips/Science Source; **right** James Gathany, CDC; **Scientific Skills Exercise** Slava Epstein; **27.24** From: RNA-directed gene editing specifically eradicates latent and prevents new HIV-1 infection. W. Hu et al. *Proc Natl Acad Sci U.S.A.* 2014 Aug 5;111(31):11461-6. Fig. 3D; **27.25** From: Synthesis of High-Molecular-Weight Polyhydroxyalkanoates by Marine Photosynthetic Purple Bacteria. M. Higuchi-Takeuchi et al. *PLoS One*. 2016 Aug 11;11(8):e0160981. doi: 10.1371/journal.pone.0160981. eCollection 2016. Fig. 2; **27.26** Accent Alaska/Alamy Stock Photo; **p. 592 pin** Biophoto Associates/Science Source.

Chapter 28 **28.1, 28.2** Brian S. Leander; **Scientific Skills Exercise** Shutterstock; **28.4** Ken Ishida; **28.5 Giardia** Tony Brain/Science Source; **diatom** M I Walker/NHPA/Phototosh/Newscom; **Volvox** Frank Fox/Science Source; **Volvox (inset)** David J. Patterson; **Globigerina** Howard Spero, University of California Davis; **Globigerina (inset)** National Oceanic and Atmospheric Administration (NOAA); **amoeba** Michael Abbey/Science Source; **28.6a** The Natural History Museum, London/Science Source; **28.6b** CSIRO; **28.7** David M. Phillips/Science Source; **28.8** David J. Patterson; **28.9** Oliver Meckes/Science Source; **28.10** David J. Patterson; **28.11** CDC; **28.12** Steve Gschmeissner/Science Source; **28.13** Colin Bates; **28.14** Paul Kay/Oxford Scientific/Getty Images; **28.15a** Jennifer L. Matthews; **28.15b** Noble Proctor/Science Source; **28.16** Guy Brugolle; **28.17a** David M. Phillips/Science Source; **28.17b** Science Source; **28.18** ©1979 Rockefeller University Press. *Journal of Experimental Medicine*. 149:172-184. doi:10.1084/jem.149.1.172; **28.19a** M. I. Walker/Science Source; **28.20** Perennou Nuridsany/Science Source; **28.21** Nature Picture Library/Alamy Stock Photo; **28.22** Eva Nowack; **28.23 Bonnemaisonia hamifera** D. P. Wilson/Science Source; **Palmaria palmata** Andrew J. Martinez/Science Source; **nori** Biophoto Associates/Science Source; **sushi** Dorling Kindersley Ltd/Alamy Stock Photo; **28.24a** Michael Abbey/Science Source; **28.24b** Laurie Campbell/Photoshot; **28.24c** David L. Ballantine; **28.25** William L. Dentler; **28.27** Ken Hickman; **28.28** Robert Kay; **28.29** Patrick Keeling; **28.30** David Rizzo; **p. 617 Didinium** Greg Antipa/Biophoto Associates/Science Source.

Chapter 29 **29.1** Exactostock/SuperStock; **29.2** From: Cellulose Biosynthesis: Exciting Times for a Difficult Field of Study, *Annual Review of Plant Physiology and Plant Molecular Biology* Vol. 50:245-276 (Volume publication date June 1999) Fig. 1; **29.3** M. I. Walker/Science Source; **29.5 left** Linda Graham/University of Wisconsin-Madison; **right** Karen

S. Renzaglia; **29.6** Johan De Meester/Arterra Picture Library/Alamy Stock Photo; **inset** Photo by Brian King, courtesy of Nancy Smith-Huerta, Miami University; **29.7** Ed Reschke/Getty Images; **29.8** Charles H. Wellman; **29.9** From: The early evolution of land plants, from fossils to genomics: a commentary on Lang (1937) 'On the plant-remains from the Downtonian of England and Wales'. D. Edwards and P. Kenrick. *Philos R Soc Lond B Biol Sci.* 2015 Apr 19;370(1666). pii: 20140343. doi: 10.1098/rstb.2014.0343; **29.11** Custom Life Science Images/Alamy Stock Photo; **29.12** Bill Malcolm & Nancy Malcolm; **29.13 thalloid liverwort** Alvin E. Staffan/Science Source; **sporophyte** Linda E. Graham; **leafy liverwort, hornwort** The Hidden Forest; **moss** Tony Wharton/Fundamental Photographs; **29.15a** John Warburton-Lee Photography/Alamy Stock Photo; **29.15b** Thierry Lauzon/Iconotec/Alamy Stock Photo; **29.16** Hans Kerp; **Scientific Skills Exercise** Richard Becker/Fundamental Photographs; **29.18 top** Michael Sundue, Ferns of the World; **bottom** FloralImages/Alamy Stock Photo; **29.19 spikemoss** Purdue University; **quillwort** Murray Fagg/Australian National Botanic Gardens; **club moss** Helga and Kurt Rasbach; **ostrich fern** John Martin/Alamy Stock Photo; **horsetail** Stephen P. Parker/Science Source; **whisk fern** Francisco Javier Yeste Garcia; **29.20** Christian Jegou/Publiphoto/Science Source; **p. 634** Ed Reschke/Getty Images; **p. 635 stomata** © W. Barthlott, lotus-salvinia.de.

Chapter 30 **30.1** Lyn Topinka, USGS; **inset** Marlin Harms; **Scientific Skills Exercise** Guy Eisner; **30.5** Rudolph Serbet, Natural History and Biodiversity Institute, University of Kansas; **30.6** Claus Habfast; **30.7 Cycas revoluta** Warren Price Photography/Shutterstock; **ginkgo seeds** www.biolib.de; **Ginkgo biloba** Travis Amos/Pearson Education; **Welwitschia** Jeroen Peys/Getty Images; **Welwitschia cones** Francesco Tomasini/Science Source; **Gnetum** Michael Clayton; **Ephedra** Bob Gibbons/Frank Lane Picture Agency Limited; **Douglas fir** vincentlouis/Fotolia; **juniper** Svetlana Tikhonova/Shutterstock; **larch** Adam Jones/Getty Images; **sequoia** Daniel Acevedo/AGE Fotostock/Alamy Stock Photo; **Wollemi fossil** Jaime Plaza/Royal Botanic Gardens Sydney; **Wollemi forest** Wildlight Photo Agency/Alamy Stock Photo; **bristlecone pine** Russ Bishop/Alamy Stock Photo; **30.9 top** Silver Spiral Arts/Shutterstock; **bottom** Paul Atkinson/Shutterstock; **30.10 tomatoes** Tim UR/Shutterstock; **grapefruit** almandreev/Shutterstock; **nectarine** Ines Behrens-Kunkel/Shutterstock; **hazelnuts** Diana Taliu/Fotolia; **milkweed** Maria Dryfhout/123RF; **30.11 explosive seed** Mike Davis; **winged fruit** Pixtal/AGE Fotostock; **mouse with fruit** Eduard Kyslynskyy/Shutterstock; **cocklebur** Nataly Studio/Shutterstock; **dog with burrs** Scott Camazine/Science Source; **30.13a** David L. Dilcher; **30.15** Nuridsany et Perennou/Science Source; **30.17 water lily** Dorling Kindersley Ltd/Alamy Stock Photo; **star anise** Floridata.com; **Amborella trichopoda** Joel McNeal; **Magnolia grandiflora** Dorling Kindersley Ltd/Alamy Stock Photo; **orchid** PS-I/Alamy Stock Photo; **barley** kenjii/Fotolia; **pygmy palm** Kanok Chantong/Shutterstock; **snow pea** Maria Dattola/Getty Images; **dog rose** Glam/Shutterstock; **Armenian oak** Dorling Kindersley Ltd/Alamy Stock Photo; **30.18 NASA**; **p. 653 milkweed** Howard Sandler/Shutterstock.

Chapter 31 **31.1 top** Arie v.d. Wolde/Shutterstock; **bottom** Ted M. Kinsman/Science Source; **31.2 top** Nata-Lia/Shutterstock; **bottom** Fred Rhoades; **bottom (inset)** George L. Barron; **31.4a** Biophoto Associates/Science Source; **Scientific Skills Exercise** U.S. Department of Energy/DOE Photo; **31.6** Olga Popova/123RF; **inset** Biophoto Associates/Science Source; **31.7** Mediscan/Alamy Stock Photo; **31.9** Martin R. Smith; **31.11** Tim James; **31.12** Electron micrograph taken by Leon White. CC by 2.5; **31.13** William E. Barstow; **31.14** Clarence Holmes Wildlife/Alamy Stock Photo; **31.15 bread** Antonio D'Albore/Getty Images; **Rhizophorus** Culture Collection of Fungi (CCF); **Sporangia** George L. Barron; **zygosporangium** Ed Reschke/Getty Images; **31.16** Sava Krstic; **31.17 left** Bryan Eastham/Fotolia; **right** Science Source; **31.19 top** Frank Paul/Alamy Stock Photo; **center** kichigin19/Fotolia; **bottom** Fletcher and Baylis/Science Source; **31.20** Biophoto Associates/Science Source; **31.21** Stephen Dorey Creatively/Alamy Stock Photo; **31.23** Mark Bowler/Science Source; **31.24 top** Ralph Lee Hopkins/National Geographic/Getty Images; **center** Don Johnston/AGE Fotostock/Alamy Stock Photo; **bottom** Eye of Science/Science Source; **31.25** Eye of Science/Science Source; **31.26a** Scott Camazine/Alamy Stock Photo; **31.26b left** Christian Hatter/imageBROKER/Alamy Stock Photo; **right** Sabena Jane Blackbird/Alamy Stock Photo; **31.26c** Hecker-Sauer/AGE Fotostock; **31.27** Vance T. Vredenburg; **31.28** Gary Strobel; **p. 672 wasp** Erich G Vallery/USDA Forest Service.

Chapter 32 **32.1 chameleon** Rolf Nussbaumer Photography/Alamy Stock Photo; **koala** Tom Brakefield/Stockbyte/Getty Images; **neuron** James Cavallini/Science Source; **muscle** Nina Zanetti/Pearson Education; **p. 676 King** Josh Frost, Pearson Education; **32.5a** Lisa-Ann Gerlshwin; **32.5b** From: The most probable Eumetazoa among late Precambrian macrofossils. A.Yu. Ivantsov. *Invertebrate Zoology*. Vol.14. No.2: 127-133 [in English], 2017. Fig 2; **32.6** From: Predatorial borings in late precambrian mineralized exoskeletons. S. Bengtson and Y. Zhao. *Science*. 1992 Jul 17;257(5068):367-9. Fig. 3. Reprinted with permission from AAAS; **32.7** John Sibbick/Science Source; **inset** Chip Clark; **32.12a** Bickwinkel/Alamy Stock Photo; **p. 685 animal** WaterFrame/Alamy Stock Photo.

Chapter 33 **33.1** Paul Anthony Stewart; **33.2 sponge** Andrew J. Martinez/Science Source; **jelly** Helmut Comeli/Alamy Stock Photo; **Acoela** Teresa Zuberbühler/placozoa From: Global diversity of the Placozoa. M. Etel et al. *PLoS One*. 2013;8(4):e57131. doi: 10.1371/journal.pone.0057131. Epub 2013 Apr 2. Fig. 1; **ctenophore** Gregory G. Dimijian/Science Source; **marine flatworm** Robinson Ed/Perspectives/Getty Images; **rotifer** M. I. Walker/Science Source; **ectoprocts** blickwinkel/Alamy Stock Photo; **brachiopod** Image Quest Marine; **gastrotrich** Sinclair Stammers/Nature Picture Library; **ribbon worm** Sue Daly/NaturePL; **cyclophor** Peter Funch; **annelid** cbimages/Alamy Stock Photo; **octopus** Photonimo/Shutterstock; **loriciferan** Reinhart Mobjerg Kristensen; **priapulan** Andreas Altenburger/Alamy Stock Photo; **onychophoran** Thomas Stromberg; **roundworm** London Scientific Films/Oxford Scientific/Getty Images; **tardigrades** Andrew Syred/Science Source; **spider** Reinhard Hözl/ImageBROKER/AGE Fotostock; **acorn worm** Leslie Newman & Andrew Flowers/Science Source; **tunicate** Ethan Daniels/Stocktrek Images/Alamy Stock Photo; **sea urchin** Louise Murray/robertharding/Alamy Stock Photo; **33.3** Andrew J. Martinez/Science Source; **33.6a left** Helmut Cornelius/Alamy Stock Photo; **right** David Doubilet/National Geographic; **33.6b left** Neil G. McDaniel/Science Source; **right** Mark Conlin/V&W/Image Quest Marine; **33.7** Biophoto Associates/Science Source; **33.8 top left** blickwinkel/

Alamy Stock Photo; **bottom left** Amar and Isabelle Guillen - Guillen Photo LLC/Alamy Stock Photo; **top right** Eldon H. Newcomb; **bottom right** Science Photo Library/Alamy Stock Photo; **33.10 CDC**; **33.11 Eye of Science/Science Source**; **33.11 Eye of Science/Science Source**; **33.12 M. I. Walker/Science Source**; **33.13 Holger Herlyn**, University of Mainz, Germany; **33.14a blickwinkel**/Alamy Stock Photo; **33.14b Image Quest Marine**; **33.16 Image Quest Marine**; **33.17a Lubos Chlubny/Fotolia**; **33.17b Terry Moore/Stocktrek Images/Alamy Stock Photo**; **Scientific Skills Exercise** Christophe Courteau/Water Rights/Alamy Stock Photo; **33.18 Andrew J. Martinez/Science Source**; **33.20 top** Mark Conlin/VWPics/Alamy Stock Photo; **center** Photonimo/Shutterstock; **bottom** SeaTops/Alamy Stock Photo; **33.21 left** Dave Clarke/Zoological Society of London; **right** The U.S. Bureau of Fisheries; **33.22 Fredrik Pleijel**; **33.23 Wolcott Henry/National Geographic**; **33.24 Astrid Michler**; Hanns-Frieder Michler/Science Source; **33.25 Wayne Taylor/The AGE/Fairfax Media via Getty Images**; **33.26 London Scientific Films/Oxford Scientific/Getty Images**; **33.27 Power and Syred/Science Source**; **33.28 Dan Cooper**; **33.29b Courtesy of Sean B. Carroll**; **33.31 Mark Newman/Frank Lane Picture Agency**; **33.32 top** Tim Flach/The Image Bank/Getty Images; **center** Andrew Syred/Science Source; **bottom** Reinhard Hözl/ImageBROKER/AGE Fotostock; **33.34a Premaphotos/Nature Picture Library**; **33.34b Tom McHugh/Science Source**; **33.36 Maximilian Weinzierl/Alamy Stock Photo**; **33.37 Peter Herring/Image Quest Marine**; **33.38 Peter Parks/Image Quest Marine**; **33.40 André Skonieczny/Fionline digitalis Bildagentur GmbH/Alamy Stock Photo**; **33.41a, b, d, e** Cathy Keifer/Shutterstock; **33.41c Jim Zipp/Science Source**; **33.42 Archaeognatha** Kevin Murphy; **Zygentoma** Denis Crawford/Alamy Stock Photo; **Coleoptera** Premaphotos/Nature Picture Library; **Diptera** Bruce Marlin; **Hymenoptera** John Cancalosi/Nature Picture Library; **Lepidoptera** Hans Christoph Kappel/Nature Picture Library; **Hemiptera** Dante Fenolio/Science Source; **Orthoptera** Chris Mattison/Alamy Stock Photo; **33.43 Andrey Nekrasov/Image Quest Marine**; **33.44 Daniel Janies**; **33.45 Jeff Rotman/Science Source**; **33.46 Louise Murray/robertharding/Alamy Stock Photo**; **33.47 Jurgen Freund/Nature Picture Library**; **33.48 Hal Beral/Corbis**; **p. 717 beetles** Lucy Arnold.

Chapter 34 **34.1 top to bottom** Derek Siveter, Tom McHugh/Science Source, Gino Santa Maria/Shutterstock; Digital Vision/Photodisc/Getty Images, Arnaz Mehta, Tom McHugh/Science Source, Rolf Nussbaumer Photography/Alamy Stock Photo, Visceralimage/Fotolia; **34.4 Natural Visions/Alamy Stock Photo**; **34.5c Ethan Daniels/Stocktrek Images/Alamy Stock Photo**; **34.8 Tom McHugh/Science Source**; **34.9 Marevision/AGE Fotostock**; **inset** Hartl/blickwinkel/Alamy Stock Photo; **34.10 Junyan Chen/Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences**; **34.14 Field Museum Library/Premium Archive/Getty Images**; **34.15a Gino Santa Maria/Shutterstock**; **34.15b Masa Ushioda/Image Quest Marine**; **34.15c RGB Ventures/SuperStock/Alamy Stock Photo**; **34.17 tuna** James D. Watt/Image Quest Marine; **lionfish** Teigler/blickwinkel/Alamy Stock Photo; **sea horse** George Grall/National Geographic; **eel** Fred McConaughey/Science Source; **34.18** Reprinted by permission from Macmillan Publishers Ltd: From: The oldest articulated osteichthyan reveals mosaic gnathostome characters. M. Zhu. *Nature*. 2009 Mar 26;458(7237):469-74. doi: 10.1038/nature07855. Fig. 2; **34.19 Arnaz Mehta/SeaPics**; **34.20 fossil, ribs, scales** Ted Daeschler/Academy of Natural Sciences/Vireo; **fin** Kalliopi Monoyios Studio; **34.22a Alberto Fernández/AGE Fotostock/Alamy Stock Photo**; **34.22b Anneka/Shutterstock**; **34.22c Zeeshan Mirza/ephotocor/Alamy Stock Photo**; **34.23a DP Wildlife Vertebrates/Alamy Stock Photo**; **34.23b FLPA/Alamy Stock Photo**; **34.23c John Cancalosi/Photolibrary/Getty Images**; **34.24 Hinrich Kaiser, Victor Valley College; Problem-Solving Exercise** Joel Sartore/National Geographic; **34.27 Nobumichi Tamura**; **34.28 Chris Mattison/Alamy Stock Photo**; **p. 736 Sereno Paul Sereno Fossil Lab**; **34.29a Natural Visions/Alamy Stock Photo**; **34.29b Lee T. Matt**; **34.29c Nick Garbutt/Nature Picture Library**; **34.29d Juniors Bildarchiv/AGE Fotostock**; **34.29e Carl & Ann Purcell/Corbis NX/Getty Images**; **34.30a Visceralimage/Fotolia**; **34.30b The Natural History Museum/Alamy Stock Photo**; **34.32 Boris Karpinski/Alamy Stock Photo**; **34.33 DLILLC/Corbis/VCG/Getty Images**; **34.34 Mariusz Blach/Fotolia**; **34.35 The Africa Image Library/Alamy Stock Photo**; **inset mychicport/Shutterstock**; **34.36 Gianpiero Ferrari/Frank Lane Picture Agency Limited**; **34.39 Clearviewstock/Shutterstock**; **inset Commonwealth Scientific and Industrial Research Organization**; **34.40a John Cancalosi/Alamy Stock Photo**; **34.40b Martin Harvey/Alamy Stock Photo**; **34.40c Rick & Nora Bowers/Alamy Stock Photo**; **34.43 ImageBroker/Alamy Stock Photo**; **34.45a Kevin Schafer/AGE Fotostock**; **34.45b J & C Sohns/Picture Press/Getty Images**; **34.46a Morales/AGE Fotostock**; **34.46b Tim Laman/NaturePL**; **34.46c T.J. Rich/Nature Picture Library**; **34.46d E.A. Janes/AGE Fotostock**; **34.46e Martin Harvey/Photolibrary/Science Source**; **34.48b T. White/David L. Brill Photography**; **34.49a John Reader/Science Source**; **34.49b Mauricio Anton/Science Source**; **Scientific Skills Exercise** Golfx/Shutterstock; **34.50 Danita Delimont/Alamy Stock Photo**; **34.52a Erik Trinkaus**; **34.52b Tom Higham, University of Oxford**; **34.53 David L. Brill Photography**; **34.54 From: Homo naledi**, a new species of the genus *Homo* from the Dinaledi Chamber, South Africa. L. R. Berger et al. *eLife* 2015;4:e09560. Fig. 6; **34.55 C. Henshilwood**; **p. 756 animal** Tony Heald/Nature Picture Library.

Unit Six Interview Courtesy of Dennis Gonsalves.

Chapter 35 **35.1 tree** Raimund Linke/Photodisc/Getty Images; **seedling** Beata Becia/Shutterstock; **leaf cross section** P&R Fotos/AGE Fotostock/Alamy Stock Photo; **chloroplasts** John Durham/Science Source; **tube-shaped cells** Science Photo Library/Alamy Stock Photo; **root hairs** Scenics & Science/Alamy Stock Photo; **35.3 Jeremy Burgess/Science Source**; **35.4 buttress roots** Karl Weidmann/Science Source; **prop roots** Natalie Bronstein; **beet** Rob Walls/Alamy Stock Photo; **pneumatophores** Bjorn Svensson/AGE Fotostock/Alamy Stock Photo; **strangling roots** Dana Tezarr/Photodisc/Getty Images; **35.5 top** Maureen Spuhler/Sealevel.com; **center** Dorling Kindersley Ltd/Alamy Stock Photo; **bottom** Toshihiko Watanabe/Aflo/Alamy Stock Photo; **35.7 tendrils** Neil Cooper/Alamy Stock Photo; **spines** Martin Ruegner/Photodisc/Getty Images; **storage leaves** Dmytro Skorobogatov/123RF; **reproductive leaves** Godunova Tatiana/Shutterstock; **Scientific Skills Exercise** Dorling Kindersley Ltd/Alamy Stock Photo; **35.9 Steve Gschmeissner/SPL/AGE Fotostock**; **35.10 parenchyma** M I (Spike) Walker/Alamy Stock Photo; **35.10 collenchyma** Keith Wheeler/Science Source; **scleireid** Graham Kent/Pearson Education; **fiber** Graham Kent/Pearson Education; **tracheids and vessels** N.C Brown Center for Ultrastructure Studies; **sieve-tube element (TEM)** From: *Plant Cell*

Biology on DVD: Information for students and a resource for teachers Springer-Verlag 2009, by B Gunning; **sieve-tube element (LM)** Ray F. Evert; **sieve plate** Graham Kent/Pearson Education; **35.13** From: ABA-mediated ROS in mitochondria regulate root meristem activity by controlling PLETHORA expression in *Arabidopsis*. Yang L. *PLoS Genet.* 2014 Dec 18;10(12):e1004791. doi: 10.1371/journal.pgen.1004791. eCollection 2014 Dec. Figure 6G; **35.14a, b** Ed Reschke; **35.14a center** Chuck Brown/Science Source; **35.15, 35.16** Michael Clayton; **35.17, 35.18** Ed Reschke; **35.20 left** Michael Clayton; **right** Alison W. Roberts; **35.23** University of Southern California; **35.25 Edu Boer, NVWA, NL**; **35.26** From: Natural variation in *Arabidopsis*: from molecular genetics to ecological genomics. D. Weigel. *Plant Physiol.* 2012 Jan;158(1):2-22. doi: 10.1104/pp.111.189845. Epub 2011 Dec 6. Fig. 1; **p. 776 Chory** Michelene Pelletier/Courtesy of Joanne Chory; **35.28** From: Microtubule plus-ends reveal essential links between intracellular polarization and localized modulation of endocytosis during division-plane establishment in plant cells. P. Dhonukshe. *BMC Biol.* 2005 Apr 14;3:11. Fig. 4B; **35.28 (inset)** B. Wells and K. Roberts; **35.29** From: The making of a compound leaf: genetic manipulation of leaf architecture in tomato. D. Hareven. *Cell.* 1996 Mar 8;84(5):735-44. Fig. 1; **35.30** From: A common position-dependent mechanism controls cell-type patterning and GLABRA2 regulation in the root and hypocotyl epidermis of *Arabidopsis*. C. Y. Hung et al. *Plant Physiol.* 1998 May;117(1):73-84. Fig. 2g; **p. 778 Benfey** Ji Huang/Duke University; **35.31** Lawrence Jensen; **35.32** From: Genetic interactions among floral homeotic genes of *Arabidopsis*. JL Bowman, DR Smyth, EM Meyerowitz. *Development.* 1991 May;112(1):1-20; Fig. 1A; **p. 780 Walbot** Courtesy of Virginia Walbot; **p. 782 woody eudicot** From: Anatomy of the vessel network within and between tree rings of *Fraxinus lanuginosa* (Oleaceae). P. B. Kitin et al. *American Journal of Botany.* 2004;91:779-788. Fig. 1; **p. 783 tea leaves** Volodymyr Burdiak/Shutterstock; **tea leaf cross section** Keith Wheeler/Science Source; **iris leaves** Rob Stark/Shutterstock; **iris leaf cross section** www.willemsmicroscope.com; **bicycle** Janet Horton/Alamy Stock Photo; **Hakea purpurea** Biophoto Associates/Science Source.

Chapter 36 **36.1 velislava**/Alamy Stock Photo; **36.3 Rolf Rutishauser and Evelin Pfeifer**; **p. 790 plant** Nigel Cattlin/Alamy Stock Photo; **36.8 Benjamin Blonder and David Elliott**; **36.10 Scott Camazine/Science Source**; **36.13 AGE Fotostock/Alamy Stock Photo**; **36.14 Power and Syred/Science Source**; **36.15 leafless ocotillo** mike lane/Alamy Stock Photo; **green ocotillo** Rick & Nora Bowers/Alamy Stock Photo; **ocotillo close-up** Mint Images/SuperStock; **oleander cross section** Natalie Bronstein; **blossom** SutidaS/Shutterstock; **cactus** Danita Delimont/Alamy Stock Photo; **36.18 M. H. Zimmerman/Harvard Forest**; **36.19** From: A coiled-coil interaction mediates cauliflower mosaic virus cell-to-cell movement. L. Stavolone et al. *Proc Natl Acad Sci U S A.* 2005 Apr 26;102(17):6219-24. Epub 2005 Apr 18. Fig. 5c; **p. 802 Zambryski** Noah Berger Photography; **p. 804 forest** Catalin Petolea/Alamy Stock Photo.

Chapter 37 **37.1 Visuals Stock/Alamy Stock Photo**; **37.2 ARS/USDA**; **37.4 National Oceanic and Atmospheric Administration (NOAA)**; **37.5 Menlo Park/USGS**; **37.6 Kevin Horan/The Image Bank/Getty Images**; **p. 811 Coruzzi** Courtesy of Gloria M. Coruzzi; **37.8 healthy** View Stock RF/AGE Fotostock; **nitrogen-deficient** Guillermo Roberto Pugliese/International Plant Nutrition Institute (IPNI); **phosphorus-deficient** C. Witt/IPNI; **potassium-deficient** M.K. Sharma and P. Kumar/IPNI; **Scientific Skills Exercise** Nigel Cattlin/Science Source; **37.9 lichen** David T. Webb, University of Montana; **lichen section** Courtesy of Ralf Wagner; **puffer** Andrej Nekrasov/Pixtal/AGE Fotostock; **Azolla** Daniel L Nickrent; **37.9 ant** Juan Carlos Vindas/Moment Open/Getty Images; **fungal garden** Martin Dohrn/Nature Picture Library; **root** Yoshihiro Kobae; **nectar** Oxford Scientific/Getty Images; **37.10 Sarah Lydia Lebeis**; **37.12 Scimat/Science Source**; **37.14 sheath** Hugues B. Massicotte/University of Northern British Columbia Ecosystem and Management Program, Prince George, BC, Canada; **cells, arbuscules** Mark Brundrett; **37.15 fern** David Wall/Alamy Stock Photo; **mistletoe** Peter Lane/Alamy Stock Photo; **dodder** Emilio Ereza/Alamy Stock Photo; **Indian pipe** Martin Shields/Alamy Stock Photo; **pitcher plants** Dorling Kindersley Ltd/Alamy Stock Photo; **ant on pitcher plant** Paul Zahl/Science Source; **sundew** Fritz Polking/Frank Lane Picture Agency Limited W. Rolfs/Arco Images GmbH/Alamy Stock Photo; **Venus flytrap** Chris Mattison/Nature Picture Library; **p. 821 footprint** Mode Images/Alamy Stock Photo.

Chapter 38 **38.1 blickwinkel**/Alamy Stock Photo; **inset** Nicolas J. Vereecken; **38.4 hazel carpellate** Friedhelm Adam/imageBROKER/Getty Images; **hazel staminate** Wild-life GmbH/Alamy Stock Photo; **dandelions** © Bjørn Rørslett/NN/Samfoto/Sipa USA; **moth** Doug Backlund/WildPhotosPhotography.com; **blowfly** Kjell B. Sandved/Science Source; **bat** Rolf Nussbaumer/imageBROKER/AGE Fotostock; **hummingbird** Rolf Nussbaumer/Nature Picture Library; **38.5 W. Barthlott and W.Rauh**/Nees Institute for Biodiversity of Plants; **38.6 top** Michael Clayton/Botany Dept., University of Wisconsin; **bottom** Ed Reschke/Photolibrary/Getty Images; **38.10 blickwinkel**/Alamy Stock Photo; **38.12 coconut** Kevin Schafer/Alamy Stock Photo; **Alsomitra macrocarpa** Aquiya/Fotolia; **dandelion** Steve Bloom Images/Alamy Stock Photo; **maple seed** Chrispo/Fotolia; **tumbleweed** Nurlan Kalchinov/Alamy Stock Photo; **Tribulus terrestris** California Department of Food and Agriculture's Plant Health and Pest Prevention Services; **squirrel** Alan Williams/Alamy Stock Photo; **feces** Kim A Cabrera; **ant** Benoit Guénard; **38.13 Dennis Frates/Alamy Stock Photo**; **Scientific Skills Exercise monkeyflower** Ken Barber/Alamy Stock Photo; **hummingbird** Dec Hogan/Shutterstock; **38.14a** Marcel Dorken; **38.14b** Nobumitsu Kawakubo; **38.15** Meriel G. Jones, University of Liverpool School of Biological Sciences; **38.16** Dorling Kindersley Ltd/Alamy Stock Photo; **p. 837 Herrera-Estrella** Michael Starghill, Michael Starghill Photography; **38.17** Gary P. Munkvold; **p. 838 Gonsalves** Courtesy of Dennis Gonsalves; **38.18 ton koene**/Alamy Stock Photo; **p. 841 pollen** Dartmouth College Electron Microscope Facility.

Chapter 39 **39.1** Christopher Ison/Alamy Stock Photo; **39.2** Natalie Bronstein; **39.6** From: Regulation of polar auxin transport by AtPIN1 in *Arabidopsis* vascular tissue. L. Gálweiler et al. *Science.* 1998 Dec 18;282(5397):2226-30; Fig. 4; **39.9a** Richard Amasino; **39.9b** Fred Jensen, Kearney Agricultural Center; **39.11 left** Mia Molvray; **right** Karen E. Koch; **39.13a** Kurt Stepnitz; **39.13b** Joseph J. Kieber; **39.14** Ed Reschke; **39.16** Nigel Cattlin/Alamy Stock Photo; **39.18** Martin Shields/Alamy Stock Photo; **p. 858 Satter** Robin Heyden/Pearson Education; **39.22** Michael L. Evans/Ohio State University; **39.23** From the cover of *Cell*, Volume 60, Issue 3, 9 February 1990. Janet Braam, Ronald W. Davis. Used by permission, Copyright ©1990 Cell Press. Image

courtesy of Elsevier Sciences, Ltd; **39.24** Martin Shields/Alamy Stock Photo; **39.25** J. L. Basq/M. C. Drew; **39.26** New York State Agricultural Experiment Station/Cornell University College of Agriculture and Life Sciences; **p. 867 Dangl** Courtesy of Jeff Dangl; **39.27 poppy seed** De Meester Johan/Arterra Picture Library/Alamy Stock Photo; **taro plant** David T. Webb; **olive leaf** Science Photo Library/Alamy Stock Photo; **cactus spines** Susumu Nishinaga/Science Source; **snowflake plant** Giuseppe Mazza; **passion flower** Lawrence E. Gilbert/University of Texas-Austin; **hummingbird** Danny Kessler; **bamboo plants** Kim Jackson/Mode Images/Alamy Stock Photo; **wasp, cocoons** Custom Life Science Images/Alamy Stock Photo; **p. 871 deer** Gary Crabbe/Alamy Stock Photo.

Unit Seven Interview

UCSD Health.

Chapter 40 **40.1 top** Paul Nicklen/National Geographic/Getty Images; **center left** CNRS/IPEV/IPHC, France; **bottom** Nature Picture Library/Alamy Stock Photo; **40.2 seal** Dave Fleetham/Robert Harding World Imagery; **penguin** WILDLIFE GmbH/Alamy Stock Photo; **tuna** Andre Seale/Image Quest Marine; **40.4 intestine** Eye of Science/Science Source; **lung, kidney** Susumu Nishinaga/Science Source; **40.5 epithelia** Steve Downing/Pearson Education; **loose connective tissue, adipose tissue, bone, skeletal muscle** Nina Zanetti/Pearson Education; **40.5 blood** Jarun Ontakrat/Shutterstock; **cartilage** Chuck Brown/Science Source; **fibrous connective tissue, smooth muscle, cardiac muscle** Ed Reschke/Photolibrary/Getty Images; **neuron** James Cavallini/Science Source; **glia** Thomas Deerinck; **40.7 otter** Kaufung Agency/blickwinkel/Alamy Stock Photo; **bass** Roderick Paul Walker/Alamy Stock Photo; **40.10 Meiqianbao**/Shutterstock; **40.11a** Paul Souders/Danita Delimont Creative/Alamy Stock Photo; **40.11b** Bill Gozansky/Alamy Stock Photo; **40.14 Mirko Grail**/Shutterstock; **40.15** From: Assessment of oxidative metabolism in brown fat using PET imaging. Otto Muzik, Thomas J. Manger and James G. Granneman. *Front. Endocrinol.*, 08 February 2012 | <http://dx.doi.org/10.3389/fendo.2012.00015> Fig. 2; **40.19 Jeff Rotman**/Alamy Stock Photo; **40.21 FLPA**/Alamy Stock Photo; **p. 893 Bartholomew** Robin Heyden **40.23 plants** Irim-K/Shutterstock; **bobcat** Thomas Kitchin/Victoria Hurst/All Canada Photos/AGE Fotostock; **sunflowers** Phil_Good/Fotolia; **fly** WildPictures/Alamy Stock Photo; **sprouts** Bogdan Wankowicz/Shutterstock; **molting** Nature's Images/Science Source; **plant vessels** Last Refuge/Robert Harding Picture Library Ltd/Alamy Stock Photo; **blood vessels** Susumu Nishinaga/Science Source; **peas** Scott Rothstein/Shutterstock; **pigs** Steven Goodier/Alamy Stock Photo; **intestinal lining** David M. Martin/Science Source; **root hairs, mesophyll** Rosanne Quinnell © The University of Sydney. eBot <http://hdl.handle.net/102.100.100/1463>; <http://hdl.handle.net/102.100.100/2574>; **alveoli** David M. Phillips/Science Source; **p. 897 macaques** Yoshiteru Takahashi/Sebum Photo/amana images/Getty Images.

Chapter 41 **41.1** Milo Burcham/First Light/Getty Images; **41.3** Stefan Huwiler/Rolf Nussbaumer Photography/Alamy Stock Photo; **41.5 baleen** Vicki Beaver/Alamy Stock Photo; **caterpillar** Stuart Wilson/Science Source; **fly** Peter Parks/Image Quest Marine; **python** Gunter Ziesler/Photolibrary/Getty Images; **41.16 left** McPhoto/INS Agency/blickwinkel/Alamy Stock Photo; **right** Tom Brakefield/Stockbyte/Getty Images; **41.19** James Archer, CDC; **p. 913 Strathdee** UCSD Health; **41.21** Peter Batson/Image Quest Marine; **Scientific Skills Exercise** ORNL/Science Source; **p. 920 owl** Stefan Huwiler/imageBROKER RF/AGE Fotostock.

Chapter 42 **42.1** John Cancalosi/Alamy Stock Photo; **42.2a** Reinhard Dirscherl/WaterFrame/Getty Images; **42.2b** Eric Grave/Science Source; **42.9 top** Indigo Instruments; **bottom** Ed Reschke/Photolibrary/Getty Images; **p. 931 Yanagisawa** Skeeter Hagler; **42.18** Eye of Science/Science Source; **42.19** Image Source Plus/Alamy Stock Photo; **Scientific Skills Exercise** cassis/Fotolia; **42.21a** Peter Batson/Image Quest Marine; **42.21b** Olgysya/Shutterstock; **42.21c** Greg Amptman/Shutterstock; **42.23c** Prepared by Dr. Hong Y. Yan, University of Kentucky and Dr. Peng Chai, University of Texas; **42.24** Motta and Macchiarelli, Anatomy Dept., Univ. La Sapienza, Rome/Science Source; **42.26** Hans-Rainer Duncker, Institute of Anatomy and Cell Biology, Justus-Liebig-University Giessen; **42.32** Doug Allan/Nature Picture Library; **p. 951 spider** CB2/ZOB/WENN.com/Newscom.

Chapter 43 **43.1 macrophage** SPL/Science Source; **virus** James Cavallini/BSIP SA/Alamy Stock Photo; **bacterium** Chris Bjornberg/Science Source; **fungus** Callista Images/Cultura Creative (RF)/Alamy Stock Photo; **influenza** Kateryna Kon/Shutterstock; **43.15** Steve Gschmeissner/Science Source; **43.27** CNRI/Science Source; **Scientific Skills Exercise** Eye of Science/Science Source; **p. 973 Wong-Staal** Bill Branson/NIH; **43.29** Stephen C. Harrison/The Laboratory of Structural Cell Biology/Harvard Medical School; **p. 974 zur Hausen** Tobias Schwerdt; **p. 976 vaccine** Tatan Yuflana/AP Images.

Chapter 44 **44.1** David Wall/Alamy Stock Photo; **44.2** Mark Conlin/VWPICS/Visual&Written SL/Alamy Stock Photo; **44.4** Eye of Science/Science Source; **Scientific Skills Exercise** Jiri Lochman/Lochman Transparencies; **44.6 left** GeorgePeters/E+/Getty Images; **center** Eric Isselée/Fotolia; **right** Maksym Gorpenyuk/Shutterstock; **44.7** Stephane Bidouze/Shutterstock; **44.12** Steve Gschmeissner/Science Source; **44.15** Michael Lynch/Shutterstock; **44.16 v_blinov**/Fotolia; **44.17 fish** Image Quest Marine; **stomata** Eye of Science/Science Source; **frog** F1online digitale Bildagentur GmbH/Alamy Stock Photo; **bacterium** Power and Syred/Science Source; **p. 998 iguana** Steven A. Wasserman.

Chapter 45 **45.1 top** Phillip Colla/Oceanlight.com; **bottom** Craig K. Lorenz/Science Source; **45.3** Volker Witte/Ludwig-Maximilians-Universitat Munchen; **45.11** Cathy Keifer/123rf; **Problem-Solving Exercise** angellodeco/Fotolia; **45.17** AP Images; **45.22 left** Blickwinkel/Alamy Stock Photo; **right** Jurgen and Christine Sohns/Frank Lane Picture Agency; **p. 1018 frogs** Eric Roubos.

Chapter 46 **46.1 coral** Auscape/UIG/Getty Images; **hydra** Roland Birke/Okopedia/Science Source; **nudibranchs** Colin Marshall/Frank Lane Picture Agency; **frogs** Andy Sands/Nature Picture Library; **sperm** Don W. Fawcett/Science Source; **cardinals** William Leaman/Alamy Stock Photo; **zebras** Mike Taylor/Alamy Stock Photo; **46.2** Colin Marshall/Frank Lane Picture Agency; **46.3a** P. de Vries/Crews, David; **46.5** Andy Sands/Nature Picture Library; **46.6** John Cancalosi/Alamy Stock Photo; **Scientific Skills Exercise** Andrew Syred/Science Source; **46.12** Design Pics Inc/Alamy Stock Photo; **46.17** Tidningarnas Telegrambyra AB; **46.21** M.I. Walker/Science Source; **p. 1042 Komodo dragon** Dave Thompson/AP Images.

Chapter 47 **47.1** Brad Smith/Stamps School of Art & Design, University of Michigan; **inset** Oxford Scientific/Getty Images; **47.3 top** Victor D. Vacquier; **bottom** From: Wave of free calcium at fertilization in the sea urchin egg visualized with fura-2. M. Hafner et al, *Cell Motil Cytoskeleton*. 1988;9(3):271-7. Fig. 1; **47.6** George von Dassow; **47.7 top** Jürgen Berger/Max Planck Institute for Developmental Biology, Tübingen Germany; **bottom** Andrew J. Ewald, Johns Hopkins Medical School; **47.13b** Alejandro Díaz Díez/AGE Fotostock/Alamy Stock Photo; **47.14a** P. Huw Williams and Jim Smith, The Wellcome Trust/Cancer Research UK Gurdon Institute; **47.14c** Thomas Poole, SUNY Health Science Center; **47.15b** Keith Wheeler/Science Source; **47.18b** From: Cell lineage analysis in ascidian embryos by intracellular injection of a tracer enzyme. III. Up to the tissue restricted stage. H. Nishida. *Dev Biol.* 1987 Jun;121(2):526-41. Fig. 1. Reprinted by permission of Academic Press; **47.19** From: Post-embryonic cell lineages of the nematode, *Caenorhabditis elegans*. E. Sulston et al. *Dev Biol.* 1977 Mar;56(1):110-56. Fig. 1; **47.20** Susan Strome; **47.21** Susan Strome; **47.24** From: Dorsal-ventral patterning and neural induction in *Xenopus* embryos. E. M. De Robertis and H. Kuroda. *Annu Rev Cell Dev Biol.* 2004;20:285-308. Fig. 1; **47.25a** Kathryn Tosney, University of Michigan; **47.26** Based on Honig and Summerbell, courtesy of Lawrence S. Honig; **p. 1066 turtle** James Gerholdt/Getty Images.

Chapter 48 **48.1** Franco Banfi/Science Source; **48.2** Edwin R. Lewis; **p. 1068 Oliveira** From: QnAs with Baldomero M. Olivera. *PNAS* August 21, 2012 109(34) 13470; <https://doi.org/10.1073/pnas.1211581109>. Fig. 1; **48.5** Thomas Deerinck/National Center for Microscopy and Imaging Research, University of California, San Diego; **48.14** Alan Peters; **p. 1084 B.A.E.**/Alamy Stock Photo.

Chapter 49 **49.10** Tamily Weissman; **49.11** Larry Mulvehill/Corbis; **49.15** From: A functional MRI study of happy and sad affective states induced by classical music. M. T. Mitterschiffthaler et al. *Hum Brain Mapp.* 2007 Nov; 28(11):1150-62. Fig. 1; **49.18** Marcus E. Raichle, Washington University Medical Center. From research based on "Positron emission tomographic studies of the cortical anatomy of single-word processing". S.E. Petersen et al. *Nature* 331:585-589 (1988); **49.19** National Library of Medicine (NLM); **p. 1099 Jarvis** Walter Oleksy/Alamy Stock Photo; **p. 1103 Heberlein** Matthew Staley; **49.25** Martin M. Rotker/Science Source; **p. 1106 microphone** Eric Delmar/Getty Images.

Chapter 50 **50.1** Kenneth Catania; **50.6** CSIRO Publishing; **50.7a** Michael Nolan/Robert Harding World Imagery; **50.7b** Grischa Georgiew/Panther Media/AGE Fotostock; **50.9** From: Richard Elzinga, *Fundamentals of Entomology*, 3rd ed. ©1987, p. 185. Reprinted by permission of Prentice-Hall, Upper Saddle River, NJ; **50.10** SPL/Science Source; **50.16a** APHS Animal and Plant Health Inspection Service/USDA; **50.17** Steve Gschmeissner/Science Source; **50.21** Neitz Laboratories; **50.26** Clara Franzini-Armstrong; **50.27** H. E. Huxley; **50.34** Joe Quinn/Alamy Stock Photo; **50.39** Dave Watts/NHPA/Science Source; **p. 1135 Terence Dawson**; **Scientific Skills Exercise** Vance A. Tucker; **p. 1138 hound dogs**/Fotolia.

Chapter 51 **51.1** Robert Koss/Shutterstock; **51.3** Manamana/Shutterstock; **51.5b** Scott Camazine/Alamy Stock Photo; **p. 1143** Jun Fletcher/Shutterstock; **p. 1144** Dustin Finkelstein/Getty Images for SXSW; **51.7** Thomas D. McAvoy/The LIFE Picture Collection/Getty Images; **51.9** Lincoln Brower/Sweet Briar College; **51.11** Dr Clive Bromhall/Oxford Scientific/Getty Images; **51.12** Richard Wrangham; **inset** Mike Korostelev www.mkorostelev.com/Moment Open/Getty Images; **Scientific Skills Exercise** Matt Goff; **51.14a** Matt T. Lee; **51.14b** David Osborn/Alamy Stock Photo; **51.14c** David Tipling/Frank Lane Picture Agency Limited; **51.15** Fotograferen.net/Alamy Stock Photo; **51.16** Gerald S. Wilkinson; **51.17** Juniors Bildarchiv/F300/Alamy Stock Photo; **51.20** Martin Harvey/Photolibrary/Getty Images; **51.21** Erik Svensson/Lund University, Sweden; **51.22** Lowell Getz; **51.23** Rory Doolin; **51.25** Jennifer Jarvis, University of Cape Town; **51.27** Fred van Wijk/Alamy Stock Photo; **51.28** Jupiterimages/Creatas/Thinkstock/Getty Images; **p. 1160 Wilson** Michael Dwyer/Alamy Stock Photo; **p. 1162 woodpecker** William Leaman/Alamy Stock Photo.

Unit Eight Interview Courtesy of Chelsea Rochman.

Chapter 52 **52.1 top** Christopher Austin; **bottom, left to right:** Siepmann/imageBROKER/Alamy Stock Photo, Anton Foltin/123RF, Digital Vision/Photodisc/Getty Images, NOAA Okeanos Explorer Program; **52.2 top to bottom:** Luca Nichetti/Shutterstock, Barrie Britton/Nature Picture Library, Oleg Znamenskiy/Fotolia, Bluegreen Pictures/Alamy Stock Photo, Juan Carlos Muñoz, AGE Fotostock/Alamy Stock Photo, 1Xpert/Fotolia; **p. 1170 Davis** Courtesy of Margaret Davis; **52.9** Susan Carpenter; **52.11 desert** Anton Foltin/123RF; **grassland** David Halbakken/AGE Fotostock; **broadleaf forest** Gary718/Shutterstock; **tropical forest** Siepmann/ImageBroker/Alamy Stock Photo; **coniferous forest** Bent G. Nordeng/Shutterstock; **tundra** Juan Carlos Munoz/Nature Picture Library; **52.12 left** JTB Media Creation, Inc./Alamy Stock Photo; **right** Krystyna Szulecka/Alamy Stock Photo; **52.13 tropical forest** Siepmann/imageBROKER/Alamy Stock Photo; **desert** Anton Foltin/123RF; **savanna** Robert Harding Picture Library/Alamy Stock Photo; **chaparral** blickwinkel/Alamy Stock Photo; **grassland** David Halbakken/AGE Fotostock; **coniferous forest** Bent Nordeng/Shutterstock; **broadleaf forest** Gary718/Shutterstock; **tundra** Juan Carlos Munoz/Nature Picture Library; **52.16 oligotrophic lake** Susan E. Powell; **eutrophic lake** AfriPics.com/Alamy Stock Photo; **wetland** David Tipling/Nature Picture Library; **headwater stream** scubaland/Shutterstock; **Loire river** Photononstop/SuperStock; **estuaries** Juan Carlos Munoz/AGE Fotostock; **intertidal zone** Stuart Westmorland/Danita Delimont/Alamy Stock Photo; **ocean** Tatonka/Shutterstock; **coral reef** Digital Vision/Photodisc/Getty Images; **benthic zone** NOAA Okeanos Explorer Program; **52.17** JL JV Image Works/Fotolia; **52.19** Sylvain Oliveira/Alamy Stock Photo; **52.20** Scott Ling; **52.22** Sabastien Lecocq/Alamy Stock Photo; **Scientific Skills Exercise** Spartina John W. Bova/Science Source; **Typha** Dave Bevan/Alamy Stock Photo; **52.23** Harold Stiver/Alamy Stock Photo; **p. 1189 giraffe** Daryl Balfour/The Image Bank/Getty Images.

Chapter 53 **53.1 top** Joel Sartore/National Geographic Image Collection; **bottom** Villiers Steyn/Shutterstock; **53.2** Todd Pusser/Nature Picture Library; **53.3a** Bernard Castelein/Nature Picture Library/Alamy Stock Photo; **53.3b** Michael S. Nolan/AGE Fotostock; **53.3c** Alexander Chaikin/Shutterstock; **Table 53.1 top** Kevin Ebi/Alamy Stock Photo; **bottom** Jennifer A. Dever; **53.8** Villiers Steyn/Shutterstock; **53.11** Bence Mate/

Nature Picture Library/Alamy Stock Photo; **Scientific Skills Exercise** Lebendkulturen.de/Shutterstock; **53.12a** Stone Nature Photography/Alamy Stock Photo; **53.12b** Kent Foster/Science Source; **inset** Robert D. and Jane L. Dorn; **53.13** Dietmar Nill/Nature Picture Library; **53.14a** Steve Bloom Images/Alamy Stock Photo; **53.14b left** Fernanda Preto/Alamy Stock Photo; **right** Edward Parker/Alamy Stock Photo; **53.16** National Geographic/Alamy Stock Photo; **53.17 wheat** FotoVoyager/E+/Getty Images; **cheetah** Ian Cumming/Axiom/Design Pics/Alamy Stock Photo; **humans** Jorge Dan/Reuters; **mice** Nicholas Bergkessel Jr./Science Source; **yeast** Andrew Syred/Science Source; **53.19** Alan & Sandy Carey/Science Source; **53.20** Robert Pickett/Papilio/Alamy Stock Photo; **p. 1206 transponder** From: Tracking butterfly movements with harmonic radar reveals an effect of population age on movement distance. O. Ovaskainen et al. *Proc Natl Acad Sci U.S.A.* 2008 Dec 9;105(49):19090-5. doi: 10.1073/pnas.0802066105. Epub 2008 Dec 8. Fig. 1; **53.25** NASA; **p. 1213 locusts** Carlos Guevara/Reuters/Newscom.

Chapter 54 **54.1 eel** Jeremy Brown/123RF; **coral reef** Jan Wlodarczyk/Alamy Stock Photo; **triggerfish** imageBROKER/Alamy Stock Photo; **shark** Andrey Armyagov/Alamy Stock Photo; **coral bleaching** Reinhard Dirscherl/Alamy Stock Photo; **54.2 left** Joseph T. Collins/Science Source; **right** National Museum of Natural History/Smithsonian Institution; **54.4** Frank W Lane/Frank Lane Picture Agency Limited; **Scientific Skills Exercise** Johan Larson/Shutterstock; **54.6a** Tony Heald/Nature Picture Library; **54.6b** Tom Brakefield/Getty Images; **54.6c** Dirk Ercken/Shutterstock; **54.6d** Barry Mansell/Nature Picture Library; **54.6e left** Daniel Janzen/JANZEN.UPENN.EDU/Caters News; **right** Robert Pickett/Papilio/Alamy Stock Photo; **54.6f left** David J Martin/Shutterstock; **right** Lightwriter1949/Alamy Stock Photo; **54.7** Roger Steene/Image Quest Marine; **p. 1219 Langkilde** Patrick Mansell/PennState; **54.8** Doug Perrine/NaturePL.com; **54.9a** Bazzano Photography/Alamy Stock Photo; **54.9b** Nicholas Smythe/Science Source; **54.10** Daryl Balfour/Gallo Images/Getty Images; **54.11a** Sally D. Hacker; **54.13** Gary W. Saunders; **54.14** Dung Vo Trung/Science Source; **54.15** Cedar Creek Ecosystem Science Reserve, University of Minnesota; **54.20a** Genny Anderson; **54.21** Adam Welz; **54.25** National Park Service (NPS.gov); **p. 1229 Turner** From: Tracking butterfly movements with harmonic radar reveals an effect of population age on movement distance. O. Ovaskainen et al. *Proc Natl Acad Sci U.S.A.* 2008 Dec 9;105(49):19090-5. doi: 10.1073/pnas.0802066105. Epub 2008 Dec 5. Fig. 1; **54.26a** Charles D. Winters/Science Source; **54.26b** Keith Boggs; **54.26c** Terry Donnelly/Mary Liz Austin; **54.26d** Glacier Bay National Park and Preserve; **54.27 left to right** Charles D. Winters/Science Source, Keith Boggs, Terry Donnelly/Mary Liz Austin, Glacier Bay National Park/Preserve; **54.28 top** R. Grant Gilmore/NOAA; **54.28 bottom** Lance Horn/National Undersea Research Center/University of North Carolina-Wilmington/NOAA; **54.32** Tim Laman/National Geographic/Getty Images; **54.34** Nishil Pradhan/Bates College/Lewiston, ME; **54.35** Josh Spic; **p. 1237 flower** Jim Holden/Alamy Stock Photo.

Chapter 55 **55.1** Steven Kazlowski/RGB Ventures/SuperStock/Alamy Stock Photo; **55.2** Stone Nature Photography/Alamy Stock Photo; **55.3 left** Scimat/Science Source; **right** Justus de Cuveland/imageBROKER/AGE Fotostock; **55.5** MODIS Science Team/Earth Observatory/NASA; **55.8** A. T. Willett/Alamy Stock Photo; **Problem-Solving Exercise tree** Steven Katovich/USDA Forest Service; **mountain pine beetles** British Columbia Ministry of Forests, Lands and Natural Resource Operations; **55.9** Matt Meadows/Photolibrary/Getty Images; **Scientific Skills Exercise** David R. Frazier Photolibrary/Science Source; **p. 1252 Likens** Courtesy of Gene Likens; **55.15** Hubbard Brook Research Foundation/USDA Forest Service; **55.16** Mark Gallagher/Princeton Hydro, LLC/Ringoes, NJ; **55.17 top to bottom** Kissimmee Division/South Florida Water Management District, Jean Hall/FLPA/Science Source, Tim Day/Xcluder Pest Proof Fencing Company, From: Species richness accelerates marine ecosystem restoration in the Coral Triangle. S. L. Williams et al. *Proc Natl Acad Sci U.S.A.* 2017 Nov 7;114(45):11986-11991. doi: 10.1073/pnas.1707962114. Epub 2017 Oct 24. Fig. 1a. Photos courtesy of D. Trockel, University of California, Davis, CA; **55.18** U.S. Department of Energy; **p. 1259 beetle** Dr Eckart Pott/NHPA/Photoshot.

Chapter 56 **56.1 gecko** Phung My Trung, vncreatures.net; **clearcutting** Mason Vranish/Alamy Stock Photo; **tusks**, **56.8** Benezech M. Mutayoba; **energy** Verneris Vasilis/Shutterstock; **park** Edwin Giesbers/Nature Picture Library; **reef** Matthew Banks/Alamy Stock Photo Image; **56.3 top** Alaz/Shutterstock; **bottom** Mark Carwardine/Photolibrary/Getty Images; **56.4** Merlin D. Tuttle/Science Source; **56.5** Scott Camazine/Science Source; **p. 1263 Wilson** Michael Dwyer/Alamy Stock Photo; **56.6** Michael Edwards/The Image Bank/Getty Images; **56.7** Bruce Coleman/Alamy Stock Photo; **56.9** Travel Pictures/Alamy Stock Photo; **56.12** Bruce Montagne/Dembinsky Photo Associates/Alamy Stock Photo; **56.13** Courtesy Interagency Grizzly Bear Study Team, USGS; **56.14a** Chuck Bargeron; **inset** William Leaman/Alamy Stock Photo; **56.14b** William D. Boyer/USDA; **56.16** Vladimir Melnikov/Shutterstock; **56.17** Richard O. Bierregaard, Jr.; **56.18** Frans Lemmens/Alamy Stock Photo; **56.21** Mark Chiappone; **56.22** Lyda Bergman, Green Teams of Canada; **56.25** Alfred Eisenstaedt/The LIFE Picture Collection/Getty Images; **56.27** Claire Fackler, NOAA National Marine Sanctuaries; **p. 1277 Rochman** Courtesy of Chelsea Rochman; **56.28** Courtesy of Bette Willis and Joleah Lamb; **Scientific Skills Exercise** Hank Morgan/Science Source; **56.31 resin canal** Biophoto Associates/Science Source; **tunnels** Ladd Livingston, Idaho Department of Lands, Bugwood.org; **dead trees** Dezene Huber; **pika** Chris Ray; **caribou** E.A. Janes/Robert Harding World Imagery; **chickweed** Gilles Delacroix/Garden World Images/AGE Fotostock; **urchin** Scott Ling; **56.34** NASA Ozone Watch; **56.36a** Serge de Sazo/Science Source; **56.36b** Javier Trueba/MSF/Science Source; **56.36c** Gabriel Rojo/Nature Picture Library; **56.36d** Titus Lacoste/The Image Bank/Getty Images; **p. 1287 tiger** Edwin Giesbers/Nature Picture Library.

Appendix A **Figure 2.17** Nigel Cattlin/Science Source; **Figure 6.24 left** Omikron/Science Source; **6.24 right** Dartmouth College Electron Microscope Facility; **Ch. 9 Test Your Understanding 10** Medical Research Council; **Figure 12.4** Biophoto/Science Source; **Figure 12.8** Jane Stout and Claire Walczak, Indiana University; **Ch. 12 Test Your Understanding 9** Scenics & Science/Alamy Stock Photo; **Ch. 16 Test Your Understanding 11** Thomas A. Steitz, Yale University, New Haven; **Figure 30.9** Paul Atkinson/Shutterstock; **Ch. 35 Test Your Understanding 11** From: Anatomy of the vessel network within and between tree rings of *Fraxinus lanuginosa* (Oleaceae). Peter B. Kitin, Tomoyuki Fujii, Hisashi Abe and Ryo Funada. *American Journal of Botany.* 2004;91:779-788.

Appendix B Bacteria, Archaea Eye of Science/Science Source; **diatoms** M I Walker/NHPA/Photoshot/Newscom; **lily** Howard Rice/Dorling Kindersley, Ltd./Alamy Stock Photo; **fungus** daksel/fotolia; **chimpanzees** E.A. Janes/AGE Fotostock.

Illustration and Text Credits

Chapter 1 **1.23** Adapted from *The Real Process of Science* (2013), Understanding Science website. The University of California Museum of Paleontology, Berkeley, and the Regents of the University of California. Retrieved from http://undsci.berkeley.edu/article/howscienceworks_02; **1.25** Data from S. N. Vignieri, J. G. Larson, and H. E. Hoekstra, The Selective Advantage of Crypsis in Mice, *Evolution* 64:2153–2158 (2010); **Scientific Skills Exercise** Data from D. W. Kaufman, Adaptive Coloration in *Peromyscus polionotus*: Experimental Selection by Owls, *Journal of Mammalogy* 55:271–283 (1974).

Chapter 2 **Scientific Skills Exercise** Data from R. Pinhasi et al., Revised Age of late Neanderthal Occupation and the End of the Middle Paleolithic in the Northern Caucasus, *Proceedings of the National Academy of Sciences USA* 147:8611–8616 (2011). doi: 10.1073/pnas.1018938108.

Chapter 3 **3.7** map based on NOAA Fisheries, Bowhead Whale (*Balaena mysticetus*); sea ice extent from National Snow and Ice Data Center (<https://nsidc.org/arcticseanews/>); **3.9** Based on Simulating Water and the Molecules of Life by Mark Gerstein and Michael Levitt, from *Scientific American*, November 1998; **Scientific Skills Exercise** Data from C. Langdon et al., Effect of Calcium Carbonate Saturation State on the Calcification Rate of an Experimental Coral Reef, *Global Biogeochemical Cycles* 14:639–654 (2000).

Chapter 4 **4.2** Data from S. L. Miller, A Production of Amino Acids Under Possible Primitive Earth Conditions, *Science* 117:528–529 (1953); **Scientific Skills Exercise** Data from E. T. Parker et al., Primordial Synthesis of Amines and Amino Acids in a 1958 Miller H₂S-rich Spark Discharge Experiment, *Proceedings of the National Academy of Sciences USA* 108:5526–5531 (2011). www.pnas.org/cgi/doi/10.1073/pnas.1019191108; **4.7** Adapted from Becker, Wayne M.; Reece, Jane B.; Poenie, Martin E., *The World of the Cell*, 3rd Ed., ©1996. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

Chapter 5 **5.11** Adapted from Wallace/Sanders/Ferl, *Biology: The Science of Life*, 3rd Ed., ©1991. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **5.13** Collagen Data from Protein Data Bank ID 1CGD: “Hydration Structure of a Collagen Peptide” by Jordi Bella et al., from *Structure*, September 1995, Volume 3(9); **5.16 Space-filling model, ribbon model** Data from PDB ID 2LYZ: R. Diamond. Real-Space Refinement of the Structure of Hen Egg-white Lysozyme. *Journal of Molecular Biology* 82(3):371–91 (Jan. 25, 1974); **5.18 Transthyretin** Data from PDB ID 3GS0: S.K. Palaninathan, N.N. Mohamedmohaideen, E. Orlandini, G. Ortore, S. Nencetti, A. Lapucci, A. Rossello, J.S. Freundlich, J.C. Sacchettini. Novel Transthyretin Amyloid Fibril Formation Inhibitors: Synthesis, Biological Evaluation, and X-ray Structural Analysis. *Public Library of Science ONE* 4:e6290–e6290 (2009); **5.18 Collagen** Data from PDB ID 1CGD: J. Bella, B. Brodsky, and H.M. Berman. Hydration Structure of a Collagen Peptide, *Structure* 3:893–906 (1995); **5.18 Hemoglobin** Data from PDB ID 2HHB: G. Fermi, M.F. Perutz, B. Shaanan, R. Fourme. The Crystal Structure of Human Deoxyhaemoglobin at 1.74 Å resolution. *J. Mol. Biol.* 175:159–174 (1984).

Chapter 6 **6.6** Adapted from Becker, Wayne M.; Reece, Jane B.; Poenie, Martin E., *The World of the Cell*, 3rd Ed., ©1996. Reprinted and electronically reproduced by permission of Pearson Education, Inc. Upper Saddle River, New Jersey; **6.8 Animal cell** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., © 2010. Printed and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **6.9–13, 6.17, 6.22, 6.24 Small cell** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., © 2010. Printed and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **6.14** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., © 2010. Printed and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **Table 6.1** Adapted from Hardin Jeff; Bertoni Gregory Paul, Kleinsmith, Lewis J., *Becker's World of the Cell*, 8th Edition, © 2012, p. 423. Reprinted and electronically reproduced by permission of Pearson Education, Inc. Upper Saddle River, New Jersey; **6.32** Data from: Proton pump: PDB ID 3B8C: Crystal Structure of the Plasma Membrane Proton Pump, Pedersen, B.P., Buch-Pedersen, M. J., Morth, J.P., Palmgren, M.G., Nissen, P. (2007) *Nature* 450: 1111–1114; calcium channel: PDB ID 5E1J: Structure of the Voltage-Gated Two-Pore Channel TPC1 from *Arabidopsis thaliana*, Guo, J., Zeng, W., Chen, Q., Lee, C., Chen, L., Yang, Y., Cang, C., Ren, D., Jiang, Y. (2016) *Nature* 531: 196–201; aquaporin: PDB ID 5I32: Crystal Structure of an Ammonia-Permeable Aquaporin, Kirscht, A., Kapton, S.S., Bienert, G.P., Chaumont, F., Nissen, P., de Groot, B.L., Kjellbom, P., Gourdon, P., Johanson, U. (2016) *Plos Biol.* 14: e1002411–e1002411; BRI1 and SERK1 co-receptors: PDB ID 4LSX: Molecular mechanism for plant steroid receptor activation by somatic embryogenesis co-receptor kinases, Santiago, J., Henzler, C., Hothorn, M. (2013) *Science* 341: 889–892; BRI1 kinase domain: PDB ID 4OAC: Crystal structures of the phosphorylated BRI1 kinase domain and implications for brassinosteroid signal initiation, Bojar, D., Martinez, J., Santiago, J., Rybin, V., Bayliss, R., Hothorn, M. (2014) *Plant J.* 78: 31–43; BAK1 kinase domain: PDB ID 3UIM: Structural basis for the impact of phosphorylation on the activation of plant receptor-like kinase BAK1, Yan, L., Ma, Y.Y., Liu, D., Wei, X., Sun, Y., Chen, X., Zhao, H., Zhou, J., Wang, Z., Shui, W., Lou, Z.Y. (2012) *Cell Res.* 22: 1304–1308; BSK8 pseudokinase: PDB ID: 4I92 Structural Characterization of the RLCK Family Member BSK8: A Pseudokinase with an Unprecedented Architecture, Grutter, C., Sreeramulu, S., Sessa, G., Rauh, D. (2013) *J. Mol. Biol.* 425: 4455–4467; ATP synthase PDB ID 1E79: The Structure of the Central Stalk in Bovine F(1)-ATPase at 2.4 Å Resolution, Gibbons, C., Montgomery, M.G., Leslie, A.G.W., Walker, J.E. (2000) *Nat. Struct. Biol.* 7: 1055; ATP synthase PDB ID 1C17: Structural changes linked to proton translocation by subunit c of the ATP synthase, Rastogi, V.K., Girvin, M.E. (1999) *Nature* 402: 263–268; ATP synthase PDB ID 1L2P: The “Second Stalk” of *Escherichia coli* ATP Synthase: Structure of the Isolated Dimerization Domain, Del Rizzo, P.A., Bi, Y., Dunn,

- S.D., Shilton, B.H. (2002) *Biochemistry* 41: 6875–6884; ATP synthase PDB ID 2A7U: Structural Characterization of the Interaction of the Delta and Alpha Sub-units of the *Escherichia coli* F(1)F(O)-ATP Synthase by NMR Spectroscopy, Wilkens, S., Borchardt, D., Weber, J., Senior, A.E. (2005) *Biochemistry* 44: 11786–11794; Phosphofructokinase: PDB ID 1PPK: Crystal Structure of the Complex of Phosphofructokinase from *Escherichia coli* with Its Reaction Products, Shirakihara, Y., Evans, P.R. (1988) *J. Mol. Biol.* 204: 973–994; Hexokinase: PDB ID 4QS8: Biochemical and Structural Study of *Arabidopsis* Hexokinase 1, Feng, J., Zhao, S., Chen, X., Wang, W., Dong, W., Chen, J., Shen, J.-R., Liu, L., Kuang, T. (2015) *Acta Crystallogr., Sect. D* 71: 367–375; Isocitrate dehydrogenase: PDB ID 3BLW: Allosteric Motions in Structures of Yeast NAD⁺-specific Isocitrate Dehydrogenase, Taylor, A.B., Hu, G., Hart, P.J., McAlister-Henn, L. (2008) *J. Biol. Chem.* 283:10872–10880; NADH-quinone oxidoreductase: PDB ID 3M9S: The architecture of respiratory complex I, Efremov, R.G., Barada-ran, R., Sazanov, L.A. (2010) *Nature* 465: 441–445; NADH-quinone oxidoreductase: PDB ID 3RK0: Structure of the membrane domain of respiratory complex I, Efremov, R.G., Sazanov, L.A. (2011) *Nature* 476: 414–420; Succinate dehydrogenase: PDB ID 1NEK: Architecture of Succinate Dehydrogenase and Reactive Oxygen Species Generation, Yankovskaya, V., Horsefield, R., Tornroth, S., Luna-Chavez, C., Miyoshi, H., Leger, C., Byrne, B., Cecchini, G., Iwata, S. (2003) *Science* 299: 700–704; Ubiquinone: http://www.proteopedia.org/wiki/index.php/Image:Co-enzyme_Q10.pdb; Cytochrome bc1: PDB ID 1BGY: Complete structure of the 11-subunit bovine mitochondrial cytochrome bc1 complex, Iwata, S., Lee, J.W., Okada, K., Lee, J.K., Iwata, M., Rasmussen, B., Link, T.A., Ramaswamy, S., Jap, B.K. (1998) *Science* 281: 64–71; Cytochrome c: PDB ID 3CYT: Redox Conformation Changes in Refined Tuna Cytochrome c, Takano, T., Dickerson, R.E. (1980) *Proc. Natl. Acad. Sci. USA* 77: 6371–6375; Cytochrome c oxidase: PDB ID 1OCO: Redox-Coupled Crystal Structural Changes in Bovine Heart Cytochrome c Oxidase, Yoshikawa, S., Shinzawa-Itoh, K., Nakashima, R., Yaono, R., Yamashita, E., Inoue, N., Yao, M., Fei, M.J., Libeu, C.P., Mizushima, T., Yamaguchi, H., Tomizaki, T., Tsukihara, T. (1998) *Science* 280: 1723–1729; Rubisco: PDB ID 1RCX: The Structure of the Complex between Rubisco and its Natural Substrate Ribulose 1,5-Bisphosphate, Taylor, T.C., Andersson, I. (1997) *J. Mol. Biol.* 265: 432–444; Photosystem II: PDB ID 1SS1: Architecture of the Photosynthetic Oxygen-Evolving Center, Ferreira, K.N., Iverson, T.M., Maghlaoui, K., Barber, J., Iwata, S. (2004) *Science* 303: 1831–1838; Plastoquinone: <http://www.rcsb.org/pdb/ligand/ligandsummary.do?hetld=PL9>; Photosystem I: PDB ID 1JB0: Three-Dimensional Structure of Cyanobacterial Photosystem I at 2.5 Å Resolution, Jordan, P., Fromme, P., Witt, H.T., Klukas, O., Saenger, W., Krauss, N. (2001) *Nature* 411: 909–917; Ferredoxin-NADP⁺ reductase: PDB ID 3WSV: Concentration-Dependent Oligomerization of Cross-Linked Complexes between Ferredoxin and Ferredoxin-NADP⁽⁺⁾ Reductase; DNA: PDB ID 1BNA: Structure of a B-DNA Dodecamer: Conformation and Dynamics, Drew, H.R., Wing, R.M., Takano, T., Broka, C., Tanaka, S., Itakura, K., Dickerson, R.E. (1981) *Proc. Natl. Acad. Sci. USA* 78: 2179–2183; RNA polymerase: PDB ID 2E2I: Structural basis of transcription: role of the trigger loop in substrate specificity and catalysis, Wang, D., Bushnell, D.A., Westover, K.D., Kaplan, C.D., Kornberg, R.D. (2006) *Cell* (Cambridge, Mass.) 127: 941–954; Nucleosome: PDB ID 1AOI: Crystal Structure of the Nucleosome Core Particle at 2.8 Å Resolution, Luger, K., Mader, A.W., Richmond, R.K., Sargent, D.F., Richmond, T.J. (1997) *Nature* 389: 251–260; tRNA: PDB ID 4TNA: Further refinement of the structure of yeast tRNAPhe, Hingerly, B., Brown, R.S., Jack, A. (1978) *J. Mol. Biol.* 124: 523–534; Ribosome: PDB ID 1FJF: Structure of the 30S Ribosomal Subunit, Wimberly, B.T., Brodersen, D.E., Clemons Jr., W.M., Morgan-Warren, R.J., Carter, A.P., Vonrhein, C., Hartsch, T., Ramakrishnan, V. (2000) *Nature* 407: 327–339; Ribosome: PDB ID 1JJ2: The Kink-Turn: A New RNA Secondary Structure Motif, Klein, D.J., Schmeing, T.M., Moore, P.B., Steitz, T.A. (2001) *EMBO J.* 20: 4214–4221; Microtubule: PDB ID 3J2U: Structural Model for Tubulin Recognition and Deformation by Kinesin-13 Microtubule Depolymerases, Asenjo, A.B., Chatterjee, C., Tan, D., Depaoli, V., Rice, W.J., Diaz-Avalos, R., Silvestry, M., Sosa, H. (2013) *Cell Rep.* 3: 759–768; Actin microfilament: PDB ID 1ATN: Atomic Structure of the Actin:DNase I Complex, Kabsch, W., Mannherz, H.G., Suck, D., Pai, E.F., Holmes, K.C. (1990) *Nature* 347: 37–44; Myosin: PDB ID 1M8Q: Molecular Modeling of Averaged Rigor Crossbridges from Tomograms of Insect Flight Muscle, Chen, L.F., Winkler, H., Reedy, M.K., Reedy, M.C., Taylor, K.A. (2002) *J. Struct. Biol.* 138: 92–104; Phosphoglucose Isomerase: PDB ID 1IAT: The Crystal Structure of Human Phosphoglucose Isomerase at 1.6 Å Resolution: Implications for Catalytic Mechanism, Cytokine Activity and Haemolytic Anaemia, Read, J., Pearce, J., Li, X., Muirhead, H., Chirgwin, J., Davies, C. (2001) *J. Mol. Biol.* 309: 447–463; Aldolase: PDB ID 1ALD: Activity and Specificity of Human Aldolases, Gamblin, S.J., Davies, G.J., Grimes, J.M., Jackson, R.M., Littlechild, J.A., Watson, H.C. (1991) *J. Mol. Biol.* 219: 573–576; Triosephosphate Isomerase: PDB ID 7TIM: Structure of the Triose-Phosphate Isomerase-Phosphoglycolohydroxamate Complex: An Analogue of the Intermediate on the Reaction Pathway, Davenport, R.C., Bash, P.A., Seaton, B.A., Karplus, M., Petsko, G.A., Ring, D. (1991) *Biochemistry* 30: 5821–5826; Glyceraldehyde-3-Phosphate Dehydrogenase: PDB ID 3GPD: Twinning in Crystals of Human Skeletal Muscle D-Glyceraldehyde-3-Phosphate Dehydrogenase, Mercer, W.D., Winn, S.I., Watson, H.C. (1976) *J. Mol. Biol.* 104: 277–283; Phosphoglycerate Kinase: PDB ID 3PGK: Sequence and Structure of Yeast Phosphoglycerate Kinase, Watson, H.C., Walker, N.P., Shaw, P.J., Bryant, T.N., Wendell, P.L., Fothergill, L.A., Perkins, R.E., Conroy, S.C., Dobson, M.J., Tuite, M.E. (1982) *EMBO J.* 1: 1635–1640; Phosphoglycerate Mutase: PDB ID 3PGM: Structure and Activity of Phosphoglycerate Mutase, Winn, S.I., Watson, H.C., Harkins, R.N., Fothergill, L.A. (1981) *Philos. Trans. R. Soc. London, Ser. B* 293: 121–130; Enolase: PDB ID 5ENL: Inhibition of Enolase: The Crystal Structures of Enolase-Ca2(+)-2-Phosphoglycerate and Enolase-Zn2(+)-Phosphoglycolate Complexes at 2.2-Å Resolution, Lebioda, L., Stec, B., Brewer, J.M., Tykarska, E. (1991) *Biochemistry* 30: 2823–2827; Pyruvate Kinase: PDB ID 1A49: Structure of the Bis(Mg2+)-ATP-Oxalate Complex of the Rabbit Muscle Pyruvate Kinase at 2.1 Å Resolution: ATP Binding over a Barrel, Larsen, T.M., Benning, M.M., Rayment, I., Reed, G.H. (1998) *Biochemistry* 37: 6247–6255; Citrate Synthase: PDB ID 1CTS: Crystallographic Refinement and Atomic Models of Two Different Forms of Citrate Synthase at 2.7 and 1.7 Å Resolution, Remington, S., Wiegand, G., Huber, R. (1982) *J. Mol. Biol.* 158: 111–152; Succinyl-CoA Synthetase: PDB ID 2FP4: Interactions of GTP with the ATP-Grasp Domain of GTP-Specific Succinyl-CoA Synthetase, Fraser, M.E., Hayakawa, K., Hume, M.S., Ryan, D.G., Brownie, E.R. (2006) *J. Biol. Chem.* 281: 11058–11065; Malate Dehydrogenase: PDB ID 4WLE: Crystal Structure of Citrate Bound MDH2, Eo, Y.M., Han, B.G., Ahn, H.C. To Be Published; **Summary art nucleus, Golgi apparatus and endoplasmic reticulum** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., ©2010. Printed and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.
- Chapter 7** **7.4** Data from L. D. Frye and M. Edidin, The Rapid Intermixing of Cell Surface Antigens after Formation of Mouse-human Heterokaryons, *Journal of Cell Science* 7:319 (1970); **7.6** Based on Similar Energetic Contributions of Packing in the Core of Membrane and Water-Soluble Proteins by Nathan H. Joh et al., from *Journal of the American Chemical Society*, Volume 131(31); **Scientific Skills Exercise** Data from Figure 1 in T. Kondo and E. Beutler, Developmental Changes in Glucose Transport of Guinea Pig Erythrocytes, *Journal of Clinical Investigation* 65:1–4 (1980).
- Chapter 8** **8 Scientific Skills Exercise** Data from S. R. Commerford et al., Diets Enriched in Sucrose or Fat Increase Gluconeogenesis and G-6-pase but not Basal Glucose Production in Rats, *American Journal of Physiology—Endocrinology and Metabolism* 283:E545–E555 (2002); **8.19** Data from Protein Data Bank ID 3e1f: “Direct and Indirect Roles of His-418 in Metal Binding and in the Activity of Beta-Galactosidase (*E. coli*)” by Douglas H. Juers et al., from *Protein Science*, June 2009, Volume 18(6); **8.20** Data from Protein Data Bank ID 1MDYO: “Crystal Structure of MyoD bHLH Domain-DNA Complex: Perspectives on DNA Recognition and Implications for Transcriptional Activation” from *Cell*, May 1994, Volume 77(3); **8.22 Small cell** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., ©2010. Printed and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.
- Chapter 9** **9.4** Adaptation of Figure 2.69 from *Molecular Biology of the Cell*, 4th Edition, by Bruce Alberts et al. Garland Science/Taylor & Francis LLC; **9.8** Figure adapted from *Biochemistry*, 4th Edition, by Christopher K. Mathews et al. Pearson Education, Inc.; **Scientific Skills Exercise** Data from M. E. Harper and M. D. Brand, The Quantitative Contributions of Mitochondrial Proton Leak and ATP Turnover Reactions to the Changed Respiration Rates of Hepatocytes from Rats of Different Thyroid Status, *Journal of Biological Chemistry* 268:14850–14860 (1993).
- Chapter 10** **10.9** Data from T. W. Engelmann, *Bacterium Photometricum. Ein Beitrag zur Vergleichenden Physiologie des Lichtund Farbensinnes*, *Archiv. für Physiologie* 30:95–124 (1883); **10.12b** Data from Architecture of the Photosynthetic Oxygen-Evolving Center by Kristina N. Ferreira et al., from *Science*, March 2004, Volume 303(5665); **10.14** Adaptation of Figure 4.1 from *Energy, Plants, and Man*, by Richard Walker and David Alan Walker. © 1992 by Richard Walker and David Alan Walker. Reprinted with permission of Richard Walker; **Scientific Skills Exercise** Data from D. T. Patterson and E. P. Flint, Potential Effects of Global Atmospheric CO₂ Enrichment on the Growth and Competitiveness of C3 and C4 Weed and Crop Plants, *Weed Science* 28(1):71–75 (1980).
- Chapter 11** **Problem-Solving Exercise** Data from N. Balaban et al., Treatment of *Staphylococcus aureus* Biofilm Infection by the Quorum-Sensing Inhibitor RIP, *Antimicrobial Agents and Chemotherapy*, 51:2226–2229 (2007); **11.8, 11.12** Adapted from Becker, Wayne M.; Reece, Jane B.; Poenie, Martin F., *The World of the Cell*, 3rd Edition, © 1996. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.
- Chapter 12** **12.9** Data from G. J. Borbsky, P.J. Sammak, and G. G. Boris, Chromosomes Move Poleward in Anaphase along Stationary Microtubules that Coordinately Disassemble from their Kinetochore Ends, *Journal of Cell Biology* 104:9–18 (1987); **12.13** Adaptation of Figure 18.41 from *Molecular Biology of the Cell*, 4th Edition, by Bruce Alberts et al. Garland Science/Taylor & Francis LLC; **12.14** Data from R. T. Johnson and P.N. Rao, Mammalian Cell Fusion: Induction of Premature Chromosome Condensation in Interphase Nuclei, *Nature* 226:717–722 (1970); **Scientific Skills Exercise** Data from K. K. Velpula et al., Regulation of Glioblastoma Progression by Cord Blood Stem Cells is Mediated by Downregulation of Cyclin D1, *PLoS ONE* 6(3): e18017 (2011).
- Chapter 14** **14.3, 14.8** Data from G. Mendel, Experiments in Plant Hybridization, *Proceedings of the Natural History Society of Brünn* 4:3–47 (1866).
- Chapter 15** **15.3** Data from T. H. Morgan, Sex-limited inheritance in *Drosophila*, *Science* 32:120–122 (1910); **15.9** Based on the data from “The Linkage of Two Factors in *Drosophila* That Are Not Sex-Linked” by Thomas Hunt Morgan and Clara J. Lynch, from *Biological Bulletin*, August 1912, Volume 23(3).
- Chapter 16** **16.2** Data from F. Griffith, The Significance of Pneumococcal Types, *Journal of Hygiene* 27:113–159 (1928); **16.4** Data from A. D. Hershey and M. Chase, Independent Functions of Viral Protein and Nucleic Acid in Growth of Bacteriophage, *Journal of General Physiology* 36:39–56 (1952); **Scientific Skills Exercise** Data from several papers by Chargaff: for example, E. Chargaff et al., Composition of the Desoxyribose Nucleic Acids of Four Genera of Sea-urchin, *Journal of Biological Chemistry* 195:155–160 (1952); **pp. 320–321 quote** J. D. Watson and F. H. C. Crick, Genetical Implications of the Structure of Deoxyribonucleic Acid, *Nature* 171:964–967 (1953); **16.11** Data from M. Meselson and F. W. Stahl, The Replication of DNA in *Escherichia coli*, *Proceedings of the National Academy of Sciences USA* 44:671–682 (1958).
- Chapter 17** **17.3** Data from A. M. Srb and N. H. Horowitz, The Ornithine Cycle in *Neurospora* and Its Genetic Control, *Journal of Biological Chemistry* 154:129–139 (1944); **17.12** Adapted from Becker, Wayne M.; Reece, Jane B.; Poenie, Martin F., *The World of the Cell*, 3rd Edition, © 1996. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **17.14** Adapted from Klein-Smith, Lewis J., Kish, Valerie M.; *Principles of Cell and Molecular Biology*. Reprinted and electronically reproduced by permissions of Pearson Education, Inc., Upper Saddle River, New Jersey; **17.18** Adapted from Mathews, Christopher K.; Van Holde, Kensi E., *Biochemistry*, 2nd ed., ©1996. Reprinted and electronically reproduced by permission of Pearson Education, Inc. Upper Saddle River, New Jersey; **Scientific Skills Exercise** Material provided courtesy of Dr. Thomas Schneider, National Cancer Institute, National Institutes of Health, 2012; **Problem-Solving Exercise** Data from N. Nishi and K. Nanjo, Insulin Gene Mutations and Diabetes, *Journal of Diabetes Investigation* Vol. 2: 92–100 (2011).

Chapter 18 **18.10** Data from PDB ID 1MDY: P. C. Ma et al. Crystal structure of MyoD bHLH Domain-DNA Complex: Perspectives on DNA Recognition and Implications for Transcriptional Activation, *Cell* 77:451–459 (1994); **Scientific Skills Exercise** Data from J. N. Walters et al., Regulation of Human Microsomal Prostaglandin E Synthase-1 by IL-1b Requires a Distal Enhancer Element with a Unique Role for C/EBP β , *Biochemical Journal* 443:561–571 (2012); **18.26** Adapted from Becker, Wayne M.; Reece, Jane B.; Poenie, Martin F., *The World of the Cell*, 3rd Edition, © 1996. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

Chapter 19 **19.2** Data from M. J. Beijerinck, Concerning a Contagium Vivum Fluidum as Cause of the Spot Disease of Tobacco Leaves, *Verhandelingen der Koninklijke Akademie Wetenschappen te Amsterdam* 65:3–21 (1898). Translation published in English as Phytopathological Classics Number 7 (1942), American Phytopathological Society Press, St. Paul, MN; **Scientific Skills Exercise** Data from J.-R. Yang et al., New Variants and Age Shift to High Fatality Groups Contribute to Severe Successive Waves in the 2009 Influenza Pandemic in Taiwan, *PLoS ONE* 6(11): e28288 (2011).

Chapter 20 **20.7** Adapted from Becker, Wayne M.; Reece, Jane B.; Poenie, Martin F., *The World of the Cell*, 3rd Edition, © 1996. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **20.16** Data from J. B. Gurdon et al., The Developmental Capacity of Nuclei Transplanted from Keratinized Cells of Adult Frogs, *Journal of Embryology and Experimental Morphology* 34:93–112 (1975); **20.21** Data from K. Takahashi et al., Induction of pluripotent stem cells from adult human fibroblasts by defined factors, *Cell* 131:861–872 (2007).

Chapter 21 **21.3** Simulated screen shots based on Mac OS X and from data found at NCBI, U.S. National Library of Medicine using Conserved Domain Database, Sequence Alignment Viewer, and Cn3D; **21.8**, **21.9** Adapted from Becker, Wayne M.; Reece, Jane B.; Poenie, Martin F., *The World of the Cell*, 3rd Edition, © 1996. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **21.10 Hemoglobin** Data from PDB ID 2HHB: G. Fermi, M.F. Perutz, B. Shaanan, and R. Fourme. The Crystal Structure of Human Deoxyhaemoglobin at 1.74 Å resolution, *J. Mol. Biol.* 175:159–174 (1984); **21.15a** Drawn from data in Protein Data Bank ID 1LZ1: “Refinement of Human Lysozyme at 1.5 Å Resolution Analysis of Non-bonded and Hydrogen-bond Interactions” by P.J. Artymiuk and C. C. Blake, from *Journal of Molecular Biology*, 1981, 152:737–762; **21.15b** Drawn from data in Protein Data Bank ID 1A4V: “Structural Evidence for the Presence of a Secondary Calcium Binding Site in Human Alpha-Lactalbumin” by N. Chandra et al., from *Biochemistry*, 1998, 37:4767–4772; **Hemoglobin** in **Scientific Skills Exercise** PDB ID 2HHB: G. Fermi, M.F. Perutz, B. Shaanan, and R. Fourme. The Crystal Structure of Human Deoxyhaemoglobin at 1.74 Å Resolution, *J. Mol. Biol.* 175:159–174 (1984); **Scientific Skills Exercise** Compiled using data from NCBI; **21.18** Data from W. Shu et al., Altered ultrasonic vocalization in mice with a disruption in the *Foxp2* gene, *Proceedings of the National Academy of Sciences USA* 102:9643–9648 (2005); **21.19** Adapted from *The Homeobox: Something Very Precious That We Share with Flies, From Egg to Adult* by Peter Radetsky, © 1992. Reprinted by permission from William McGinnis; **21.20** Adaptation from “Hox Genes and the Evolution of Diverse Body Plans” by Michael Akam, from *Philosophical Transactions of the Royal Society B: Biological Sciences*, September 29, 1995, Volume 349(1329): 313–319. Reprinted by permission from The Royal Society.

Chapter 22 **22.8** Artwork by Utako Kikutani (as appeared in “What Can Make a Four-Ton Mammal a Most Sensitive Beast?” by Jeshesel Shoshani, from *Natural History*, November 1997, Volume 106(1), 36–45). Copyright © 1997 by Utako Kikutani. Reprinted with permission of the artist; **22.13** Data from “Host Race Radiation in the Soapberry Bug: Natural History with the History” by Scott P. Carroll and Christin Boyd, from *Evolution*, 1992, Volume 46(4); **22.14** Figure created by Dr. Binh Diep on request of Michael Cain. Copyright © 2011 by Binh Diep. Reprinted with permission; **Scientific Skills Exercise** Data from J. A. Endler, Natural Selection on Color Patterns in *Poecilia reticulata*, *Evolution* 34:76–91 (1980); **Test Your Understanding Question 7** Data from C. F. Curtis et al., Selection for and Against Insecticide Resistance and Possible Methods of Inhibiting the Evolution of Resistance in Mosquitoes, *Ecological Entomology* 3:273–287 (1978).

Chapter 23 **23.4** Based on the data from *Evolution*, by Douglas J. Futuyma. Sinauer Associates, 2006; and Nucleotide Polymorphism at the Alcohol Dehydrogenase Locus of *Drosophila melanogaster* by Martin Kreitman, from *Nature*, August 1983, Volume 304(5925); **23.11a** Maps adapted from Figure 20.6 from *Discover Biology*, 2nd Edition, edited by Michael L. Cain, Hans Damman, Robert A. Lue, and Carol Kaesuk Loom, W. W. Norton & Company, Inc.; **23.12** Data from Joseph H. Camin and Paul R. Ehrlich, Natural Selection in Water Snakes (*Natrix sipedon* L.) on Islands in Lake Erie, *Evolution* 12:504–511 (1958); **23.14** Based on many sources: *Evolution* by Douglas J. Futuyma. Sinauer Associates 2005; and *Vertebrate Paleontology and Evolution* by Robert L. Carroll. W.H. Freeman & Co., 1988; **23.16** Data from A. M. Welch et al., Call Duration as an Indicator of Genetic Quality in Male Gray Tree Frogs, *Science* 280:1928–1930 (1998); **23.17** Adapted from Frequency-Dependent Natural Selection in the Handedness of Scale-Eating Cichlid Fish by Michio Hori, from *Science*, April 1993, Volume 260(5105); **Test Your Understanding Question 7** Data from R. K. Koehn and T. J. Hilbish, The Adaptive Importance of Genetic Variation, *American Scientist* 75:134–141 (1987).

Chapter 24 **24.6** Original unpublished graph created by Brian Langerhans; **24.7** Data from D. M. B. Dodd, Reproductive Isolation as a Consequence of Adaptive Divergence in *Drosophila pseudoobscura*, *Evolution* 43:1308–1311 (1989); **Scientific Skills Exercise** Data from S. G. Tilley, A. Verrell, and S. J. Arnold, Correspondence between Sexual Isolation and Allozyme Differentiation: A Test in the Salamander *Desmognathus ochrophaeus*, *Proceedings of the National Academy of Sciences USA* 87:2715–2719 (1990); **24.12** Data from O. Seehausen and J. J. M. van Alphen, The Effect of Male Coloration on Female Mate Choice in Closely Related Lake Victoria Cichlids (*Haplochromis nyererei* complex), *Behavioral Ecology and Sociobiology* 42:1–8 (1998); **24.13d** Based on *Hybrid Zone and the Evolutionary Process*, edited by Richard G. Harrison. Oxford University Press; **24.19b** Data from Role of Gene Interactions in Hybrid Speciation: Evidence from Ancient and Experimental Hybrids by Loren H. Rieseberg et al., from *Science*, May 1996, Volume 272(5262).

Chapter 25 **25.2** Based on data from The Miller Volcanic Spark Discharge Experiment by Adam P. Johnson et al., from *Science*, October 2008, Volume 322(5900); **25.4** Based on “Experimental Models of Primitive Cellular Compartments: Encapsulation, Growth, and Division” by Martin M. Hanczyc, Shelly M. Fujikawa, and Jack W. Szostak, from *Science*, October 2003, Volume 302(5645); **25.6** Eicher, D. L., *Geologic Time*, 2nd Ed., © 1976, p. 119. Adapted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **25.7 First four skulls** Adapted from many sources including D.J. Futuyma, *Evolution*, Fig. 4.10, Sunderland, MA: Sinauer Associates, Sunderland, MA (2005) and from R.L. Carroll, *Vertebrate Paleontology and Evolution*. W.H. Freeman & Co. (1988); **25.7 Last skull** Adapted from Z. Lue et al., A New Mammaliform from the Early Jurassic and Evolution of Mammalian Characteristics, *Science* 292:1535 (2001); **25.8** Adapted from When Did Photosynthesis Emerge on Earth? by David J. Des Marais, from *Science*, September 2000, Volume 289(5485); **25.9** Adapted from The Rise of Atmospheric Oxygen by Lee R. Kump, from *Nature*, January 2008, Volume 451(7176); **Scientific Skills Exercise** Data from T. A. Hansen, Larval Dispersal and Species Longevity in Lower Tertiary Gastropods, *Science* 199:885–887 (1978); **25.16** Based on *Earthquake Information Bulletin*, December 1977, Volume 9(6), edited by Henry Spall; **25.18** Based on many sources: D.M. Raup and J. J. Sepkoski, Jr., Mass Extinctions in the Marine Fossil Record, *Science* 215:1501–1503 (1982); J. J. Sepkoski, Jr., A Kinetic Model of Phanerozoic Taxonomic Diversity. III. Post-Paleozoic Families and Mass Extinctions, *Paleobiology* 10:246–267 (1984); and D. J. Futuyma, *The Evolution of Biodiversity*, p. 143, Fig. 7.3a and p. 145, Fig. 7.6, Sinauer Associates, Sunderland, MA; **25.20** Based on data from A Long-Term Association between Global Temperature and Biodiversity, Origination and Extinction in the Fossil Record by P.J. Mayhew, G.B. Jenkins and T.G. Benton, *Proceedings of the Royal Society B: Biological Sciences* 275(1630):47–53. The Royal Society, 2008; **25.21** Adapted from Anatomical and Ecological Constraints on Phanerozoic Animal Diversity in the Marine Realm by Richard K. Bambach et al., from *Proceedings of the National Academy of Sciences USA*, May 2002, Volume 99(10); **25.26** Based on data from The Miller Volcanic Spark Discharge Experiment by Adam P. Johnson et al., from *Science*, October 2008, Volume 322(5900); **25.27** Data from Genetic and Developmental Basis of Evolutionary Pelvic Reduction in Threespine Sticklebacks by Michael D. Shapiro et al., from *Nature*, April 2004, Volume 428(6984); **25.29** Adaptations of Figure 3-1 (a-d, f) from *Evolution*, 3rd Edition, by Monroe W. Strickberger. Jones & Bartlett Learning, Burlington, MA.

Chapter 26 **26.6** Data from C. S. Baker and S. R. Palumbi, Which Whales Are Hunted? A Molecular Genetic Approach to Monitoring Whaling, *Science* 265:1538–1539 (1994); **26.13** Based on The Evolution of the Hedgehog Gene Family in Chordates: Insights from Amphioxus Hedgehog by Sebastian M. Shimeld, from *Developmental Genes and Evolution*, January 1999, Volume 209(1); **26.19** Based on *Molecular Markers, Natural History, and Evolution*, 2nd Ed., by J.C. Advisé. Sinauer Associates, 2004; **26.20** Adapted from Timing the Ancestor of the HIV-1 Pandemic Strains by B. Korber et al., *Science* 288(5472):1789–1796 (6/9/00); **Scientific Skills Exercise** Data from Nancy A. Moran, Yale University. See N. A. Moran and T. Jarvik, Lateral transfer of genes from fungi underlies carotenoid production in aphids, *Science* 328:624–627 (2010); **26.23** Adapted from Phylogenetic Classification and the Universal Tree by W.F. Doolittle, *Science* 284(5423):2124–2128 (6/25/99).

Chapter 27 **27.10** Graph Data from V. S. Cooper and R. E. Lenski, The Population Genetics of Ecological Specialization in Evolving *Escherichia coli* Populations, *Nature* 407:736–739 (2000); **27.19** Data from Root-Associated Bacteria Contribute to Mineral Weathering and to Mineral Nutrition in Trees: A Budgeting Analysis by Christophe Calvaruso et al., *Applied and Environmental Microbiology*, February 2006, Volume 72(2); **27.22** Data from K. Kupferschmidt, Resistance Fighters, *Science* 352(6287):758–761. 13 May 2016; **Scientific Skills Exercise** Data from L. Ling et al. A New Antibiotic Kills Pathogens without Detectable Resistance, *Nature* 517:455–459 (2015); **Test Your Understanding Question 8** Data from J. J. Burdon et al., Variation in the Effectiveness of Symbiotic Associations between Native Rhizobia and Temperate Australian Acacia: Within Species Interactions, *Journal of Applied Ecology* 36:398–408 (1999).

Chapter 28 **Scientific Skills Exercise** Data from D. Yang et al., Mitochondrial Origins, *Proceedings of the National Academy of Sciences USA* 82:4443–4447 (1985); **28.19** Adaptation of illustration by Kenneth X. Probst, from *Microbiology* by R.W. Bauman. Copyright © 2004 by Kenneth X. Probst; **28.26** Data from R. Derelle et al., Bacterial proteins pinpoint a single eukaryotic root, *Proceedings of the National Academy of Sciences USA* 112:E693–699 (2015); **28.32** Based on Global Phytoplankton Decline over the Past Century by Daniel G. Boyce et al., from *Nature*, July 29, 2010, Volume 466(7306); and authors' personal communications.

Chapter 29 **29.14** Data from “Inputs, Outputs, and Accumulation of Nitrogen in an Early Successional Moss (*Polytrichum*) Ecosystem” by Richard D. Bowden, from *Ecological Monographs*, June 1991, Volume 61(2); **Scientific Skills Exercise** Data from T.M. Lenton et al., First Plants Cooled the Ordovician, *Nature Geoscience* 5:86–89 (2012); **Test Your Understanding Question 8** Data from O. Zackrisson et al., Nitrogen Fixation Increases with Successional Age in Boreal Forests, *Ecology* 85:3327–3334 (2006).

Chapter 30 **Scientific Skills Exercise** Data from S. Sallon et al., Germination, Genetics, and Growth of an Ancient Date Seed. *Science* 320:1464 (2008); **30.14a** Adapted from “A Revision of *Williamsoniella*” by T. M. Harris, from *Proceedings of the Royal Society B: Biological Sciences*, October 1944, Volume 231(583): 313–328; **30.14b** Adaptation of Figure 2.3, *Phylogeny and Evolution of Angiosperm*, 2nd Edition, by Douglas E. Soltis et al. (2005). Sinauer Associates, Inc.

Chapter 31 **Scientific Skills Exercise** Data from F. Martin et al., The genome of *Laccaria bicolor* provides insights into mycorrhizal symbiosis, *Nature* 452:88–93 (2008); **31.22** Data from A. E. Arnold et al., Fungal Endophytes Limit Pathogen Damage in a Tropical Tree, *Proceedings of the National Academy of Sciences USA* 100:15649–15654 (2003); **31.27** Adaption of Figure 1 from “Reversing Introduced Species Effects: Experimental Removal of Introduced Fish Leads to Rapid Recovery of a Declining Frog” by Vance T. Vredenburg, from *Proceedings of the National Academy of Sciences USA*, May 2004, Volume 101(20). Copyright (2004) National Academy of Sciences, U.S.A.;

Test Your Understanding Question 5 Data from R. S. Redman et al., Thermotolerance Generated by Plant/Fungal Symbiosis, *Science* 298:1581 (2002).

Chapter 32 Scientific Skills Exercise Data from Bradley Deline, University of West Georgia, and Kevin Peterson, Dartmouth College, 2013.

Chapter 33 Scientific Skills Exercise Data from R. Rochette et al., Interaction between an Invasive Decapod and a Native Gastropod: Predator Foraging Tactics and Prey Architectural Defenses, *Marine Ecology Progress Series* 330:179–188 (2007); **33.21** Adaptation of Figure 3 from “The Global Decline of Nonmarine Mollusks” by Charles Lydeard et al., from *Bioscience*, April 2004, Volume 54(4). American Institute of Biological Sciences. Oxford University Press; **33.29** Tree Data from J. K. Grenier et al., Evolution of the Entire Arthropod Hox Gene Set Predicted the Origin and Radiation of the Onychophoran/Arthropod Clade, *Current Biology* 7:547–553 (1997).

Chapter 34 34.10 Adaptation of Figure 1a from “Fossil Sister Group of Craniates: Predicted and Found” by Jon Mallatt and Jun-yuan Chen, from *Journal of Morphology*, May 15, 2003, Volume 258(1). John Wiley & Sons, Inc.; **34.12** Adapted from *Vertebrates: Comparative Anatomy, Function, Evolution* (2002) by Kenneth Kardong. The McGraw-Hill Companies, Inc.; **34.18** Adaptation of Figure 3 from “The Oldest Articulated Osteichthyan Reveals Mosaic Gnathostome Characters” by Min Zhu et al., from *Nature*, March 26, 2009, Volume 458(7237); **34.21** Adaptation of Figure 4 from “The Pectoral Fin of *Tiktaalik roseae* and the Origin of the Tetrapod Limb” by Neil H. Shubin et al., from *Nature*, April 6, 2006, Volume 440(7085). Macmillan Publishers Ltd.; **34.21** *Acanthostega* adaptation of Figure 27 from “The Devonian Tetrapod *Acanthostega gunnari* Jarvik: Postcranial Anatomy, Basal Tetrapod Relationships and Patterns of Skeletal Evolution” by Michael I. Coates, from *Transactions of the Royal Society of Edinburgh: Earth Sciences*, Volume 87: 398; **34.38a** Based on many sources including Figure 4.10 from *Evolution*, by Douglas J. Futuyma. Sinauer Associates, 2005; and *Vertebrate Paleontology and Evolution* by Robert L. Carroll. W.H. Freeman & Co., 1988; **34.47** Based on many photos of fossils. Some sources are *O. tugenensis* photo in “Early Hominid Sows Division” by Michael Balter, from *Science Now*, Feb. 22, 2001; *A. garhi* and *H. neanderthalensis* based on *The Human Evolution Coloring Book* by Adrienne L. Zihlman and Carla J. Simmons. Harper Collins, 2001; *K. platyops* based on photo in “New Hominin Genus from Eastern Africa Shows Diverse Middle Pliocene Lineages” by Meave Leakey et al., from *Nature*, March 2001, Volume 410(6827); *P. boisei* based on a photo by David Brill; *H. ergaster* based on a photo at www.museumsinhand.com; *S. tchadensis* based on Figure 1b from “A New Hominid from the Upper Miocene of Chad, Central Africa” by Michel Brunet et al., from *Nature*, July 2002, Volume 418(6894); **Scientific Skills Exercise** Data from Dean Falk, Florida State University, 2013; **Test Your Understanding Question 8** Data from D. Sol et al., Big-Brained Birds Survive Better in Nature, *Proceedings of the Royal Society B* 274:763–769 (2007).

Chapter 35 Scientific Skills Exercise Data from D. L. Royer et al., Phenotypic Plasticity of Leaf Shape Along a Temperature Gradient in *Acer rubrum*, *PLOS ONE* 4(10):e7653 (2009); **35.21** Data from “Mongolian Tree Rings and 20th-Century Warming” by Gordon C. Jacoby, et al., from *Science*, August 9, 1996, Volume 273(5276): 771–773.

Chapter 36 Scientific Skills Exercise Data from J. D. Murphy and D. L. Noland, Temperature Effects on Seed Imbibition and Leakage Mediated by Viscosity and Membranes, *Plant Physiology* 69:428–431 (1982); **36.18** Data from S. Rogers and A. J. Peel, Some Evidence for the Existence of Turgor Pressure in the Sieve Tubes of Willow (*Salix*), *Planta* 126:259–267 (1975).

Chapter 37 37.10b Data from D.S. Lundberg et al., Defining the Core *Arabidopsis thaliana* Root Microbiome, *Nature* 488:86–94 (2012).

Chapter 38 Scientific Skills Exercise Data from S. Sutherland and R. K. Vickery, Jr. Trade-offs between Sexual and Asexual Reproduction in the Genus *Mimulus*. *Oecologia* 76:330–335 (1998).

Chapter 39 39.5 Data from C. R. Darwin, *The Power of Movement in Plants*, John Murray, London (1880). P. Boysen-Jensen, Concerning the Performance of Phototropic Stimuli on the Avenacoleoptile, *Berichte der Deutschen Botanischen Gesellschaft (Reports of the German Botanical Society)* 31:559–566 (1913); **39.6** Data from L. Gálweiler et al., Regulation of Polar Auxin Transport by AtPIN1 in *Arabidopsis* Vascular Tissue, *Science* 282:2226–2230 (1998); **39.15a** Based on *Plantwatching: How Plants Remember, Tell Time, Form Relationships and More* by Malcolm Wilkins. Facts on File, 1988; **39.16** Data from H. Borthwick et al., A Reversible Photo Reaction Controlling Seed Germination, *Proceedings of the National Academy of Sciences USA* 38:662–666 (1952); **Problem-Solving Exercise** Map data from Camilo Mora et al. Days for Plant Growth Disappear under Projected Climate Change: Potential Human and Biotic Vulnerability. *PLoS Biol.* 13(6): e1002167 (2015); **Scientific Skills Exercise** Data from O. Falik et al., Rumor Has It ...: Reley Communication of Stress Cues in Plants, *PLoS ONE* 6(11):e23625 (2011).

Chapter 40 40.16 Data from V. H. Hutchison, H. G. Dowling, and A. Vinegar, Thermoregulation in a Brooding Female Indian Python, *Python molurus bivittatus*, *Science* 151:694–696 (1966); **Scientific Skills Exercise** Based on the data from M. A. Chappell et al., Energetics of Foraging in Breeding Adélie Penguins, *Ecology* 74:2450–2461 (1993); M. A. Chappell et al., Voluntary Running in Deer Mice: Speed, Distance, Energy Costs, and Temperature Effects, *Journal of Experimental Biology* 207:3839–3854 (2004); T. M. Ellis and M. A. Chappell, Metabolism, Temperature Relations, Maternal Behavior, and Reproductive Energetics in the Ball Python (*Python regius*), *Journal of Comparative Physiology B* 157:393–402 (1987); **40.22** Data from F. G. Revel et al., The Circadian Clock Stops Ticking During Deep Hibernation in the European Hamster, *Proceedings of the National Academy of Sciences USA* 104:13816–13820 (2007).

Chapter 41 41.4 Data from R. W. Smithells et al., Possible Prevention of Neural-Tube Defects by Periconceptional Vitamin Supplementation, *Lancet* 315:339–340 (1980); **41.8** Adapted from Marieb, Elaine; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Edition, 2010, p. 852, Reprinted and electronically reproduced by permission of Pearson Education, Upper Saddle River, New Jersey; **41.17** Adapted from Ottman N., Smidt H., de Vos W.M. and Belzer C. (2012) The function of our microbiota: who is out there and what do they do? *Front. Cell. Inf. Microbiol.* 2:104. doi: 10.3389/fcimb.2012.00104; **41.24** Republished with permission of American Association for the Advancement of

Science, from Cellular Warriors at the Battle of the Bulge by Kathleen Sutliff and Jean Marx, from *Science*, February 2003, Volume 299(5608); **Scientific Skills Exercise** Based on the data from D. L. Coleman, Effects of Parabiosis of Obese Mice with Diabetes and Normal Mice, *Diabetologia* 9:294–298 (1973).

Chapter 42 Scientific Skills Exercise Data from J. C. Cohen et al., Sequence Variations in PCSK9, Low LDL, and Protection Against Coronary Heart Disease, *New England Journal of Medicine* 354:1264–1272 (2006); **42.25** Data from M. E. Avery and J. Mead, Surface Properties in Relation to Atelectasis and Hyaline Membrane Disease, *American Journal of Diseases of Children* 97:517–523 (1959).

Chapter 43 43.5 Adapted from *Microbiology: An Introduction*, 11th Edition, by Gerard J. Tortora, Berdell R. Funke, and Christine L. Case. Pearson Education, Inc.; **43.6** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., © 2010. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **43.24** Based on multiple sources: WHO/UNICEF Coverage Estimates 2014 Revision. July 2015. Map Production: Immunization Vaccines and Biologicals (IVB). World Health Organization, 16 July 2015; Our Progress Against Polio, May 1, 2014. CDC; **Scientific Skills Exercise** Data from sources: L. J. Morrison et al., Probabilistic Order in Antigenic Variation of *Trypanosoma brucei*, *International Journal for Parasitology* 35:961–972 (2005); and L. J. Morrison et al., Antigenic Variation in the African Trypanosome: Molecular Mechanisms and Phenotypic Complexity, *Cellular Microbiology* 1: 1724–1734 (2009).

Chapter 44 Scientific Skills Exercise Data from R. E. MacMillen et al., Water Economy and Energy Metabolism of the Sandy Inland Mouse, *Leggadina hermannsburgensis*, *Journal of Mammalogy* 53:529–539 (1972); **44.6** Adapted from Mitchell, Lawrence G., *Zoology*, © 1998. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **44.12 Kidney structure** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., 2010. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **44.13a Kidney structure** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., 2010. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **44.20** Data in tables from P. M. Deen et al., Requirement of Human Renal Water Channel Aquaporin-2 for Vasopressin-Dependent Concentration of Urine, *Science* 264:92–95 (1994); **Summary Figure** Adapted from Beck, *Life: An Introduction to Biology*, 3rd Ed., ©1991, p. 643. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **Test Your Understanding Question 7** Data for kangaroo rat from *Animal Physiology: Adaptation and Environment* by Knut Schmidt-Nielsen, Cambridge University Press, 1991.

Chapter 45 Scientific Skills Exercise Data from J. Born et al., Timing the End of Nocturnal Sleep, *Nature* 397:29–30 (1999).

Chapter 46 46.8 Data from R. R. Snook and D. J. Hosken, Sperm Death and Dumping in *Drosophila*, *Nature* 428:939–941 (2004); **Scientific Skills Exercise** Data from A. Jost, Recherches Sur la Différenciation Sexuelle de l’embryon de Lapin (Studies on the Sexual Differentiation of the Rabbit Embryo), *Archives d’Anatomie Microscopique et de Morphologie Experimentale* 36:271–316 (1947); **46.16** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., 2010. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

Chapter 47 47.3 Data from “Intracellular Calcium Release at Fertilization in the Sea Urchin Egg” by R. Steinhardt et al., from *Developmental Biology*, July 1977, Volume 58(1); **Scientific Skills Exercise** Data from J. Newport and M. Kirschner, A Major Developmental Transition in Early *Xenopus* Embryos: I. Characterization and Timing of Cellular Changes at the Midblastula Stage, *Cell* 30:675–686 (1982); **47.10** Adapted from Keller, R. E. 1986. The Cellular Basis of Amphibian Gastrulation. In L. Browder (ed.), *Developmental Biology: A Comprehensive Synthesis*, Vol. 2. Plenum, New York, pp. 241–327; **47.14** Based on “Cell Commitment and Gene Expression in the Axolotl Embryo” by T. J. Mohun et al., from *Cell*, November 1980, Volume 22(1); **47.17 Principles of Development**, 2nd Edition by Wolpert (2002), Fig. 8.26, p. 275. By permission of Oxford University Press; **47.19** Republished with permission of Garland Science, Taylor & Francis Group, from *Molecular Biology of the Cell*, Bruce Alberts et al., 4th Edition, © 2002; permission conveyed through Copyright Clearance Center, Inc.; **47.23** Data from H. Spemann, *Embryonic Development and Induction*, Yale University Press, New Haven, CT (1938); **47.24** Data from H. Spemann and H. Mangold, Induction of Embryonic Primordia by Implantation of Organizers from a Different Species, Trans. V. Hamburger (1924). Reprinted in *International Journal of Developmental Biology* 45:13–38 (2001); **47.26** Data from L. S. Honig and D. Summerbell, Maps of strength of positional signaling activity in the developing chick wing bud, *Journal of Embryology and Experimental Morphology* 87:163–174 (1985); **47.27** Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Edition, 2010. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

Chapter 48 48.12 Graph Based on Figure 6-2d from *Cellular Physiology of Nerve and Muscle*, 4th Edition, by Gary G. Matthews. Wiley-Blackwell, 2003; **Scientific Skills Exercise** Data from C. B. Pert and S. H. Snyder, Opiate Receptor: Demonstration in Nervous Tissue, *Science* 179:1011–1014 (1973).

Chapter 49 49.7 Adapted from Marieb, Elaine N.; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., © 2010. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **49.12** Based on “Sleep in Marine Mammals” by L. M. Mukhametov, from *Sleep Mechanisms*, edited by Alexander A. Borberly and J. L. Valatx. Springer; **Scientific Skills Exercise** Data from M. R. Ralph et al., Transplanted Suprachiasmatic Nucleus Determines Circadian Period, *Science* 247:975–978 (1990); **49.20** Adaptation of Figure 1c from “Avian Brains and a New Understanding of Vertebrate Brain Evolution” by Erich D. Jarvis et al., from *Nature Reviews Neuroscience*, February 2005, Volume 6(2); **49.23** Adaptation of Figure 10 from *Schizophrenia Genesis: The Origins of Madness* by Irving I. Gottesman. Worth Publishers.

Chapter 50 **50.12a, 50.13, 50.17 eye structure, 50.24a, 50.26, 50.31** Adapted from Marieb, Elaine N; Hoehn, Katja, *Human Anatomy and Physiology*, 8th Ed., © 2010 Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **50.23** Data from K. L. Mueller et al., The receptors and coding logic for bitter taste, *Nature* 434:225–229 (2005); **50.35 grasshopper** Based on Hickman et al., *Integrated Principles of Zoology*, 9th ed., p. 518, Fig. 22.6, McGraw-Hill Higher Education, NY (1993); **Scientific Skills Exercise** Data from K. Schmidt-Nielsen, Locomotion: Energy Cost of Swimming, Flying, and Running, *Science* 177:222–228 (1972).

Chapter 51 **51.4** Based on “*Drosophila*: Genetics Meets Behavior” by Marla B. Sokolowski, from *Nature Reviews: Genetics*, November 2001, Volume 2(11); **51.8** Data from *The Study of Instinct*, N. Tinbergen, Clarendon Press, Oxford (1951); **51.10** Adapted from “Prospective and Retrospective Learning in Honeybees” by Martin Giurfa and Julie Bernard, from *International Journal of Comparative Psychology*, 2006, Volume 19(3); **51.13** Adapted from Evolution of Foraging Behavior in *Drosophila* by Density Dependent Selection by Maria B. Sokolowski et al., from *Proceedings of the National Academy of Sciences USA*, July 8, 1997, Volume 94(14); **Scientific Skills Exercise** Data from Shell Dropping: Decision-Making and Optimal Foraging in Northwestern Crows by Reto Zach, from *Behaviour*, 1979, Volume 68(1–2); **51.18** Reprinted by permission from Klaudia Witte; **51.24 Illustration** Adaptations of photograph by Jonathan Blair, Figure/PhotoID: 3.14, as appeared in *Animal Behavior: An Evolutionary Approach*, 8th Edition, Editor: John Alcock, p. 88. Reprinted by permission; **51.24 Map** data from “Rapid Microevolution of Migratory Behaviour in a Wild Bird Species” by P. Berthold et al., from *Nature*, December 1992, Volume 360(6405); **Art for Concept 51.2 Summary**: Data from *The Study of Instinct*, N. Tinbergen, Clarendon Press, Oxford (1951).

Chapter 52 **52.19** Based on the data from *Ecology and Field Biology* by Robert L. Smith. Pearson Education, 1974; and *Sibley Guide to Birds* by David Allen Sibley. Random House, 2000; **52.20** Based on the data from W.J. Fletcher, Interactions among Subtidal Australian Sea Urchins, Gastropods and Algae: Effects of Experimental Removals, *Ecological Monographs* 57:89–109 (1987); **52.21** Based on S. D. Ling et al., Climate-Driven Range Extension of a Sea Urchin: Inferring Future Trends by Analysis of Recent Population Dynamics, *Global Change Biology* (2009) 15, 719–731, doi: 10.1111/j.1365-2486.2008.01734.x.; **Scientific Skills Exercise** Based on the data from C. M. Crain et al., Physical and Biotic Drivers of Plant Distribution Across Estuarine Salinity Gradients, *Ecology* 85:2539–2549 (2004); **Graph for Test Your Understanding Question 11** Based on the data from J. Clausen et al., *Experimental Studies on the Nature of Species. III. Environmental Responses of Climatic Races of Achillea*, Carnegie Institution of Washington Publication No. 581 (1948).

Chapter 53 **53.2** Data from A. M. Gormley et al., Capture-Recapture Estimates of Hector’s Dolphin Abundance at Banks Peninsula, New Zealand, *Marine Mammal Science* 21:204–216 (2005); **Table 53.1** Data from P. W. Sherman and M. L. Morton, Demography of Belding’s Ground Squirrel, *Ecology* 65:1617–1628 (1984); **53.4** Based on Demography of Belding’s Ground Squirrels by Paul W. Sherman and Martin L. Morton, from *Ecology*, October 1984, Volume 65(5); **53.13** Data from Brood Size Manipulations in the Kestrel (*Falco tinnunculus*): Effects on Offspring and Parent Survival by C. Dijkstra et al., from *Journal of Animal Ecology*, 1990, Volume 59(1); **53.15** Based on Climate and Population Regulation: The Biogeographer’s Dilemma by J. T. Enright, from *Oecologia*, 1976, Volume 24(4); **53.16** Based on the data from Predator Responses, Prey Refuges, and Density-Dependent Mortality of a Marine Fish by T.W. Anderson, *Ecology* 82(1):245–257 (2001); **53.18** Based on the data provided by Dr. Rolf O. Peterson; **53.21** Based on U.S. Census Bureau International Data Base; **53.22** Based on U.S. Census Bureau International Data Base; **53.23** Based on U.S. Census Bureau International Data Base; **53.24** Based on Ewing B., D. Moore, S. Goldfinger, A. Oursler, A. Reed, and M. Wackernagel. 2010. *The Ecological Footprint Atlas 2010*. Oakland: Global Footprint Network, p. 33 (www.footprintnetwork.org).

Chapter 54 **54.1, 54.2** Based on A. Stanley Rand and Ernest E. Williams. The Anoles of La Palma: Aspects of Their Ecological Relationships, *Breviora*, Volume 327: 1–19. Museum of Comparative Zoology, Harvard University; **54.3** Data from J. H. Connell, The Influence of Interspecific Competition and Other Factors on the Distribution of the Barnacle *Chthamalus stellatus*, *Ecology* 42:710–723 (1961); **Scientific Skills Exercise** Based on the data from B. L. Phillips and R. Shine, An Invasive Species Induces Rapid Adaptive Change in a Native Predator: Cane Toads and Black Snakes in Australia, *Proceedings of the Royal Society B* 273:1545–1550 (2006); **54.11** Based on the data from Sally D. Hacker and Mark D. Bertness, Experimental Evidence for Factors Maintaining Plant Species Diversity in a New England Salt Marsh. *Ecology*, September 1999, Volume

80(6); **54.14 Graph** Data from N. Fierer and R. B. Jackson, The Diversity and Biogeography of Soil Bacterial Communities, *Proceedings of the National Academy of Sciences USA* 103:626–631 (2006); **54.17** Based on George A. Knox. Antarctic Marine Ecosystems, from *Antarctic Ecology*, Volume 1, edited by Martin W. Holdgate, Academic Press, 1970; **54.18** Adapted from Denise L. Breitburg et al., Varying Effects of Low Dissolved Oxygen on Trophic Interactions in an Estuarine Food Web, *Ecological Monographs*, November 1997, Volume 67(4). Used by permission of the Ecological Society of America; **54.19** Based on B. Jenkins et al., Productivity, Disturbance and Food Web Structure at a Local Spatial Scale in Experimental Container Habitats. *OIKOS*, November 1992, Volume 65(2); **54.20 Graph** Data from R. T. Paine, Food web complexity and species diversity, *American Naturalist* 100:65–75 (1966); **54.24** Based on the data from C.R. Townsend, M.R. Scarsbrook, and S. Doledc, The Intermediate Disturbance Hypothesis, Refugia, and Biodiversity in Streams, *Limnology and Oceanography* 42:938–949 (1997); **54.26** Based on Robert L. Crocker and Jack Major. Soil Development in Relation to Vegetation and Surface Age at Glacier Bay, Alaska. *Journal of Ecology*, July 1955, Volume 43(2); **54.27** Adapted from F. Stuart Chapin et al., Mechanisms of Primary Succession Following Deglaciation at Glacier Bay. *Ecological Monographs*, May 1994, Volume 64(2). Ecological Society of America; **54.29** Adapted from D. J. Currie. Energy and Large-Scale Patterns of Animal-and Plant-Species Richness. *American Naturalist*, January 1991, Volume 137(1): 27–49; **54.30** Adapted from Robert H. MacArthur and Edward O. Wilson, An Equilibrium Theory of Insular Zoogeography. *Evolution*, December 1963, Volume 17(4). Society for the Study of Evolution; **54.33** Based on Daniel S. Simberloff and Edward O. Wilson. 1969. Experimental Zoogeography of Islands: The Colonization of Empty Islands. *Ecology*, Vol. 50, No. 2 (Mar., 1969), pp. 278–296.

Chapter 55 **55.4** Based on Figure 1.2 from Donald L. DeAngelis (1992), *Dynamics of Nutrient Cycling and Food Webs*. Taylor & Francis; **55.6** Data from J. H. Ryther and W. M. Dunstan, Nitrogen, Phosphorus, and Eutrophication in the Coastal Marine Environment, *Science* 171:1008–1013 (1971); **Table 55.1** Data from D. W. Menzel and J. H. Ryther, Nutrients Limiting the Production of Phytoplankton in the Sargasso Sea, with Special Reference to Iron, *Deep Sea Research* 7:276–281 (1961); **55.7** Based on the data from Fig. 4, p. 82, in R.H. Whittaker (1970), *Communities and Ecosystems*. Macmillan, New York; **55.8** Based on Fig. 3c and 3d from Temperate Forest Health in an Era of Emerging Megadisturbance, Constance I. Millar and Nathan L. Stephenson, *Science* 349, 823 (2015); doi: 10.1126/science.aaa9933; **Scientific Skills Exercise** Data from J. M. Teal, Energy Flow in the Salt Marsh Ecosystem of Georgia, *Ecology* 43:614–624 (1962); **55.12** Data from J. A. Trofymow and the CIDET Working Group, The Canadian Intersite Decomposition Experiment: Project and Site Establishment Report (Information Report BC-X-378), Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre (1998) and T. R. Moore et al., Litter decomposition rates in Canadian forests, *Global Change Biology* 5:75–82 (1999); **55.14** Adapted from Figure 7.4 from Robert E. Ricklefs (2001), *The Economy of Nature*, 5th edition. W.H. Freeman and Company; **55.18b** Based on the data from Wei-Min Wu et al. (2006), Pilot-Scale in Situ Bioremediation of Uranium in a Highly Contaminated Aquifer. 2. Reduction of U(VI) and Geochemical Control of U(VI) Bioavailability. *Environmental Science Technology* 40 (12):3986–3995 (5/13/06); **Art for Concept 55.1 Summary** Based on Figure 1.2 from Donald L. DeAngelis (1992), *Dynamics of Nutrient Cycling and Food Webs*. Taylor & Francis.

Chapter 56 **56.10** Based on data from Gene Likens; **56.11** Krebs, Charles J., *Ecology: The Experimental Analysis of Distribution and Abundance*, 5th Ed., © 2001. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey; **56.13** Data from “Tracking the Long-Term Decline and Recovery of an Isolated Population” by R.L. Westemeier et al., *Science* Volume 282(5394):1695–1698 (11/27/98), AAAS; **56.19** Adapted from Norman Myers et al. (2000). Biodiversity Hotspots for Conservation Priorities, *Nature*, February 24, 2000, Volume 403(6772); **56.28** Based on CO₂ data from www.esrl.noaa.gov/gmd/ccgg/trends. Temperature data from www.giss.nasa.gov/gistemp/graphs/Fig_A.lrg.gif; **Scientific Skills Exercise** Based on data from National Oceanic & Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division; **56.32** Based on the data from “History of the Ozone Hole,” from NASA website, February 26, 2013; and “Antarctic Ozone,” from British Antarctic Society website, June 7, 2013; **56.35** Based on the data from Instituto Nacional de Estadística y Censos de Costa Rica and Centro Centroamericano de Población, Universidad de Costa Rica.

Appendix A Figure 5.11 Wallace/Sanders/Ferl, *Biology: The Science of Life*, 3rd Ed., © 1991. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

Pronunciation Key

ā	ace
a/ah	ash
ch	chose
ē	meet
e/eh	bet
g	game
ī	ice
i	hit
ks	box
kw	quick
ng	song
ō	robe
o	ox
oy	boy
s	say
sh	shell
th	thin
ū	boot
u/uh	up
z	zoo
' = primary accent	
' = secondary accent	

5' cap A modified form of guanine nucleotide added onto the 5' end of a pre-mRNA molecule.

ABC hypothesis A model of flower formation identifying three classes of organ identity genes that direct formation of the four types of floral organs.

abiotic (ā'-bi-ot'-ik) Nonliving; referring to the physical and chemical properties of an environment.

abortion The termination of a pregnancy in progress.

abscisic acid (ABA) (ab-sis'-ik) A plant hormone that slows growth, often antagonizing the actions of growth hormones. Two of its many effects are to promote seed dormancy and facilitate drought tolerance.

absorption The third stage of food processing in animals: the uptake of small nutrient molecules by an organism's body.

absorption spectrum The range of a pigment's ability to absorb various wavelengths of light; also a graph of such a range.

abyssal zone (uh-bis'-ul) The part of the ocean's benthic zone between 2,000 and 6,000 m deep.

acanthodian (ak'-an-thō'-dē-un) Any of a group of ancient jawed aquatic vertebrates from the Silurian and Devonian periods.

accessory fruit A fruit, or assemblage of fruits, in which the fleshy parts are derived largely or entirely from tissues other than the ovary.

acclimatization (uh-kli'-muh-tī -zā'-shun) Physiological adjustment to a change in an environmental factor.

acetyl CoA Acetyl coenzyme A; the entry compound for the citric acid cycle in cellular respiration, formed from a two-carbon fragment of pyruvate attached to a coenzyme.

acetylcholine (as'-uh-til-kō'-lēn) One of the most common neurotransmitters; functions by binding to receptors and altering the permeability of the postsynaptic membrane to specific ions, either depolarizing or hyperpolarizing the membrane.

acid A substance that increases the hydrogen ion concentration of a solution.

acquired immunodeficiency syndrome (AIDS)

The symptoms and signs present during the late stages of HIV infection, defined by a specified reduction in the number of T cells and the appearance of characteristic secondary infections.

acrosomal reaction (ak'-ruh-sōm'-ul) The discharge of hydrolytic enzymes from the acrosome, a vesicle in the tip of a sperm, when the sperm approaches or contacts an egg.

acrosome (ak'-ruh-sōm) A vesicle in the tip of a sperm containing hydrolytic enzymes and other proteins that help the sperm reach the egg.

actin (ak'-tin) A globular protein that links into chains, two of which twist helically about each other, forming microfilaments (actin filaments) in muscle and other kinds of cells.

action potential An electrical signal that propagates (travels) along the membrane of a neuron or other excitable cell as a nongraded (all-or-none) depolarization.

action spectrum A graph that profiles the relative effectiveness of different wavelengths of radiation in driving a particular process.

activation energy The amount of energy that reactants must absorb before a chemical reaction will start; also called free energy of activation.

activator A protein that binds to DNA and stimulates gene transcription. In prokaryotes, activators bind in or near the promoter; in eukaryotes, activators generally bind to control elements in enhancers.

active immunity Long-lasting immunity conferred by the action of B cells and T cells and the resulting B and T memory cells specific for a pathogen. Active immunity can develop as a result of natural infection or immunization.

active site The specific region of an enzyme that binds the substrate and that forms the pocket in which catalysis occurs.

active transport The movement of a substance across a cell membrane against its concentration or electrochemical gradient, mediated by specific transport proteins and requiring an expenditure of energy.

adaptation Inherited characteristic of an organism that enhances its survival and reproduction in a specific environment.

adaptive evolution A process in which traits that enhance survival or reproduction tend to increase in frequency over time, resulting in a better match between organisms and their environment.

adaptive immunity A vertebrate-specific defense that is mediated by B lymphocytes (B cells) and T lymphocytes (T cells) and that exhibits specificity, memory, and self-nonsellect recognition; also called acquired immunity.

adaptive radiation Period of evolutionary change in which groups of organisms form many new species whose adaptations allow them to fill different ecological roles in their communities.

addition rule A rule of probability stating that the probability of any one of two or more mutually exclusive events occurring can be determined by adding their individual probabilities.

adenosine triphosphate See ATP (adenosine triphosphate).

adenylyl cyclase (uh-den'-uh-lil) An enzyme that converts ATP to cyclic AMP in response to an extracellular signal.

adhesion The clinging of one substance to another, such as water to plant cell walls, in this case by means of hydrogen bonds.

adipose tissue A connective tissue that insulates the body and serves as a fuel reserve; contains fat-storing cells called adipose cells.

adrenal gland (uh-drē'-nul) One of two endocrine glands located adjacent to the kidneys in mammals. Endocrine cells in the outer portion (cortex) respond to adrenocorticotrophic hormone (ACTH) by secreting steroid hormones that help maintain homeostasis during long-term stress. Neurosecretory cells in the central portion (medulla) secrete epinephrine and norepinephrine in response to nerve signals triggered by short-term stress.

aerobic respiration A catabolic pathway for organic molecules, using oxygen (O_2) as the final electron acceptor in an electron transport chain and ultimately producing ATP. This is the most efficient catabolic pathway and is carried out in most eukaryotic cells and many prokaryotic organisms.

age structure The relative number of individuals of each age in a population.

aggregate fruit A fruit derived from a single flower that has more than one carpel.

AIDS (acquired immunodeficiency syndrome) The symptoms and signs present during the late stages of HIV infection, defined by a specified reduction in the number of T cells and the appearance of characteristic secondary infections.

alcohol fermentation Glycolysis followed by the reduction of pyruvate to ethyl alcohol, regenerating NAD^+ and releasing carbon dioxide.

alga (plural, **algae**) A general term for any species of photosynthetic protist, including both unicellular and multicellular forms. Algal species are included in three eukaryote supergroups (Excavata, SAR, and Archaeplastida).

alimentary canal (al'-uh-men'-tuh-rē) A complete digestive tract, consisting of a tube running between a mouth and an anus.

alkaline vent A deep-sea hydrothermal vent that releases water that is warm (40–90°C) rather than hot and has a high pH (is basic). These vents consist of tiny pores lined with iron and other catalytic minerals that some scientists hypothesize might have been the location of the earliest abiotic synthesis of organic compounds.

allele (uh-lē'-ul) Any of the alternative versions of a gene that may produce distinguishable phenotypic effects.

allopatric speciation (al'-uh-pat'-rik) The formation of new species in populations that are geographically isolated from one another.

allopolyploid (al'-ō-pol'-ē-ployd) A fertile individual that has more than two chromosome sets as a result of two different species interbreeding and combining their chromosomes.

allosteric regulation The binding of a regulatory molecule to a protein at one site that affects the function of the protein at a different site.

alpha (α) helix (al'-fuh hē'-likz) A coiled region constituting one form of the secondary structure of proteins, arising from a specific pattern of hydrogen bonding between atoms of the polypeptide backbone (not the side chains).

alternation of generations A life cycle in which there is both a multicellular diploid form, the sporophyte, and a multicellular haploid form, the gametophyte; characteristic of plants and some algae.

alternative RNA splicing A type of eukaryotic gene regulation at the RNA-processing level in which different mRNA molecules are produced from the same primary transcript, depending on which RNA segments are treated as exons and which as introns.

altruism (al'-trū-iz-um) Selflessness; behavior that reduces an individual's fitness while increasing the fitness of another individual.

alveolates (al-vē'-uh-lets) One of the three major subgroups for which the SAR eukaryotic supergroup is named. This clade arose by secondary endosymbiosis, and its members have membrane-enclosed sacs (alveoli) located just under the plasma membrane.

alveolus (al-vē'-uh-lus) (plural, **alveoli**) One of the dead-end air sacs where gas exchange occurs in a mammalian lung.

Alzheimer's disease (alts'-hī-merz) An age-related dementia (mental deterioration) characterized by confusion and memory loss.

amino acid (uh-mēn'-ō) An organic molecule possessing both a carboxyl and an amino group. Amino acids serve as the monomers of polypeptides.

amino group (uh-mēn'-ō) A chemical group consisting of a nitrogen atom bonded to two hydrogen atoms; can act as a base in solution, accepting a hydrogen ion and acquiring a charge of 1+.

aminoacyl-tRNA synthetase An enzyme that joins each amino acid to the appropriate tRNA.

ammonia A small, toxic molecule (NH_3) produced by nitrogen fixation or as a metabolic waste product of protein and nucleic acid metabolism.

ammonite A member of a group of shelled cephalopods that were important marine predators for hundreds of millions of years until their extinction at the end of the Cretaceous period (65.5 million years ago).

amniocentesis (am'-nē-ō-sen-tē'-sis) A technique associated with prenatal diagnosis in which amniotic fluid is obtained by aspiration from a needle inserted into the uterus. The fluid and the fetal cells it contains are analyzed to detect certain genetic and congenital defects in the fetus.

amniote (am'-nē-ōt) A member of a clade of tetrapods named for a key derived character, the amniotic egg, which contains specialized membranes, including the fluid-filled amnion, that protect the embryo. Amniotes include mammals as well as birds and other reptiles.

amniotic egg An egg that contains specialized membranes that function in protection, nourishment, and gas exchange. The amniotic egg was a major evolutionary innovation, allowing embryos to develop on land in a fluid-filled sac, thus reducing the dependence of tetrapods on water for reproduction.

amoeba (uh-mē'-buh) A protist characterized by the presence of pseudopodia.

amoebocyte (uh-mē'-buh-sīt') An amoeba-like cell that moves by pseudopodia and is found in most animals. Depending on the species, it may digest and distribute food, dispose of wastes, form skeletal fibers, fight infections, or change into other cell types.

amoebozoan (uh-mē'-buh-zō'-an) A protist in a clade that includes many species with lobe- or tube-shaped pseudopodia.

amphibian A member of the clade of tetrapods that includes salamanders, frogs, and caecilians.

amphipathic (am'-fē-path'-ik) Having both a hydrophilic region and a hydrophobic region.

amplification The strengthening of stimulus energy during transduction.

amygdala (uh-mig'-duh-luh) A structure in the temporal lobe of the vertebrate brain that has a major role in the processing of emotions.

amylase (am'-uh-lās') An enzyme that hydrolyzes starch (a glucose polymer from plants) and glycogen (a glucose polymer from animals) into smaller polysaccharides and the disaccharide maltose.

anabolic pathway (an'-uh-bol'-ik) A metabolic pathway that consumes energy to synthesize a complex molecule from simpler molecules.

anaerobic respiration (an-er-ō'-bik) A catabolic pathway in which inorganic molecules other than oxygen accept electrons at the “downhill” end of electron transport chains.

analogous Having characteristics that are similar because of convergent evolution, not homology.

analogy (an-al'-uh-jē) Similarity between two species that is due to convergent evolution rather than to descent from a common ancestor with the same trait.

anaphase The fourth stage of mitosis, in which the chromatids of each chromosome have separated and the daughter chromosomes are moving to the poles of the cell.

anatomy The structure of an organism.

anchorage dependence The requirement that a cell must be attached to a substratum in order to initiate cell division.

androgen (an'-drō-jen) Any steroid hormone, such as testosterone, that stimulates the development and maintenance of the male reproductive system and secondary sex characteristics.

aneuploidy (an'-yū-ploy'-dē) A chromosomal aberration in which one or more chromosomes are present in extra copies or are deficient in number.

angiosperm (an'-jē-ō-sperm) A flowering plant, which forms seeds inside a protective chamber called an ovary.

anhydrobiosis (an-hī'-drō-bī-ō'-sis) A dormant state involving loss of almost all body water.

animal pole The point at the end of an egg in the hemisphere where the least yolk is concentrated; opposite of vegetal pole.

anion (an'-ī-on) A negatively charged ion.

anterior Pertaining to the front, or head, of a bilaterally symmetrical animal.

anterior pituitary A portion of the pituitary gland that develops from nonneural tissue; consists of endocrine cells that synthesize and secrete several tropic and non tropic hormones.

anther In an angiosperm, the terminal pollen sac of a stamen, where pollen grains containing sperm-producing male gametophytes form.

antheridium (an-thuh-rid'-ē-um) (plural, **antheridia**) In plants, the male gametangium, a moist chamber in which gametes develop.

anthropoid (an'-thruh-poyd) A member of a primate group made up of the monkeys and the apes (gibbons, orangutans, gorillas, chimpanzees, bonobos, and humans).

antibody A protein secreted by plasma cells (differentiated B cells) that binds to a particular antigen; also called immunoglobulin. All antibodies have the same Y-shaped structure and in their monomer form consist of two identical heavy chains and two identical light chains.

anticodon (an'-tī-kō'-don) A nucleotide triplet at one end of a tRNA molecule that base-pairs with a particular complementary codon on an mRNA molecule.

antidiuretic hormone (ADH) (an'-tī-di-yū-ret'-ik) A peptide hormone, also called vasopressin, that promotes water retention by the kidneys. Produced in the hypothalamus and released from the posterior pituitary, ADH also functions in the brain.

antigen (an'-ti-jen) A substance that elicits an immune response by binding to receptors of B or T cells.

antigen presentation (an'-ti-jen) The process by which an MHC molecule binds to a fragment of an intracellular protein antigen and carries it to the cell surface, where it is displayed and can be recognized by a T cell.

antigen-presenting cell (an'-ti-jen) A cell that upon ingesting pathogens or internalizing pathogen proteins generates peptide fragments that are bound by class II MHC molecules and subsequently displayed on the cell surface to T cells. Macrophages, dendritic cells, and B cells are the primary antigen-presenting cells.

antigen receptor (an'-ti-jen) The general term for a surface protein, located on B cells and T cells, that binds to antigens, initiating adaptive immune responses. The antigen receptors on B cells are called B cell receptors, and the antigen receptors on T cells are called T cell receptors.

antiparallel Referring to the arrangement of the sugar-phosphate backbones in a DNA double helix (they run in opposite 5' → 3' directions).

aphotic zone (ä'-fö'-tik) The part of an ocean or lake beneath the photic zone, where light does not penetrate sufficiently for photosynthesis to occur.

apical bud (ä'-pik-ul) A bud at the tip of a plant stem; also called a terminal bud.

apical dominance (ä'-pik-ul) Tendency for growth to be concentrated at the tip of a plant shoot because the apical bud partially inhibits axillary bud growth.

apical ectodermal ridge (AER) (ä'-pik-ul) A thickened area of ectoderm at the tip of a limb bud that promotes outgrowth of the limb bud.

apical meristem (ä'-pik-ul mär'-uh-stem)

A localized region at a growing tip of a plant body where one or more cells divide repeatedly. The dividing cells of an apical meristem enable the plant to grow in length.

apicomplexan (ap'-ë-kom-pleks'-un) A group of alveolate protists, this clade includes many species that parasitize animals. Some apicomplexans cause human disease.

apomixis (ap'-uh-mik'-sis) The ability of some plant species to reproduce asexually through seeds without fertilization by a male gamete.

apoplast (ap'-ō-plast) Everything external to the plasma membrane of a plant cell, including cell walls, intercellular spaces, and the space within dead structures such as xylem vessels and tracheids.

apoptosis (ä-puh-tö'-sus) A type of programmed cell death, which is brought about by activation of enzymes that break down many chemical components in the cell.

aposematic coloration (ap'-ō-si-mat'-ik) The bright warning coloration of many animals with effective physical or chemical defenses.

appendix A small, finger-like extension of the vertebrate cecum; contains a mass of white blood cells that contribute to immunity.

aquaporin A channel protein in a cellular membrane that specifically facilitates osmosis, the diffusion of free water across the membrane.

aqueous solution (ä'-kwë-us) A solution in which water is the solvent.

arachnid A member of a subgroup of the major arthropod clade Chelicerata. Arachnids have six pairs of appendages, including four pairs of walking legs, and include spiders, scorpions, ticks, and mites.

arbuscular mycorrhiza (ar-bus'-kyü-lur mi'-kö-ri'-zuh) Association of a fungus

with a plant root system in which the fungus causes the invagination of the host (plant) cells' plasma membranes; also called endomycorrhiza.

arbuscular mycorrhizal fungus (ar-bus'-kyü-lur) A symbiotic fungus whose hyphae grow through the cell wall of plant roots and extend into the root cell (enclosed in tubes formed by invagination of the root cell plasma membrane).

arbuscules Specialized branching hyphae that are found in some mutualistic fungi and exchange nutrients with living plant cells.

Archaea (är'-ké'-uh) One of two prokaryotic domains, the other being Bacteria.

Archaeplastida (är'-ké-plas'-tid-uh) One of four supergroups of eukaryotes proposed in a current hypothesis of the evolutionary history of eukaryotes. This monophyletic group, which includes red algae, green algae, and plants, descended from an ancient protistan ancestor that engulfed a cyanobacterium. See also Excavata, SAR, and Unikonta.

archegonium (är-ki-gö'-në-um) (plural, **archegonia**) In plants, the female gametangium, a moist chamber in which gametes develop.

archenteron (är-ken'-tuh-ron) The endoderm-lined cavity, formed during gastrulation, that develops into the digestive tract of an animal.

archosaur (är'-kō-sör) A member of the reptilian group that includes crocodiles, alligators and dinosaurs, including birds.

arteriole (är-ter'-ē-öl) A vessel that conveys blood between an artery and a capillary bed.

artery A vessel that carries blood away from the heart to organs throughout the body.

arthropod A segmented ecdysozoan with a hard exoskeleton and jointed appendages. Familiar examples include insects, spiders, millipedes, and crabs.

artificial selection The selective breeding of domesticated plants and animals to encourage the occurrence of desirable traits.

ascocarp The fruiting body of a sac fungus (ascomycete).

ascomycete (as'-kuh-mi'-sët) A member of the fungal phylum Ascomycota, commonly called sac fungus. The name comes from the saclike structure in which the spores develop.

ascus (plural, **asci**) A saclike spore capsule located at the tip of a dikaryotic hypha of a sac fungus.

asexual reproduction The generation of offspring from a single parent that occurs without the fusion of gametes. In most cases, the offspring are genetically identical to the parent.

A site One of a ribosome's three binding sites for tRNA during translation. The A site holds the tRNA carrying the next amino acid to be added to the polypeptide chain. (A stands for aminoacyl tRNA.)

assisted migration The translocation of a species to a favorable habitat beyond its native range for the purpose of protecting the species from human-caused threats.

associative learning The acquired ability to associate one environmental feature (such as a color) with another (such as danger).

atherosclerosis A cardiovascular disease in which fatty deposits called plaques develop in the inner walls of the arteries, obstructing the arteries and causing them to harden.

atom The smallest unit of matter that retains the properties of an element.

atomic mass The total mass of an atom, numerically equivalent to the mass in grams of 1 mole of the atom. (For an element with more than one isotope, the atomic mass is the average mass of the naturally occurring isotopes, weighted by their abundance.)

atomic nucleus An atom's dense central core, containing protons and neutrons.

atomic number The number of protons in the nucleus of an atom, unique for each element and designated by a subscript.

ATP (adenosine triphosphate) (a-den'-ō-sën-tri-fos'-fät) An adenine-containing nucleoside triphosphate that releases free energy when its phosphate bonds are hydrolyzed. This energy is used to drive endergonic reactions in cells.

ATP synthase A complex of several membrane proteins that functions in chemiosmosis with adjacent electron transport chains, using the energy of a hydrogen ion (proton) concentration gradient to make ATP. ATP synthases are found in the inner mitochondrial membranes of eukaryotic cells and in the plasma membranes of prokaryotes.

atrial natriuretic peptide (ANP) (ä'-trë-ül-nä'-trë-yü-ret'-ik) A peptide hormone secreted by cells of the atria of the heart in response to high blood pressure. ANP's effects on the kidney alter ion and water movement and reduce blood pressure.

atrioventricular (AV) node A region of specialized heart muscle tissue between the left and right atria where electrical impulses are delayed for about 0.1 second before spreading to both ventricles and causing them to contract.

atrioventricular (AV) valve A heart valve located between each atrium and ventricle that prevents a backflow of blood when the ventricle contracts.

atrium (ä'-trë-üm) (plural, **atria**) A chamber of the vertebrate heart that receives blood from the veins and transfers blood to a ventricle.

autocrine Referring to a secreted molecule that acts on the cell that secreted it.

autoimmune disease An immunological disorder in which the immune system turns against self.

autonomic nervous system (ot'-ō-nom'-ik) An efferent branch of the vertebrate peripheral nervous system that regulates the internal environment; consists of the sympathetic and parasympathetic divisions and the enteric nervous system.

autopolyploid (ot'-ō-pol'-ē-ployd) An individual that has more than two chromosome sets that are all derived from a single species.

autosome (ot'-ō-söm) A chromosome that is not directly involved in determining sex; not a sex chromosome.

autotroph (ot'-ō-trof') An organism that obtains organic food molecules without eating other organisms or substances derived from other organisms. Autotrophs use energy from the sun or from oxidation of inorganic substances to make organic molecules from inorganic ones.

auxin (ok'-sin) A term that primarily refers to indoleacetic acid (IAA), a natural plant

hormone That has a variety of effects, including cell elongation, root formation, secondary growth, and fruit growth.

axillary bud (ak'-sil-är-ē) A structure that has the potential to form a lateral shoot, or branch. The bud appears in the angle formed between a leaf and a stem.

axon (ak'-son) A typically long extension, or process, of a neuron that carries nerve impulses away from the cell body toward target cells.

B cells The lymphocytes that complete their development in the bone marrow and become effector cells for the humoral immune response.

Bacteria One of two prokaryotic domains, the other being Archaea.

bacteriophage (bak-tēr'-ē-ō-fāj) A virus that infects bacteria; also called a phage.

bacteroid A form of the bacterium *Rhizobium* contained within the vesicles formed by the root cells of a root nodule.

balancing selection Natural selection that maintains two or more phenotypic forms in a population.

bar graph A graph in which the independent variable represents groups or nonnumerical categories and the values of the dependent variable(s) are shown by bars.

bark All tissues external to the vascular cambium, consisting mainly of the secondary phloem and layers of periderm.

Barr body A dense object lying along the inside of the nuclear envelope in cells of female mammals, representing a highly condensed, inactivated X chromosome.

basal angiosperm A member of one of three clades of early-diverging lineages of extant flowering plants. Examples are *Amborella*, water lilies, and star anise and its relatives.

basal body (bā'-sul) A eukaryotic cell structure consisting of a "9 + 0" arrangement of microtubule triplets. The basal body may organize the microtubule assembly of a cilium or flagellum and is structurally very similar to a centriole.

basal metabolic rate (BMR) The metabolic rate of a resting, fasting, and nonstressed endotherm at a comfortable temperature.

basal taxon In a specified group of organisms, a taxon whose evolutionary lineage diverged early in the history of the group.

base A substance that reduces the hydrogen ion concentration of a solution.

basidiocarp Elaborate fruiting body of a dikaryotic mycelium of a club fungus.

basidiomycete (buh-sid'-ē-ō-mī'-sēt) A member of the fungal phylum Basidiomycota, commonly called club fungus. The name comes from the club-like shape of the basidium.

basidium (plural, **basidia**) (buh-sid'-ē-um, buh-sid'-ē-ah) A reproductive appendage that produces sexual spores on the gills of mushrooms (club fungi).

Batesian mimicry (bāt'-zē-un mim'-uh-krē) A type of mimicry in which a harmless species resembles an unpalatable or harmful species to which it is not closely related.

behavior Individually, an action carried out by muscles or glands under control of the nervous system in response to a stimulus; collectively, the sum of an animal's responses to external and internal stimuli.

behavioral ecology The study of behavioral interactions between individuals within populations and communities, usually in an evolutionary context.

benign tumor A mass of abnormal cells with specific genetic and cellular changes such that the cells are not capable of surviving at a new site and generally remain at the site of the tumor's origin.

benthic zone The bottom surface of an aquatic environment.

benthos (ben'-thōz) The communities of organisms living in the benthic zone of an aquatic biome.

beta (β) pleated sheet One form of the secondary structure of proteins in which the polypeptide chain folds back and forth. Two regions of the chain lie parallel to each other and are held together by hydrogen bonds between atoms of the polypeptide backbone (not the side chains).

beta oxidation A metabolic sequence that breaks fatty acids down to two-carbon fragments that enter the citric acid cycle as acetyl CoA.

bilateral symmetry Body symmetry in which a central longitudinal plane divides the body into two equal but opposite halves.

bilaterian (bi'-luh-ter'-ē-uhn) A member of a clade of animals with bilateral symmetry and three germ layers.

bile A mixture of substances that is produced in the liver and stored in the gallbladder; enables formation of fat droplets in water as an aid in the digestion and absorption of fats.

binary fission A method of asexual reproduction in single-celled organisms in which the cell grows to roughly double its size and then divides into two cells. In prokaryotes, binary fission does not involve mitosis, but in single-celled eukaryotes that undergo binary fission, mitosis is part of the process.

binomial A common term for the two-part, latinized format for naming a species, consisting of the genus and specific epithet; also called a binomen.

biodiversity hot spot A relatively small area with numerous endemic species and a large number of endangered and threatened species.

bioenergetics (1) The overall flow and transformation of energy in an organism. (2) The study of how energy flows through organisms.

biofilm A surface-coating colony of one or more species of unicellular organisms that engage in metabolic cooperation; most known biofilms are formed by prokaryotes.

biofuel A fuel produced from biomass.

biogeochemical cycle Any of the various chemical cycles, which involve both biotic and abiotic components of ecosystems.

biogeography The scientific study of the past and present geographic distributions of species.

bioinformatics The use of computers, software, and mathematical models to process and integrate biological information from large data sets.

biological augmentation An approach to restoration ecology that uses organisms to add essential materials to a degraded ecosystem.

biological clock An internal timekeeper that controls an organism's biological rhythms. The

biological clock marks time with or without environmental cues but often requires signals from the environment to remain tuned to an appropriate period. *See also circadian rhythm.*

biological magnification A process in which retained substances become more concentrated at each higher trophic level in a food chain.

biological species concept Definition of a species as a group of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring but do not produce viable, fertile offspring with members of other such groups.

biology The scientific study of life.

biomass The total mass of organic matter comprising a group of organisms in a particular habitat.

biome (bī'-ōm) Any of the world's major ecosystem types, often classified according to the predominant vegetation for terrestrial biomes and the physical environment for aquatic biomes and characterized by adaptations of organisms to that particular environment.

bioremediation The use of organisms to detoxify and restore polluted and degraded ecosystems.

biosphere The entire portion of Earth inhabited by life; the sum of all the planet's ecosystems.

biotechnology The manipulation of organisms or their components to produce useful products.

biotic (bī-ot'-ik) Pertaining to the living factors—the organisms—in an environment.

bipolar disorder A depressive mental illness characterized by swings of mood from high to low; also called manic-depressive disorder.

birth control pill A hormonal contraceptive that inhibits ovulation, retards follicular development, or alters a woman's cervical mucus to prevent sperm from entering the uterus.

blade (1) A leaflike structure of a seaweed that provides most of the surface area for photosynthesis. (2) The flattened portion of a typical leaf.

blastocoel (blas'-tuh-sēl) The fluid-filled cavity that forms in the center of a blastula.

blastocyst (blas'-tuh-sist) The blastula stage of mammalian embryonic development, consisting of an inner cell mass, a cavity, and an outer layer, the trophoblast. In humans, the blastocyst forms 1 week after fertilization.

blastomere An early embryonic cell arising during the cleavage stage of an early embryo.

blastopore (blas'-tō-pōr) In a gastrula, the opening of the archenteron that typically develops into the anus in deuterostomes and the mouth in protostomes.

blastula (blas'-tyū-luh) A hollow ball of cells that marks the end of the cleavage stage during early embryonic development in animals.

blood A connective tissue with a fluid matrix called plasma in which red blood cells, white blood cells, and cell fragments called platelets are suspended.

blue-light photoreceptor Any of several classes of light-absorbing molecules that have physiological effects when activated by blue light.

body cavity A fluid- or air-filled space between the digestive tract and the body wall.

body plan In multicellular eukaryotes, a set of morphological and developmental traits that are integrated into a functional whole—the living organism.

Bohr shift A lowering of the affinity of hemoglobin for oxygen, caused by a drop in pH. It facilitates the release of oxygen from hemoglobin in the vicinity of active tissues.

bolus A lubricated ball of chewed food.

bone A connective tissue consisting of living cells held in a rigid matrix of collagen fibers embedded in calcium salts.

book lung An organ of gas exchange in spiders, consisting of stacked plates contained in an internal chamber.

bottleneck effect Genetic drift that occurs when the size of a population is reduced, as by a natural disaster or human actions. Typically, the surviving population is no longer genetically representative of the original population.

bottom-up control A situation in which the abundance of organisms at each trophic level is limited by nutrient supply or the availability of food at lower trophic levels; thus, the supply of nutrients controls plant numbers, which control herbivore numbers, which in turn control predator numbers.

Bowman's capsule (bō'-mūnz) A cup-shaped receptacle in the vertebrate kidney that is the initial, expanded segment of the nephron, where filtrate enters from the blood.

brachiopod (bra'-kē-uh-pod') A marine lophotrochozoan with a shell divided into dorsal and ventral halves; also called lamp shells.

brain Organ of the central nervous system where information is processed and integrated.

brainstem A collection of structures in the vertebrate brain, including the midbrain, the pons, and the medulla oblongata; functions in homeostasis, coordination of movement, and conduction of information to higher brain centers.

branch point The representation on a phylogenetic tree of the divergence of two or more taxa from a common ancestor. A branch point is usually shown as a dichotomy in which a branch representing the ancestral lineage splits (at the branch point) into two branches, one for each of the two descendant lineages.

brassinosteroid A steroid hormone in plants that has a variety of effects, including inducing cell elongation, retarding leaf abscission, and promoting xylem differentiation.

breathing Ventilation of the lungs through alternating inhalation and exhalation.

bronchiole (brong'-kē-ōl') A fine branch of the bronchi that transports air to alveoli.

bronchus (brong'-kus) (plural, **bronchi**) One of a pair of breathing tubes that branch from the trachea into the lungs.

brown alga A multicellular, photosynthetic protist with a characteristic brown or olive color that results from carotenoids in its plastids. Most brown algae are marine, and some have a plantlike body.

bryophyte (brī'-uh-fit) An informal name for a moss, liverwort, or hornwort; a nonvascular plant that lives on land but lacks some of the terrestrial adaptations of vascular plants.

buffer A solution that contains a weak acid and its corresponding base. A buffer minimizes

changes in pH when acids or bases are added to the solution.

bulk feeder An animal that eats relatively large pieces of food.

bulk flow The movement of a fluid due to a difference in pressure between two locations.

bundle-sheath cell In C₄ plants, a type of photosynthetic cell arranged into tightly packed sheaths around the veins of a leaf.

C₃ plant A plant that uses the Calvin cycle for the initial steps that incorporate CO₂ into organic material, forming a three-carbon compound as the first stable intermediate.

C₄ plant A plant in which the Calvin cycle is preceded by reactions that incorporate CO₂ into a four-carbon compound, the end product of which supplies CO₂ for the Calvin cycle.

calcitonin (kal'-si-tō'-nin) A hormone secreted by the thyroid gland that lowers the blood calcium level by promoting calcium deposition in bone and calcium excretion from the kidneys; nonessential in adult humans.

callus A mass of dividing, undifferentiated cells growing at the site of a wound or in culture.

calorie (cal) The amount of heat energy required to raise the temperature of 1 g of water by 1°C; also the amount of heat energy that 1 g of water releases when it cools by 1°C. The Calorie (with a capital C), usually used to indicate the energy content of food, is a kilocalorie.

Calvin cycle The second of two major stages in photosynthesis (following the light reactions), involving fixation of atmospheric CO₂ and reduction of the fixed carbon into carbohydrate.

Cambrian explosion A relatively brief time in geologic history when many present-day phyla of animals first appeared in the fossil record. This burst of evolutionary change occurred about 535–525 million years ago and saw the emergence of the first large, hard-bodied animals.

cAMP (cyclic AMP) Cyclic adenosine monophosphate, named because of its ring structure, is a common chemical signal that has a diversity of roles, including as a second messenger in many eukaryotic cells, and as a regulator of some bacterial operons.

CAM plant A plant that uses crassulacean acid metabolism, an adaptation for photosynthesis in arid conditions. In this process, CO₂ entering open stomata during the night is converted to organic acids, which release CO₂ for the Calvin cycle during the day, when stomata are closed.

canopy The uppermost layer of vegetation in a terrestrial biome.

capillary (kap'-il-är'-ē) A microscopic blood vessel that penetrates the tissues and consists of a single layer of endothelial cells that allows exchange between the blood and interstitial fluid.

capillary bed (kap'-il-är'-ē) A network of capillaries in a tissue or organ.

capsid The protein shell that encloses a viral genome. It may be rod-shaped, polyhedral, or more complex in shape.

capsule (1) In many prokaryotes, a dense and well-defined layer of polysaccharide or

protein that surrounds the cell wall and is sticky, protecting the cell and enabling it to adhere to substrates or other cells. (2) The sporangium of a bryophyte (moss, liverwort, or hornwort).

carbohydrate (kar'-bō-hī'-drāt) A sugar (monosaccharide) or one of its dimers (disaccharides) or polymers (polysaccharides).

carbon fixation The initial incorporation of carbon from CO₂ into an organic compound by an autotrophic organism (a plant, another photosynthetic organism, or a chemoautotrophic prokaryote).

carbonyl group (kar'-buh-nil) A chemical group present in aldehydes and ketones and consisting of a carbon atom double-bonded to an oxygen atom.

carboxyl group (kar-bok'-sil) A chemical group present in organic acids and consisting of a single carbon atom double-bonded to an oxygen atom and also bonded to a hydroxyl group.

cardiac cycle (kar'-dē-ak) The alternating contractions and relaxations of the heart.

cardiac muscle (kar'-dē-ak) A type of striated muscle that forms the contractile wall of the heart. Its cells are joined by intercalated disks that relay the electrical signals underlying each heartbeat.

cardiac output (kar'-dē-ak) The volume of blood pumped per minute by each ventricle of the heart.

cardiovascular system A closed circulatory system with a heart and branching network of arteries, capillaries, and veins. The system is characteristic of vertebrates.

carnivore An organism that consumes animals for nutrition.

carotenoid (kuh-rot'-uh-noy'd) An accessory pigment, either yellow or orange, in the chloroplasts of plants and in some prokaryotes. By absorbing wavelengths of light that chlorophyll cannot, carotenoids broaden the spectrum of colors that can drive photosynthesis.

carpel (kar'-pul) The ovule-producing reproductive organ of a flower, consisting of the stigma, style, and ovary.

carrier In genetics, an individual who is heterozygous at a given genetic locus for a recessively inherited disorder. The heterozygote is generally phenotypically normal for the disorder but can pass on the recessive allele to offspring.

carrying capacity The maximum population size that can be supported by the available resources, symbolized as K.

cartilage (kar'-til-ij) A flexible connective tissue with an abundance of collagenous fibers embedded in chondroitin sulfate.

Casparian strip (ka-spār'-ē-un) A water-impermeable ring of wax in the endodermal cells of plants that blocks the passive flow of water and solutes into the stele by way of cell walls.

catabolic pathway (kat'-uh-bol'-ik) A metabolic pathway that releases energy by breaking down complex molecules to simpler molecules.

catalysis (kuh-ta'-luh-sis) A process by which a chemical agent called a catalyst selectively increases the rate of a reaction without being consumed by the reaction.

- catalyst** (kat'-uh-list) A chemical agent that selectively increases the rate of a reaction without being consumed by the reaction.
- cation** (cat'-i'-on) A positively charged ion.
- cation exchange** (cat'-i'-on) A process in which positively charged minerals are made available to a plant when hydrogen ions in the soil displace mineral ions from the clay particles.
- cecum** (se'-kum) (plural, **ceca**) The blind pouch forming one branch of the large intestine.
- cell** Life's fundamental unit of structure and function; the smallest unit of organization that can perform all activities required for life.
- cell body** The part of a neuron that houses the nucleus and most other organelles.
- cell cycle** An ordered sequence of events in the life of a cell, from its origin in the division of a parent cell until its own division into two. The eukaryotic cell cycle is composed of interphase (including G₁, S, and G₂ phases) and M phase (including mitosis and cytokinesis).
- cell cycle control system** A cyclically operating set of molecules in the eukaryotic cell that both triggers and coordinates key events in the cell cycle.
- cell division** The reproduction of cells.
- cell fractionation** The disruption of a cell and separation of its parts by centrifugation at successively higher speeds.
- cell-mediated immune response** The branch of adaptive immunity that involves the activation of cytotoxic T cells, which defend against infected cells.
- cell plate** A membrane-bounded, flattened sac located at the midline of a dividing plant cell, inside which the new cell wall forms during cytokinesis.
- cellular respiration** The catabolic pathways of aerobic and anaerobic respiration, which break down organic molecules and use an electron transport chain for the production of ATP.
- cellulose** (sel'-yū-lōs) A structural polysaccharide of plant cell walls, consisting of glucose monomers joined by β glycosidic linkages.
- cell wall** A protective layer external to the plasma membrane in the cells of plants, prokaryotes, fungi, and some protists. Polysaccharides such as cellulose (in plants and some protists), chitin (in fungi), and peptidoglycan (in bacteria) are important structural components of cell walls.
- central nervous system (CNS)** The portion of the nervous system where signal integration occurs; in vertebrate animals, the brain and spinal cord.
- central vacuole** In a mature plant cell, a large membranous sac with diverse roles in growth, storage, and sequestration of toxic substances.
- centriole** (sen'-trē-ōl) A structure in the centrosome of an animal cell composed of a cylinder of microtubule triplets arranged in a "9 + 0" pattern. A centrosome has a pair of centrioles.
- centromere** (sen'-trō-mēr) In a duplicated chromosome, the region on each sister chromatid where it is most closely attached to its sister chromatid by proteins that bind to the centromeric DNA. Other proteins condense the chromatin in that region, so it appears as a narrow "waist" on the duplicated chromosome. (An unduplicated chromosome has a single centromere, identified by the proteins bound there.)
- centrosome** (sen'-trō-sōm) A structure present in the cytoplasm of animal cells that functions as a microtubule-organizing center and is important during cell division. A centrosome has two centrioles.
- cercozoan** An amoeboid or flagellated protist that feeds with threadlike pseudopodia.
- cerebellum** (sär'-ruh-bel'-um) Part of the vertebrate hindbrain located dorsally; functions in unconscious coordination of movement and balance.
- cerebral cortex** (suh-rē'-brul) The surface of the cerebrum; the largest and most complex part of the mammalian brain, containing nerve cell bodies of the cerebrum; the part of the vertebrate brain most changed through evolution.
- cerebrum** (suh-rē'-brum) The dorsal portion of the vertebrate forebrain, composed of right and left hemispheres; the integrating center for memory, learning, emotions, and other highly complex functions of the central nervous system.
- cervix** (ser'-viks) The neck of the uterus, which opens into the vagina.
- chaparral** A scrubland biome of dense, spiny evergreen shrubs found at midlatitudes along coasts where cold ocean currents circulate offshore; characterized by mild, rainy winters and long, hot, dry summers.
- chaperonin** (shap'-er-o'-nin) A protein complex that assists in the proper folding of other proteins.
- character** An observable heritable feature that may vary among individuals.
- character displacement** The tendency for characteristics to be more divergent in sympatric populations of two species than in allopatric populations of the same two species.
- checkpoint** A control point in the cell cycle where stop and go-ahead signals can regulate the cycle.
- chelicera** (kē-lih'-suh-ruh) (plural, **chelicerae**) One of a pair of clawlike feeding appendages characteristic of chelicerates.
- chelicerate** (kē-lih-suh'-rātē) An arthropod that has chelicerae and a body divided into a cephalothorax and an abdomen. Living chelicerates include sea spiders, horseshoe crabs, scorpions, ticks, and spiders.
- chemical bond** An attraction between two atoms, resulting from a sharing of outer-shell electrons or the presence of opposite charges on the atoms. The bonded atoms gain complete outer electron shells.
- chemical energy** Energy available in molecules for release in a chemical reaction; a form of potential energy.
- chemical equilibrium** In a chemical reaction, the state in which the rate of the forward reaction equals the rate of the reverse reaction, so that the relative concentrations of the reactants and products do not change with time.
- chemical reaction** The making and breaking of chemical bonds, leading to changes in the composition of matter.
- chemiosmosis** (kem'-ē-oz-mō'-sis) An energy-coupling mechanism that uses energy stored in the form of a hydrogen ion gradient across a membrane to drive cellular work, such as the synthesis of ATP. Under aerobic conditions, most ATP synthesis in cells occurs by chemiosmosis.
- chemoautotroph** (kē'-mō-ot'-ō-trōf) An organism that obtains energy by oxidizing inorganic substances and needs only carbon dioxide as a carbon source.
- chemoheterotroph** (kē'-mō-het'-er-ō-trōf) An organism that requires organic molecules for both energy and carbon.
- chemoreceptor** A sensory receptor that responds to a chemical stimulus, such as a solute or an odorant.
- chiasma** (plural, **chiasmata**) (ki-az'-muh, ki-az'-muh-tuh) The X-shaped, microscopically visible region where crossing over has occurred earlier in prophase I between homologous nonsister chromatids. Chiasmata become visible after synapsis ends, with the two homologs remaining associated due to sister chromatid cohesion.
- chitin** (ki'-tin) A structural polysaccharide, consisting of amino sugar monomers, found in many fungal cell walls and in the exoskeletons of all arthropods.
- chlorophyll** (klōr'-ō-fil) A green pigment located in membranes within the chloroplasts of plants and algae and in the membranes of certain prokaryotes. Chlorophyll *a* participates directly in the light reactions, which convert solar energy to chemical energy.
- chlorophyll *a*** (klōr'-ō-fil) A photosynthetic pigment that participates directly in the light reactions, which convert solar energy to chemical energy.
- chlorophyll *b*** (klōr'-ō-fil) An accessory photosynthetic pigment that transfers energy to chlorophyll *a*.
- chloroplast** (klōr'-ō-plast) An organelle found in plants and photosynthetic protists that absorbs sunlight and uses it to drive the synthesis of organic compounds from carbon dioxide and water.
- choanocyte** (kō-an'-uh-sīt) A flagellated feeding cell found in sponges. Also called a collar cell, it has a collar-like ring that traps food particles around the base of its flagellum.
- cholesterol** (kō-les'-uh-rol) A steroid that forms an essential component of animal cell membranes and acts as a precursor molecule for the synthesis of other biologically important steroids, such as many hormones.
- chondrichthyan** (kon-drīk'-thē-an) A member of the clade Chondrichthyes, vertebrates with skeletons made mostly of cartilage, such as sharks and rays.
- chordate** A member of the phylum Chordata, animals that at some point during their development have a notochord; a dorsal, hollow nerve cord; pharyngeal slits or clefts; and a muscular, post-anal tail.
- chorionic villus sampling (CVS)** (kōr'-ē-on'-ik vil'-us) A technique associated with prenatal diagnosis in which a small sample of the fetal portion of the placenta is removed for analysis to detect certain genetic and congenital defects in the fetus.
- chromatin** (krō'-muh-tin) The complex of DNA and proteins that makes up eukaryotic chromosomes. When the cell is not dividing, chromatin exists in its dispersed form, as a mass of

very long, thin fibers that are not visible with a light microscope.

chromosome (krō'-muh-sōm) A cellular structure consisting of one DNA molecule and associated protein molecules. A duplicated chromosome has two DNA molecules. (In some contexts, such as genome sequencing, the term may refer to the DNA alone.) A eukaryotic cell typically has multiple, linear chromosomes, which are located in the nucleus. A prokaryotic cell often has a single, circular chromosome, which is found in the nucleoid, a region that is not enclosed by a membrane. *See also* chromatin.

chromosome theory of inheritance (krō'-muh-sōm) A basic principle in biology stating that genes are located at specific positions (loci) on chromosomes and that the behavior of chromosomes during meiosis accounts for inheritance patterns.

chylomicron (ki'-lō-mi'-kron) A lipid transport globule composed of fats mixed with cholesterol and coated with proteins.

chyme (kim) The mixture of partially digested food and digestive juices formed in the stomach.

chytrid (ki'-trid) A member of the fungal phylum Chytridiomycota, mostly aquatic fungi with flagellated zoospores that represent an early-diverging fungal lineage.

ciliate (sil'-ē-it) A type of protist that moves by means of cilia.

cilium (sil'-ē-um) (plural, **cilia**) A short appendage containing microtubules in eukaryotic cells. A motile cilium is specialized for locomotion or moving fluid past the cell; it is formed from a core of nine outer doublet microtubules and two inner single microtubules (the "9 + 2" arrangement) ensheathed in an extension of the plasma membrane. A primary cilium is usually nonmotile and plays a sensory and signaling role; it lacks the two inner microtubules (the "9 + 0" arrangement).

circadian rhythm (ser-kā'-dē-un) A physiological cycle of about 24 hours that persists even in the absence of external cues.

cis-trans isomer One of several compounds that have the same molecular formula and covalent bonds between atoms but differ in the spatial arrangements of their atoms owing to the inflexibility of double bonds; also called a geometric isomer.

citric acid cycle A chemical cycle involving eight steps that completes the metabolic breakdown of glucose molecules begun in glycolysis by oxidizing acetyl CoA (derived from pyruvate) to carbon dioxide; occurs within the mitochondrion in eukaryotic cells and in the cytosol of prokaryotes; together with pyruvate oxidation, the second major stage in cellular respiration.

clade (klād) A group of species that includes an ancestral species and all of its descendants. A clade is equivalent to a monophyletic group.

cladistics (kluh-dis'-tiks) An approach to systematics in which organisms are placed into groups called clades based primarily on common descent.

class In Linnaean classification, the taxonomic category above the level of order.

cleavage (1) The process of cytokinesis in animal cells, characterized by pinching of the plasma membrane. (2) The succession of rapid cell divisions without significant growth during early embryonic development that converts the zygote to a ball of cells.

cleavage furrow The first sign of cleavage in an animal cell; a shallow groove around the cell in the cell surface near the old metaphase plate.

climate The long-term prevailing weather conditions at a given place.

climate change A directional change in temperature, precipitation, or other aspect of the global climate that lasts for three decades or more.

climograph A plot of the temperature and precipitation in a particular region.

clitoris (klit'-uh-ris) An organ at the upper intersection of the labia minora that engorges with blood and becomes erect during sexual arousal.

cloaca (klō-ā'-kuh) A common opening for the digestive, urinary, and reproductive tracts found in many nonmammalian vertebrates but in few mammals.

clonal selection The process by which an antigen selectively binds to and activates only those lymphocytes bearing receptors specific for the antigen. The selected lymphocytes proliferate and differentiate into a clone of effector cells and a clone of memory cells specific for the stimulating antigen.

clone (1) A group of genetically identical individuals or cells. (2) In popular usage, an individual that is genetically identical to another individual. (3) As a verb, to make one or more genetic replicas of an individual or cell. *See also* gene cloning.

cloning vector In genetic engineering, a DNA molecule that can carry foreign DNA into a host cell and replicate there. Cloning vectors include plasmids and bacterial artificial chromosomes (BACs), which move recombinant DNA from a test tube back into a cell, and viruses that transfer recombinant DNA by infection.

closed circulatory system A circulatory system in which blood is confined to vessels and is kept separate from the interstitial fluid.

cnidocyte (ni'-duh-sit) A specialized cell unique to the phylum Cnidaria; contains a capsule-like organelle housing a coiled thread that, when discharged, explodes outward and functions in prey capture or defense.

cochlea (kok'-lē-uh) The complex, coiled organ of hearing that contains the organ of Corti.

coding strand Nontemplate strand of DNA, which has the same sequence as the mRNA except it has thymine (T) instead of uracil (U).

codominance The situation in which the phenotypes of both alleles are exhibited in the heterozygote because both alleles affect the phenotype in separate, distinguishable ways.

codon (kō'-don) A three-nucleotide sequence of DNA or mRNA that specifies a particular amino acid or termination signal; the basic unit of the genetic code.

coefficient of relatedness The fraction of genes that, on average, are shared by two individuals.

coelom (sē'-lōm) A body cavity lined by tissue derived only from mesoderm.

coenocytic fungus (sē'-no-si'-tic) A fungus that lacks septa and hence whose body is made up of a continuous cytoplasmic mass that may contain hundreds or thousands of nuclei.

coenzyme (kō-en'-zim) An organic molecule serving as a cofactor. Most vitamins function as coenzymes in metabolic reactions.

coevolution The joint evolution of two interacting species, each in response to selection imposed by the other.

cofactor Any nonprotein molecule or ion that is required for the proper functioning of an enzyme. Cofactors can be permanently bound to the active site or may bind loosely and reversibly, along with the substrate, during catalysis.

cognition The process of knowing that may include awareness, reasoning, recollection, and judgment.

cognitive map A neural representation of the abstract spatial relationships between objects in an animal's surroundings.

cohesion The linking together of like molecules, often by hydrogen bonds.

cohesion-tension hypothesis The leading explanation of the ascent of xylem sap. It states that transpiration exerts pull on xylem sap, putting the sap under negative pressure, or tension, and that the cohesion of water molecules transmits this pull along the entire length of the xylem from shoots to roots.

cohort A group of individuals of the same age in a population.

coleoptile (kō'-lē-op'-tul) The covering of the young shoot of the embryo of a grass seed.

coleorhiza (kō'-lē-uh-ri'-zuh) The covering of the young root of the embryo of a grass seed.

collagen A glycoprotein in the extracellular matrix of animal cells that forms strong fibers, found extensively in connective tissue and bone; the most abundant protein in the animal kingdom.

collecting duct The location in the kidney where processed filtrate, called urine, is collected from the renal tubules.

collenchyma cell (kō-lēn'-kim-uh) A flexible plant cell type that occurs in strands or cylinders that support young parts of the plant without restraining growth.

colon (kō'-len) The largest section of the vertebrate large intestine; functions in water absorption and formation of feces.

commensalism (kuh-men'-suh-lizm) A +/0 ecological interaction that benefits the individuals of one species but neither harms nor helps the individuals of the other species.

communication (1) In behavior, a process involving the transmission and reception of signals between organisms. (2) Transfer of information from one cell or molecule to another by means of chemical or physical signals.

community All the organisms that inhabit a particular area; an assemblage of populations of different species living close enough together for potential interaction.

community ecology The study of how interactions between species affect community structure and organization.

community structure The number of species found in an ecological community, the particular species that are present, and the relative abundance of these species.

companion cell A type of plant cell that is connected to a sieve-tube element by many plasmodesmata and whose nucleus and ribosomes may serve one or more adjacent sieve-tube elements.

competition A –/– interaction that occurs when individuals of different species both use a resource that limits the survival and reproduction of each species.

competitive exclusion The concept that when populations of two similar species compete for the same limited resources, one population will use the resources more efficiently and have a reproductive advantage that will eventually lead to the elimination of the other population.

competitive inhibitor A substance that reduces the activity of an enzyme by entering the active site in place of the substrate, whose structure it mimics.

complement system A group of about 30 blood proteins that may amplify the inflammatory response, enhance phagocytosis, or directly lyse extracellular pathogens.

complementary DNA (cDNA) A double-stranded DNA molecule made *in vitro* using mRNA as a template and the enzymes reverse transcriptase and DNA polymerase. A cDNA molecule corresponds to the exons of a gene.

complete dominance The situation in which the phenotypes of the heterozygote and dominant homozygote are indistinguishable.

complete flower A flower that has all four basic floral organs: sepals, petals, stamens, and carpels.

complete metamorphosis The transformation of a larva into an adult that looks very different, and often functions very differently in its environment, than the larva.

compound A substance consisting of two or more different elements combined in a fixed ratio.

compound eye A type of multifaceted eye in insects and crustaceans consisting of up to several thousand light-detecting, focusing ommatidia.

concentration gradient A region along which the density of a chemical substance increases or decreases.

conception The fertilization of an egg by a sperm in humans.

cone A cone-shaped cell in the retina of the vertebrate eye, sensitive to color.

conformer An animal for which an internal condition conforms to (changes in accordance with) changes in an environmental variable.

conidium (plural, **conidia**) A haploid spore produced at the tip of a specialized hypha in ascomycetes during asexual reproduction.

conifer A member of the largest gymnosperm phylum. Most conifers are cone-bearing trees, such as pines and firs.

conjugation (kon'-jū-gā'-shun) (1) In prokaryotes, the direct transfer of DNA between two cells that are temporarily joined. When the two cells are members of different species, conjugation results in horizontal gene transfer. (2) In ciliates, a sexual process in which

two cells exchange haploid micronuclei but do not reproduce.

connective tissue Animal tissue that functions mainly to bind and support other tissues, having a sparse population of cells scattered through an extracellular matrix.

conodont An early, soft-bodied vertebrate with prominent eyes and dental elements.

conservation biology The integrated study of ecology, evolutionary biology, physiology, molecular biology, and genetics to sustain biological diversity at all levels.

consumer An organism that feeds on producers, other consumers, or nonliving organic material.

contraception The deliberate prevention of pregnancy.

contractile vacuole A membranous sac that helps move excess water out of certain freshwater protists.

control element A segment of noncoding DNA that helps regulate transcription of a gene by serving as a binding site for a transcription factor. Multiple control elements are present in a eukaryotic gene's enhancer.

control group In a controlled experiment, a set of subjects that lacks (or does not receive) the specific factor being tested. Ideally, the control group is identical to the experimental group in other respects.

controlled experiment An experiment designed to compare an experimental group with a control group; ideally, the two groups differ only in the factor being tested.

convergent evolution The evolution of similar features in independent evolutionary lineages.

convergent extension A process in which the cells of a tissue layer rearrange themselves in such a way that the sheet of cells becomes narrower (converges) and longer (extends).

cooperativity A kind of allosteric regulation whereby a shape change in one subunit of a protein caused by substrate binding is transmitted to all the other subunits, facilitating binding of additional substrate molecules to those subunits.

coral reef Typically a warm-water, tropical ecosystem dominated by the hard skeletal structures secreted primarily by corals. Some coral reefs also exist in cold, deep waters.

corepressor A small molecule that binds to a bacterial repressor protein and changes the protein's shape, allowing it to bind to the operator and switch an operon off.

cork cambium (kam'-bē-um) A cylinder of meristematic tissue in woody plants that replaces the epidermis with thicker, tougher cork cells.

corpus callosum (kor'-pus kuh-lō'-sum) The thick band of nerve fibers that connects the right and left cerebral hemispheres in mammals, enabling the hemispheres to process information together.

corpus luteum (kor'-pus lü'-tē-um) A secreting tissue in the ovary that forms from the collapsed follicle after ovulation and produces progesterone.

cortex (1) The outer region of cytoplasm in a eukaryotic cell, lying just under the plasma membrane, that has a more gel-like

consistency than the inner regions due to the presence of multiple microfilaments. (2) In plants, ground tissue that is between the vascular tissue and dermal tissue in a root or eudicot stem.

cortical nephron In mammals and birds, a nephron with a loop of Henle located almost entirely in the renal cortex.

cotransport The coupling of the “downhill” diffusion of one substance to the “uphill” transport of another against its own concentration gradient.

cotyledon (kot'-uh-lē'-dun) A seed leaf of an angiosperm embryo. Some species have one cotyledon, others two.

countercurrent exchange The exchange of a substance or heat between two fluids flowing in opposite directions. For example, blood in a fish gill flows in the opposite direction of water passing over the gill, maximizing diffusion of oxygen into and carbon dioxide out of the blood.

countercurrent multiplier system A countercurrent system in which energy is expended in active transport to facilitate exchange of materials and generate concentration gradients.

covalent bond (kō-vā'-lēnt) A type of strong chemical bond in which two atoms share one or more pairs of valence electrons.

crassulacean acid metabolism (CAM) (crass-yū-lā'-shen) An adaptation for photosynthesis in arid conditions, first discovered in the family Crassulaceae. In this process, a plant takes up CO₂ and incorporates it into a variety of organic acids at night; during the day, CO₂ is released from organic acids for use in the Calvin cycle.

CRISPR-Cas9 system A technique for editing genes in living cells, involving a bacterial protein called Cas9 associated with a guide RNA complementary to a gene sequence of interest.

crista (plural, **cristae**) (kris'-tuh, kris'-tē) An infolding of the inner membrane of a mitochondrion. The inner membrane houses electron transport chains and molecules of the enzyme catalyzing the synthesis of ATP (ATP synthase).

critical load The amount of added nutrient, usually nitrogen or phosphorus, that can be absorbed by plants without damaging ecosystem integrity.

crop rotation The practice of growing different crops in succession on the same land chiefly to preserve the productive capacity of the soil.

cross-fostering study A behavioral study in which the young of one species are placed in the care of adults from another species.

crossing over The reciprocal exchange of genetic material between nonsister chromatids during prophase I of meiosis.

cross-pollination In angiosperms, the transfer of pollen from an anther of a flower on one plant to the stigma of a flower on another plant of the same species.

cryptic coloration Camouflage that makes a potential prey difficult to spot against its background.

cryptomycete A member of the fungal phylum Cryptomycota, unicellular fungi that have flagellated spores; cryptomycetes and their sister taxon (microsporidians) are a basal fungal lineage.

culture A system of information transfer through social learning or teaching that influences the behavior of individuals in a population.

cuticle (kyü'-tuh-kul) Any of a variety of tough but flexible, non-mineral outer coverings of an organism, or parts of an organism, which provide protection.

cyclic AMP (cAMP) Cyclic adenosine monophosphate, named because of its ring structure, is a common chemical signal that has a diversity of roles, including as a second messenger in many eukaryotic cells, and as a regulator of some bacterial operons.

cyclic electron flow A route of electron flow during the light reactions of photosynthesis that involves only one photosystem and that produces ATP but not NADPH or O₂.

cyclin (sī'-klin) A cellular protein that occurs in a cyclically fluctuating concentration and that plays an important role in regulating the cell cycle.

cyclin-dependent kinase (Cdk) (sī'-klin) A protein kinase that is active only when attached to a particular cyclin.

cyclostome (sī'-cluh-stōm) Member of one of the two main clades of vertebrates; cyclostomes lack jaws and include lampreys and hagfishes. *See also gnathostome*.

cystic fibrosis (sis'-tik fī-brō'-sis) A human genetic disorder caused by a recessive allele for a chloride channel protein; characterized by an excessive secretion of mucus and consequent vulnerability to infection; fatal if untreated.

cytochrome (sī'-tō-krōm) An iron-containing protein that is a component of electron transport chains in the mitochondria and chloroplasts of eukaryotic cells and the plasma membranes of prokaryotic cells.

cytokine (sī'-tō-kīn') Any of a group of small proteins secreted by a number of cell types, including macrophages and helper T cells, that regulate the function of other cells.

cytokinesis (sī'-tō-kuh-nē'-sis) The division of the cytoplasm to form two separate daughter cells immediately after mitosis, meiosis I, or meiosis II.

cytokinin (sī'-tō-kī'-nin) Any of a class of related plant hormones that retard aging and act in concert with auxin to stimulate cell division, influence the pathway of differentiation, and control apical dominance.

cytoplasm (sī'-tō-plaz-um) The contents of the cell bounded by the plasma membrane; in eukaryotes, the portion exclusive of the nucleus.

cytoplasmic determinant A maternal substance, such as a protein or RNA, that when placed into an egg influences the course of early development by regulating the expression of genes that affect the developmental fate of cells.

cytoplasmic streaming A circular flow of cytoplasm, involving interactions of myosin and actin filaments, that speeds the distribution of materials within cells.

cytoskeleton A network of microtubules, microfilaments, and intermediate filaments that extend throughout the cytoplasm and serve a variety of mechanical, transport, and signaling functions.

cytosol (sī'-tō-sol) The semifluid portion of the cytoplasm.

cytotoxic T cell A type of lymphocyte that, when activated, kills infected cells as well as certain cancer cells and transplanted cells.

dalton A measure of mass for atoms and subatomic particles; the same as the atomic mass unit, or amu.

data Recorded observations.

day-neutral plant A plant in which flower formation is not controlled by photoperiod or day length.

decomposer An organism that absorbs nutrients from nonliving organic material such as corpses, fallen plant material, and the wastes of living organisms and converts them to inorganic forms; a detritivore.

deductive reasoning A type of logic in which specific results are predicted from a general premise.

de-etiolation The changes a plant shoot undergoes in response to sunlight; also known informally as greening.

dehydration reaction A chemical reaction in which two molecules become covalently bonded to each other with the removal of a water molecule.

deletion (1) A deficiency in a chromosome resulting from the loss of a fragment through breakage. (2) A mutational loss of one or more nucleotide pairs from a gene.

demographic transition In a stable population, a shift from high birth and death rates to low birth and death rates.

demography The study of changes over time in the vital statistics of populations, especially birth rates and death rates.

denaturation (dē-nā'-chur-ā'-shun) In proteins, a process in which a protein loses its native shape due to the disruption of weak chemical bonds and interactions, thereby becoming biologically inactive; in DNA, the separation of the two strands of the double helix. Denaturation occurs under extreme (noncellular) conditions of pH, salt concentration, or temperature.

dendrite (den'-drīt) One of usually numerous, short, highly branched extensions of a neuron that receive signals from other neurons.

dendritic cell An antigen-presenting cell, located mainly in lymphatic tissues and skin, that is particularly efficient in presenting antigens to helper T cells, thereby initiating a primary immune response.

density The number of individuals per unit area or volume.

density dependent Referring to any characteristic that varies with population density.

density-dependent inhibition The phenomenon observed in normal animal cells that causes them to stop dividing when they come into contact with one another.

density independent Referring to any characteristic that is not affected by population density.

deoxyribonucleic acid (DNA) (dē-ok'-sē-rī'-bō-nū-klā'-ik) A nucleic acid molecule, usually a double-stranded helix, in which each polynucleotide strand consists of nucleotide monomers with a deoxyribose sugar and the nitrogenous bases adenine (A), cytosine (C), guanine (G), and thymine (T); capable of being replicated and determining the inherited structure of a cell's proteins.

deoxyribose (dē-ok'-si-rī'-bōs) The sugar component of DNA nucleotides, having one fewer hydroxyl group than ribose, the sugar component of RNA nucleotides.

dependent variable A factor whose value is measured during an experiment or other test to see whether it is influenced by changes in another factor (the independent variable).

depolarization A change in a cell's membrane potential such that the inside of the membrane is made less negative relative to the outside. For example, a neuron membrane is depolarized if a stimulus decreases its voltage from the resting potential of -70 mV in the direction of zero voltage.

dermal tissue The outer protective covering of plants.

desert A terrestrial biome characterized by very low precipitation.

desmosome A type of intercellular junction in animal cells that functions as a rivet, fastening cells together.

determinate cleavage A type of embryonic development in protostomes that rigidly casts the developmental fate of each embryonic cell very early.

determinate growth A type of growth characteristic of most animals and some plant organs, in which growth stops after a certain size is reached.

determination The progressive restriction of developmental potential in which the possible fate of each cell becomes more limited as an embryo develops. At the end of determination, a cell is committed to its fate.

detritus (di-trī'-tus) Dead organic matter.

deuteromycete (dū'-tuh-rō-mī'-sēt) Traditional classification for a fungus with no known sexual stage.

deuterostome development (dū'-tuh-rō-stōm') In animals, a developmental mode distinguished by the development of the anus from the blastopore; often also characterized by radial cleavage and by the body cavity forming as outpockets of mesodermal tissue.

Deuterostomia (dū'-tuh-rō-stōm'-ē-uh) One of the three main lineages of bilaterian animals. *See also* Ecdysozoa and Lophotrochozoa.

development The events involved in an organism's changing gradually from a simple to a more complex or specialized form.

diabetes mellitus (di'-uh-beē'-tis mel'-uh-tus)

An endocrine disorder marked by an inability to maintain glucose homeostasis. The type 1 form results from autoimmune destruction of insulin-secreting cells; treatment usually requires daily insulin injections. The type 2 form most commonly results from reduced responsiveness of target cells to insulin; obesity and lack of exercise are risk factors.

diacylglycerol (DAG) (dī-a'-sil-glis'-er-ol) A second messenger produced by the cleavage of the phospholipid PIP₂ in the plasma membrane.

diaphragm (di'-uh-frām') (1) A sheet of muscle that forms the bottom wall of the thoracic cavity in mammals. Contraction of the diaphragm pulls air into the lungs. (2) A dome-shaped rubber cup fitted into the upper portion of the vagina before sexual intercourse. It serves as a physical barrier to the passage of sperm into the uterus.

diapsid (di-ap'-sid) A member of an amniote clade distinguished by a pair of holes on each side of the skull. Diapsids include the lepidosaurs and archosaurs.

diastole (di-as'-tō-lē) The stage of the cardiac cycle in which a heart chamber is relaxed and fills with blood.

diastolic pressure Blood pressure in the arteries when the ventricles are relaxed.

diatom Photosynthetic protist in the stramenopile clade; diatoms have a unique glass-like wall made of silicon dioxide embedded in an organic matrix.

dicot A term traditionally used to refer to flowering plants that have two embryonic seed leaves, or cotyledons. Recent molecular evidence indicates that dicots do not form a clade; species once classified as dicots are now grouped into eudicots, magnoliids, and several lineages of basal angiosperms.

differential gene expression The expression of different sets of genes by cells with the same genome.

differentiation The process by which a cell or group of cells becomes specialized in structure and function.

diffusion The random thermal motion of particles of liquids, gases, or solids. In the presence of a concentration or electrochemical gradient, diffusion results in the net movement of a substance from a region where it is more concentrated to a region where it is less concentrated.

digestion The second stage of food processing in animals: the breaking down of food into molecules small enough for the body to absorb.

dihybrid (di'-hī'-brid) An organism that is heterozygous with respect to two genes of interest. All the offspring from a cross between parents doubly homozygous for different alleles are dihybrids. For example, parents of genotypes *AABB* and *aabb* produce a dihybrid of genotype *AaBb*.

dihybrid cross (di'-hī'-brid) A cross between two organisms that are each heterozygous for both of the characters being followed (or the self-pollination of a plant that is heterozygous for both characters).

dikaryotic (di'-kär-ē-ot'-ik) Referring to a fungal mycelium with two haploid nuclei per cell, one from each parent.

dinoflagellate (di'-nō-flaj'-uh-let) A member of a group of mostly unicellular photosynthetic algae with two flagella situated in perpendicular grooves in cellulose plates covering the cell.

dinosaur A member of an extremely diverse clade of reptiles varying in body shape, size, and habitat. Birds are the only extant dinosaurs.

dioecious (di-ē'-shus) In plant biology, having the male and female reproductive parts on different individuals of the same species.

diploblastic Having two germ layers.

diploid cell (dip'-loyd) A cell containing two sets of chromosomes ($2n$), one set inherited from each parent.

diplomonad A protist that has modified mitochondria, two equal-sized nuclei, and multiple flagella.

directional selection Natural selection in which individuals at one end of the phenotypic range survive or reproduce more successfully than do other individuals.

disaccharide (di-sak'-uh-rid) A double sugar, consisting of two monosaccharides joined by a glycosidic linkage formed by a dehydration reaction.

dispersal The movement of individuals or gametes away from their parent location. This movement sometimes expands the geographic range of a population or species.

dispersion The pattern of spacing among individuals within the boundaries of a population.

disruptive selection Natural selection in which individuals on both extremes of a phenotypic range survive or reproduce more successfully than do individuals with intermediate phenotypes.

distal tubule In the vertebrate kidney, the portion of a nephron that helps refine filtrate and empties it into a collecting duct.

disturbance A natural or human-caused event that changes a biological community and usually removes organisms from it. Disturbances, such as fires and storms, play a pivotal role in structuring many communities.

disulfide bridge A strong covalent bond formed when the sulfur of one cysteine monomer bonds to the sulfur of another cysteine monomer.

DNA (deoxyribonucleic acid) (dē-ōk'-sē-rī'-bō-nū-klā'-ik) A nucleic acid molecule, usually a double-stranded helix, in which each polynucleotide strand consists of nucleotide monomers with a deoxyribose sugar and the nitrogenous bases adenine (A), cytosine (C), guanine (G), and thymine (T); capable of being replicated and determining the inherited structure of a cell's proteins.

DNA cloning The production of multiple copies of a specific DNA segment.

DNA ligase (li'-gās) A linking enzyme essential for DNA replication; catalyzes the covalent bonding of the 3' end of one DNA fragment (such as an Okazaki fragment) to the 5' end of another DNA fragment (such as a growing DNA chain).

DNA methylation The presence of methyl groups on the DNA bases (usually cytosine) of plants, animals, and fungi. (The term also refers to the process of adding methyl groups to DNA bases.)

DNA microarray assay A method to detect and measure the expression of thousands of genes at one time. Tiny amounts of a large number of single-stranded DNA fragments representing different genes are fixed to a glass slide and tested for hybridization with samples of labeled cDNA.

DNA polymerase (puh-lim'-er-ās) An enzyme that catalyzes the elongation of new DNA (for example, at a replication fork) by the addition of nucleotides to the 3' end of an existing chain. There are several different DNA polymerases; DNA polymerase III and DNA polymerase I play major roles in DNA replication in *E. coli*.

DNA replication The process by which a DNA molecule is copied; also called DNA synthesis.

DNA sequencing Determining the complete nucleotide sequence of a gene or DNA segment.

DNA technology Techniques for sequencing and manipulating DNA.

domain (1) A taxonomic category above the kingdom level. The three domains are Archaea, Bacteria, and Eukarya. (2) A discrete structural and functional region of a protein.

dominant allele An allele that is fully expressed in the phenotype of a heterozygote.

dormancy A condition typified by extremely low metabolic rate and a suspension of growth and development.

dorsal In an animal with bilateral symmetry, pertaining to the top (in most animals) or back (in animals with upright posture) of the body.

dorsal lip The region above the blastopore on the dorsal side of the amphibian embryo.

double bond A double covalent bond; the sharing of two pairs of valence electrons by two atoms.

double circulation A circulatory system consisting of separate pulmonary and systemic circuits, in which blood passes through the heart after completing each circuit.

double fertilization A mechanism of fertilization in angiosperms in which two sperm cells unite with two cells in the female gametophyte (embryo sac) to form the zygote and endosperm.

double helix The form of native DNA, referring to its two adjacent antiparallel polynucleotide strands wound around an imaginary axis into a spiral shape.

Down syndrome A human genetic disease usually caused by the presence of an extra chromosome 21; characterized by developmental delays and heart and other defects that are generally treatable or non-life-threatening.

Duchenne muscular dystrophy (duh-shen') A human genetic disease caused by a sex-linked recessive allele; characterized by progressive weakening and a loss of muscle tissue.

duodenum (dū'-uh-dēn'-um) The first section of the small intestine, where chyme from the stomach mixes with digestive juices from the pancreas, liver, and gallbladder as well as from gland cells of the intestinal wall.

duplication An aberration in chromosome structure due to fusion with a fragment from a homologous chromosome, such that a portion of a chromosome is duplicated.

dynein (di'-nē-un) In cilia and flagella, a large motor protein extending from one microtubule doublet to the adjacent doublet. ATP hydrolysis drives changes in dynein shape that lead to bending of cilia and flagella.

E site One of a ribosome's three binding sites for tRNA during translation. The E site is the place where discharged tRNAs leave the ribosome. (E stands for exit.)

Ecdysozoa (ek'-dē-sō-zō'-uh) One of the three main lineages of bilaterian animals; many ecdysozoans are molting animals. *See also* Deuterostomia and Lophotrochozoa.

echinoderm (i-kī'-nō-derm) A slow-moving or sessile marine deuterostome with a water vascular system and, in larvae, bilateral symmetry. Echinoderms include sea stars, brittle stars, sea urchins, feather stars, and sea cucumbers.

ecological footprint The aggregate land and water area required by a person, city, or nation to produce all of the resources it consumes and to absorb all of the waste it generates.

ecological niche (nich) The sum of a species' use of the biotic and abiotic resources in its environment.

ecological species concept Definition of a species in terms of ecological niche, the sum of how members of the species interact with the nonliving and living parts of their environment.

ecological succession Transition in the species composition of a community following a disturbance; establishment of a community in an area virtually barren of life.

ecology The study of how organisms interact with each other and their environment.

ecosystem All the organisms in a given area as well as the abiotic factors with which they interact; one or more communities and the physical environment around them.

ecosystem ecology The study of energy flow and the cycling of chemicals among the various biotic and abiotic components in an ecosystem.

ecosystem engineer An organism that influences community structure by causing physical changes in the environment.

ecosystem service A function performed by an ecosystem that directly or indirectly benefits humans.

ecotone The transition from one type of habitat or ecosystem to another, such as the transition from a forest to a grassland.

ectoderm (ek'-tō-durm) The outermost of the three primary germ layers in animal embryos; gives rise to the outer covering and, in some phyla, the nervous system, inner ear, and lens of the eye.

ectomycorrhiza (plural, **ectomycorrhizae**) (ek'-tō-mī'-kō-rī'-zuh, ek'-tō-mī'-kō-rī'-zē) Association of a fungus with a plant root system in which the fungus surrounds the roots but does not cause invagination of the host (plant) cell's plasma membrane.

ectomycorrhizal fungus A symbiotic fungus that forms sheaths of hyphae over the surface of plant roots and also grows into extracellular spaces of the root cortex.

ectoparasite A parasite that feeds on the external surface of a host.

ectopic Occurring in an abnormal location.

ectoproct A sessile, colonial lophotrochozoan; also called a bryozoan.

ectothermic Referring to organisms for which external sources provide most of the heat for temperature regulation.

Ediacaran biota (ē'-dē-uh-keh'-run bī-ō'-tuh) An early group of macroscopic, mostly soft-bodied, multicellular eukaryotes known from fossils that range in age from 635 million to 541 million years old.

effective population size An estimate of the size of a population based on the numbers of females and males that successfully breed; generally smaller than the total population.

effector A pathogen-encoded protein that cripples the host's innate immune system.

effector cell (1) A muscle cell or gland cell that carries out the body's response to stimuli as directed by signals from the brain or other processing center of the nervous system. (2) A lymphocyte that has undergone clonal selection and is capable of mediating an adaptive immune response.

egg The female gamete.

ejaculation The propulsion of sperm from the epididymis through the muscular vas deferens, ejaculatory duct, and urethra.

electrocardiogram (ECG or EKG) A record of the electrical impulses that travel through heart muscle during the cardiac cycle.

electrochemical gradient The diffusion gradient of an ion, which is affected by both the concentration difference of an ion across a membrane (a chemical force) and the ion's tendency to move relative to the membrane potential (an electrical force).

electrogenic pump An active transport protein that generates voltage across a membrane while pumping ions.

electromagnetic receptor A receptor of electromagnetic energy, such as visible light, electricity, or magnetism.

electromagnetic spectrum The entire spectrum of electromagnetic radiation, ranging in wavelength from less than a nanometer to more than a kilometer.

electron A subatomic particle with a single negative electrical charge and a mass about 1/2,000 that of a neutron or proton. One or more electrons move around the nucleus of an atom.

electron microscope (EM) A microscope that uses magnets to focus an electron beam on or through a specimen, resulting in a practical resolution that is 100-fold greater than that of a light microscope using standard techniques. A transmission electron microscope (TEM) is used to study the internal structure of thin sections of cells. A scanning electron microscope (SEM) is used to study the fine details of cell surfaces.

electron shell An energy level of electrons at a characteristic average distance from the nucleus of an atom.

electron transport chain A sequence of electron carrier molecules (membrane proteins) that shuttle electrons down a series of redox reactions that release energy used to make ATP.

electronegativity The attraction of a given atom for the electrons of a covalent bond.

electroporation A technique to introduce recombinant DNA into cells by applying a brief electrical pulse to a solution containing the cells. The pulse creates temporary holes in the cells' plasma membranes, through which DNA can enter.

element Any substance that cannot be broken down to any other substance by chemical reactions.

elimination The fourth and final stage of food processing in animals: the passing of undigested material out of the body.

embryo sac (em'-brē-ō) The female gametophyte of angiosperms, formed from the growth and division of the megasporangium into a multicellular structure that typically has eight haploid nuclei.

embryonic lethal A mutation with a phenotype leading to death of an embryo or larva.

embryophyte Alternate name for land plants that refers to their shared derived trait of multicellular, dependent embryos.

emergent properties New properties that arise with each step upward in the hierarchy of life,

owing to the arrangement and interactions of parts as complexity increases.

emigration The movement of individuals out of a population.

enantiomer (en-an'-tē-ō-mer) One of two compounds that are mirror images of each other and that differ in shape due to the presence of an asymmetric carbon.

endangered species A species that is in danger of extinction throughout all or a significant portion of its range.

endemic (en-dem'-ik) Referring to a species that is confined to a specific geographic area.

endergonic reaction (en'-der-gon'-ik) A non-spontaneous chemical reaction in which free energy is absorbed from the surroundings.

endocrine gland (en'-dō-krin) A ductless gland that secretes hormones directly into the interstitial fluid, from which they diffuse into the bloodstream.

endocrine system (en'-dō-krin) In animals, the internal system of communication involving hormones, the ductless glands that secrete hormones, and the molecular receptors on or in target cells that respond to hormones; functions in concert with the nervous system to effect internal regulation and maintain homeostasis.

endocytosis (en'-dō-sī-tō'-sis) Cellular uptake of biological molecules and particulate matter via formation of vesicles from the plasma membrane.

endoderm (en'-dō-durm) The innermost of the three primary germ layers in animal embryos; lines the archenteron and gives rise to the liver, pancreas, lungs, and the lining of the digestive tract in species that have these structures.

endodermis In plant roots, the innermost layer of the cortex that surrounds the vascular cylinder.

endomembrane system The collection of membranes inside and surrounding a eukaryotic cell, related either through direct physical contact or by the transfer of membranous vesicles; includes the plasma membrane, the nuclear envelope, the smooth and rough endoplasmic reticulum, the Golgi apparatus, lysosomes, vesicles, and vacuoles.

endometriosis (en'-dō-mē-trē-ō'-sis) The condition resulting from the presence of endometrial tissue outside of the uterus.

endometrium (en'-dō-mē'-trē-ūm) The inner lining of the uterus, which is richly supplied with blood vessels.

endoparasite A parasite that lives within a host.

endophyte A harmless fungus, or occasionally another organism, that lives between cells of a plant part or multicellular alga.

endoplasmic reticulum (ER) (en'-dō-plaz'-mik ruh-tik'-yū-lum) An extensive membranous network in eukaryotic cells, continuous with the outer nuclear membrane and composed of ribosome-studded (rough) and ribosome-free (smooth) regions.

endorphin (en-dōr'-fin) Any of several hormones produced in the brain and anterior pituitary that inhibit pain perception.

endoskeleton A hard skeleton buried within the soft tissues of an animal.

endosperm In angiosperms, a nutrient-rich tissue formed by the union of a sperm with

- two polar nuclei during double fertilization.** The endosperm provides nourishment to the developing embryo in angiosperm seeds.
- endospore** A thick-coated, resistant cell produced by some bacterial cells when they are exposed to harsh conditions.
- endosymbiont theory** The theory that mitochondria and plastids originated as prokaryotic cells engulfed by a host cell. The engulfed cell and its host cell then evolved into a single organism. *See also* endosymbiosis.
- endosymbiosis** A relationship between two species in which one organism lives inside the cell or cells of another organism. *See also* endosymbiont theory.
- endothelium** (en'-dō-thē'-lē-ūm) The simple squamous layer of cells lining the lumen of blood vessels.
- endothermic** Referring to organisms that are warmed by heat generated by their own metabolism. This heat usually maintains a relatively stable body temperature higher than that of the external environment.
- endotoxin** A toxic component of the outer membrane of certain gram-negative bacteria that is released only when the bacteria die.
- energetic hypothesis** The concept that the length of a food chain is limited by the inefficiency of energy transfer along the chain.
- energy** The capacity to cause change, especially to do work (to move matter against an opposing force).
- energy coupling** In cellular metabolism, the use of energy released from an exergonic reaction to drive an endergonic reaction.
- enhancer** A segment of eukaryotic DNA containing multiple control elements, usually located far from the gene whose transcription it regulates.
- enteric nervous system** Within the autonomic nervous system, a distinct network of neurons that exerts partially independent control over the digestive tract, pancreas, and gallbladder.
- entropy** A measure of molecular disorder, or randomness.
- enzyme** (en'-zim) A macromolecule serving as a catalyst, a chemical agent that increases the rate of a reaction without being consumed by the reaction. Most enzymes are proteins.
- enzyme-substrate complex** (en'-zim) A temporary complex formed when an enzyme binds to its substrate molecule(s).
- eosinophil** Immune system cell that secretes destructive enzymes and helps defend against multicellular pathogens.
- epicotyl** (ep'-uh-kot'-ul) In an angiosperm embryo, the embryonic axis above the point of attachment of the cotyledon(s) and below the first pair of miniature leaves.
- epidemic** A widespread outbreak of a disease.
- epidermis** (1) The dermal tissue of nonwoody plants, usually consisting of a single layer of tightly packed cells. (2) The outermost layer of cells in an animal.
- epididymis** (ep'-uh-did'-uh-mus) A coiled tubule located adjacent to the mammalian testis where sperm are stored.
- epigenetics** The study of the inheritance of traits transmitted by mechanisms that do not involve the nucleotide sequence.
- epinephrine** (ep'-i-nef'-rin) A catecholamine that, when secreted as a hormone by the adrenal medulla, mediates “fight-or-flight” responses to short-term stresses; also released by some neurons as a neurotransmitter; also called adrenaline.
- epiphyte** (ep'-uh-fit) A plant that nourishes itself but grows on the surface of another plant for support, usually on the branches or trunks of trees.
- epistasis** (ep'-i-stā'-sis) A type of gene interaction in which the phenotypic expression of one gene alters that of another independently inherited gene.
- epithelial tissue** (ep'-uh-thē'-lē-ūl) Sheets of tightly packed cells that line organs and body cavities as well as external surfaces.
- epithelium** (plural, **epithelia**) An epithelial tissue.
- epitope** A small, accessible region of an antigen to which an antigen receptor or antibody binds.
- equilibrium potential (E_{ion})** The magnitude of a cell’s membrane voltage at equilibrium; calculated using the Nernst equation.
- erythrocyte** (eh-rith'-ruh-sīt) A blood cell that contains hemoglobin, which transports oxygen; also called a red blood cell.
- erythropoietin (EPO)** (eh-rith'-rō-poy'-uh-tin) A hormone that stimulates the production of erythrocytes. It is secreted by the kidney when body tissues do not receive enough oxygen.
- esophagus** (eh-sof'-uh-gus) A muscular tube that conducts food, by peristalsis, from the pharynx to the stomach.
- essential amino acid** An amino acid that an animal cannot synthesize itself and must be obtained from food in prefabricated form.
- essential element** A chemical element required for an organism to survive, grow, and reproduce.
- essential fatty acid** An unsaturated fatty acid that an animal needs but cannot make.
- essential nutrient** A substance that an organism cannot synthesize from any other material and therefore must absorb in preassembled form.
- estradiol** (es'-truh-di'-ol) A steroid hormone that stimulates the development and maintenance of the female reproductive system and secondary sex characteristics; the major estrogen in mammals.
- estrogen** (es'-trō-jen) Any steroid hormone, such as estradiol, that stimulates the development and maintenance of the female reproductive system and secondary sex characteristics.
- estrous cycle** (es'-trus) A reproductive cycle characteristic of female mammals except humans and certain other primates, in which the endometrium is reabsorbed in the absence of pregnancy and sexual response occurs only during a mid-cycle point known as estrus.
- estuary** The area where a freshwater stream or river merges with the ocean.
- ethylene** (eth'-uh-lēn) A gaseous plant hormone involved in responses to mechanical stress, programmed cell death, leaf abscission, and fruit ripening.
- etiolation** Plant morphological adaptations for growing in darkness.
- euchromatin** (yū-krō'-muh-tin) The less condensed form of eukaryotic chromatin that is available for transcription.
- eudicot** (yū-dī'-kot) A member of a clade that contains the vast majority of flowering plants that have two embryonic seed leaves, or cotyledons.
- euglenid** (yū'-glen-id) A protist, such as *Euglena* or its relatives, characterized by an anterior pocket from which one or two flagella emerge.
- euglenozoan** A member of a diverse clade of flagellated protists that includes predatory heterotrophs, photosynthetic autotrophs, and pathogenic parasites.
- Eukarya** (yū-kār'-ē-uh) The domain that includes all eukaryotic organisms.
- eukaryote** A single-celled or multicellular organism comprised of eukaryotic cells; eukaryotes include protists, plants, fungi, and animals.
- eukaryotic cell** (yū'-kār-ē-ot'-ik) A type of cell with a membrane-enclosed nucleus and membrane-enclosed organelles. Organisms with eukaryotic cells (protists, plants, fungi, and animals) are called eukaryotes.
- eumetazoan** (yū'-met-uh-zō'-un) A member of a clade of animals with true tissues. All animals except sponges and a few other groups are eumetazoans.
- eurypterid** (yur-ip'-tuh-rid) An extinct carnivorous chelicerate; also called a water scorpion.
- Eustachian tube** (yū-stā'-shun) The tube that connects the middle ear to the pharynx.
- eutherian** (yū-thēr'-ē-un) Placental mammal; mammal whose young complete their embryonic development within the uterus, joined to the mother by the placenta.
- eutrophic lake** (yū-trōf'-ik) A lake that has a high rate of biological productivity supported by a high rate of nutrient cycling.
- eutrophication** A process by which nutrients, particularly phosphorus and nitrogen, become highly concentrated in a body of water, leading to increased growth of organisms such as algae or cyanobacteria.
- evaporative cooling** The process in which the surface of an object becomes cooler during evaporation, a result of the molecules with the greatest kinetic energy changing from the liquid to the gaseous state.
- evapotranspiration** The total evaporation of water from an ecosystem, including water transpired by plants and evaporated from a landscape, usually measured in millimeters and estimated for a year.
- evo-devo** Evolutionary developmental biology; a field of biology that compares developmental processes of different multicellular organisms to understand how these processes have evolved and how changes can modify existing organismal features or lead to new ones.
- evolution** Descent with modification; the process by which species accumulate differences from their ancestors as they adapt to different environments over time; also defined as a change in the genetic composition of a population from generation to generation.
- evolutionary lineage** The sequence of ancestral organisms leading to a particular taxon;

represented by a branch (line) in a phylogenetic tree.

evolutionary tree A branching diagram that reflects a hypothesis about evolutionary relationships among groups of organisms.

Excavata (ex'-kuh-vah'-tuh) One of four supergroups of eukaryotes proposed in a current hypothesis of the evolutionary history of eukaryotes. Excavates have unique cytoskeletal features, and some species have an “excavated” feeding groove on one side of the cell body. See also SAR, Archaeplastida, and Unikonta.

excitatory postsynaptic potential (EPSP) An electrical change (depolarization) in the membrane of a postsynaptic cell caused by the binding of an excitatory neurotransmitter from a presynaptic cell to a postsynaptic receptor; makes it more likely for a postsynaptic cell to generate an action potential.

excretion The disposal of nitrogen-containing metabolites and other waste products.

exergonic reaction (ek'-ser-gon'-ik) A spontaneous chemical reaction in which there is a net release of free energy.

exocytosis (ek'-sō-sī-tō'-sis) The cellular secretion of biological molecules by the fusion of vesicles containing them with the plasma membrane.

exon A sequence within a primary transcript that remains in the RNA after RNA processing; also refers to the region of DNA from which this sequence was transcribed.

exoskeleton A hard encasement on the surface of an animal, such as the shell of a mollusc or the cuticle of an arthropod, that provides protection and points of attachment for muscles.

exotoxin (ek'-sō-tok'-sin) A toxic protein that is secreted by a prokaryote or other pathogen and that produces specific symptoms, even if the pathogen is no longer present.

expansin Plant enzyme that breaks the cross-links (hydrogen bonds) between cellulose microfibrils and other cell wall constituents, loosening the wall's fabric.

experiment A scientific test. Often carried out under controlled conditions that involve manipulating one factor in a system in order to see the effects of changing that factor.

experimental group A set of subjects that has (or receives) the specific factor being tested in a controlled experiment. Ideally, the experimental group is identical to the control group for all other factors.

exploitation A +/- ecological interaction in which individuals of one species benefit by feeding on (and thereby harming) individuals of the other species. Exploitative interactions include predation, herbivory, and parasitism.

exponential population growth Growth of a population in an ideal, unlimited environment, represented by a J-shaped curve when population size is plotted over time.

expression vector A cloning vector that contains a highly active bacterial promoter just upstream of a restriction site where a eukaryotic gene can be inserted, allowing the gene to be expressed in a bacterial cell. Expression vectors are also available that have been genetically engineered for use in specific types of eukaryotic cells.

extinction vortex A downward population spiral in which inbreeding and genetic drift

combine to cause a small population to shrink and, unless the spiral is reversed, become extinct.

extracellular matrix (ECM) The meshwork surrounding animal cells, consisting of glycoproteins, polysaccharides, and proteoglycans synthesized and secreted by cells.

extraembryonic membrane One of four membranes (yolk sac, amnion, chorion, and allantois) located outside the embryo that support the developing embryo in reptiles and mammals.

extreme halophile An organism that lives in a highly saline environment, such as the Great Salt Lake or the Dead Sea.

extreme thermophile An organism that thrives in hot environments (often 60–80°C or hotter).

extremophile An organism that lives in environmental conditions so extreme that few other species can survive there. Extremophiles include extreme halophiles (“salt lovers”) and extreme thermophiles (“heat lovers”).

F₁ generation The first filial, hybrid (heterozygous) offspring arising from a parental (P generation) cross.

F₂ generation The offspring resulting from interbreeding (or self-pollination) of the hybrid F₁ generation.

facilitated diffusion The passage of molecules or ions down their electrochemical gradient across a biological membrane with the assistance of specific transmembrane transport proteins, requiring no energy expenditure.

facultative anaerobe (fak'-ul-tā'-tiv an'-uh-rōb) An organism that makes ATP by aerobic respiration if oxygen is present but that switches to anaerobic respiration or fermentation if oxygen is not present.

family In Linnaean classification, the taxonomic category above genus.

fast-twitch fiber A muscle fiber used for rapid, powerful contractions.

fat A lipid consisting of three fatty acids linked to one glycerol molecule; also called a triacylglycerol or triglyceride.

fate map A territorial diagram of embryonic development that displays the future derivatives of individual cells and tissues.

fatty acid A carboxylic acid with a long carbon chain. Fatty acids vary in length and in the number and location of double bonds; three fatty acids linked to a glycerol molecule form a fat molecule, also called triacylglycerol or triglyceride.

feces (fē'-sēz) The wastes of the digestive tract.

feedback inhibition A method of metabolic control in which the end product of a metabolic pathway acts as an inhibitor of an enzyme within that pathway.

feedback regulation The regulation of a process by its output or end product.

fermentation A catabolic process that makes a limited amount of ATP from glucose (or other organic molecules) without an electron transport chain and that produces a characteristic end product, such as ethyl alcohol or lactic acid.

fertilization (1) The union of haploid gametes to produce a diploid zygote. (2) The addition of mineral nutrients to the soil.

fetus (fē'-tus) A developing mammal that has all the major structures of an adult. In humans, the fetal stage lasts from the 9th week of gestation until birth.

factor In bacteria, the DNA segment that confers the ability to form pili for conjugation and associated functions required for the transfer of DNA from donor to recipient. The F factor may exist as a plasmid or be integrated into the bacterial chromosome.

fibroblast (fī'-brō-blast) A type of cell in loose connective tissue that secretes the protein ingredients of the extracellular fibers.

fibronectin An extracellular glycoprotein secreted by animal cells that helps them attach to the extracellular matrix.

filament In an angiosperm, the stalk portion of the stamen, the pollen-producing reproductive organ of a flower.

filter feeder An animal that feeds by using a filtration mechanism to strain small organisms or food particles from its surroundings.

filtrate Cell-free fluid extracted from the body fluid by the excretory system.

filtration In excretory systems, the extraction of water and small solutes, including metabolic wastes, from the body fluid.

fimbria (plural, **fimbriae**) A short, hairlike appendage of a prokaryotic cell that helps it adhere to the substrate or to other cells.

first law of thermodynamics The principle of conservation of energy: Energy can be transferred and transformed, but it cannot be created or destroyed.

fission The separation of an organism into two or more individuals of approximately equal size.

fixed action pattern In animal behavior, a sequence of unlearned acts that is essentially unchangeable and, once initiated, usually carried to completion.

flaccid (flas'-id) Limp. Lacking turgor (stiffness or firmness), as in a plant cell in surroundings where there is a tendency for water to leave the cell. (A walled cell becomes flaccid if it has a higher water potential than its surroundings, resulting in the loss of water.)

flagellum (fluh-jel'-um) (plural, **flagella**) A long cellular appendage specialized for locomotion. Like motile cilia, eukaryotic flagella have a core with nine outer doublet microtubules and two inner single microtubules (the “9 + 2” arrangement) ensheathed in an extension of the plasma membrane. Prokaryotic flagella have a different structure.

florigen A flowering signal, probably a protein, that is made in leaves under certain conditions and that travels to the shoot apical meristems, inducing them to switch from vegetative to reproductive growth.

flower In an angiosperm, a specialized shoot with up to four sets of modified leaves, bearing structures that function in sexual reproduction.

fluid feeder An animal that lives by sucking nutrient-rich fluids from another living organism.

fluid mosaic model The currently accepted model of cell membrane structure, which envisions the membrane as a mosaic of protein molecules drifting laterally in a fluid bilayer of phospholipids.

follicle (fol'-uh-kul) A microscopic structure in the ovary that contains the developing oocyte and secretes estrogens.

follicle-stimulating hormone (FSH) (fol'-uh-kul) A tropic hormone that is produced and secreted by the anterior pituitary and that stimulates the production of eggs by the ovaries and sperm by the testes.

food chain The pathway along which food energy is transferred from trophic level to trophic level, beginning with producers.

food vacuole A membranous sac formed by phagocytosis of microorganisms or particles to be used as food by the cell.

food web The interconnected feeding relationships in an ecosystem.

foot (1) The portion of a bryophyte sporophyte that gathers sugars, amino acids, water, and minerals from the parent gametophyte via transfer cells. (2) One of the three main parts of a mollusc; a muscular structure usually used for movement. *See also* mantle and visceral mass.

foraging The seeking and obtaining of food.

foram (foraminiferan) An aquatic protist that secretes a hardened shell containing calcium carbonate and extends pseudopodia through pores in the shell.

forebrain One of three ancestral and embryonic regions of the vertebrate brain; develops into the thalamus, hypothalamus, and cerebrum.

fossil A preserved remnant or impression of an organism that lived in the past.

foundation species A species that has strong effects on its community as a result of its large size, high abundance, or pivotal role in community dynamics. Foundation species may provide significant habitat or food for other species; they may also be competitively dominant in exploiting key resources.

founder effect Genetic drift that occurs when a few individuals become isolated from a larger population and form a new population whose gene pool composition is not reflective of that of the original population.

fovea (fō'-vē-uh) The place on the retina at the eye's center of focus, where cones are highly concentrated.

F plasmid The plasmid form of the F factor.

fragmentation A means of asexual reproduction whereby a single parent breaks into parts that regenerate into whole new individuals.

frameshift mutation A mutation occurring when nucleotides are inserted in or deleted from a gene and the number inserted or deleted is not a multiple of three, resulting in the improper grouping of the subsequent nucleotides into codons.

free energy The portion of a biological system's energy that can perform work when temperature and pressure are uniform throughout the system. The change in free energy of a system (ΔG) is calculated by the equation $\Delta G = \Delta H - T\Delta S$, where ΔH is the change in enthalpy (in biological systems, equivalent to total energy), T is the absolute temperature, and ΔS is the change in entropy.

frequency-dependent selection Selection in which the fitness of a phenotype depends on how common the phenotype is in a population.

fruit A mature ovary of a flower. The fruit protects dormant seeds and often functions in their dispersal.

functional group A specific configuration of atoms commonly attached to the carbon skeletons of organic molecules and involved in chemical reactions.

fusion In evolutionary biology, a process in which gene flow between two species that can form hybrid offspring weakens barriers to reproduction between the species. This process causes their gene pools to become increasingly alike and can cause the two species to fuse into a single species.

G₀ phase A nondividing state occupied by cells that have left the cell cycle, sometimes reversibly.

G₁ phase The first gap, or growth phase, of the cell cycle, consisting of the portion of interphase before DNA synthesis begins.

G₂ phase The second gap, or growth phase, of the cell cycle, consisting of the portion of interphase after DNA synthesis occurs.

gallbladder An organ that stores bile and releases it as needed into the small intestine.

game theory An approach to evaluating alternative strategies in situations where the outcome of a particular strategy depends on the strategies used by other individuals.

gametangium (gam'-uh-tan'-jē-um) (plural, **gametangia**) Multicellular plant structure in which gametes are formed. Female gametangia are called archegonia, and male gametangia are called antheridia.

gamete (gam'-ēt) A haploid reproductive cell, such as an egg or sperm, that is formed by meiosis or is the descendant of cells formed by meiosis. Gametes unite during sexual reproduction to produce a diploid zygote.

gametogenesis (guh-mē'-tō-gen'-uh-sis) The process by which gametes are produced.

gametophyte (guh-mē'-tō-fit) In organisms (plants and some algae) that have alternation of generations, the multicellular haploid form that produces haploid gametes by mitosis. The haploid gametes unite and develop into sporophytes.

ganglion (gan'-glē-uhn) (plural, **ganglia**) A cluster (functional group) of nerve cell bodies.

gap junction A type of intercellular junction in animal cells, consisting of proteins surrounding a pore that allows the passage of materials between cells.

gas exchange The uptake of molecular oxygen from the environment and the discharge of carbon dioxide to the environment.

gastric juice A digestive fluid secreted by the stomach.

gastrovascular cavity A central cavity with a single opening in the body of certain animals, including cnidarians and flatworms, that functions in both the digestion and distribution of nutrients.

gastrula (gas'-trū-luh) An embryonic stage in animal development encompassing the formation of three layers: ectoderm, mesoderm, and endoderm.

gastrulation (gas'-trū-lā'-shun) In animal development, a series of cell and tissue movements in which the blastula-stage embryo folds inward, producing a three-layered embryo, the gastrula.

gated channel A transmembrane protein channel that opens or closes in response to a particular stimulus.

gated ion channel A gated channel for a specific ion. The opening or closing of such channels may alter a cell's membrane potential.

gel electrophoresis (ē-lek'-trō-fōr-ē'-sis) A technique for separating nucleic acids or proteins on the basis of their size and electrical charge, both of which affect their rate of movement through an electric field in a gel made of agarose or another polymer.

gene A discrete unit of hereditary information consisting of a specific nucleotide sequence in DNA (or RNA, in some viruses).

gene annotation Analysis of genomic sequences to identify protein-coding genes and determine the function of their products.

gene cloning The production of multiple copies of a gene.

gene drive A process that biases inheritance such that a particular allele is more likely to be inherited than are other alleles, causing the favored allele to spread (be "driven") through the population.

gene editing Altering genes in a specific, predictable way.

gene expression The process by which information encoded in DNA directs the synthesis of proteins or, in some cases, RNAs that are not translated into proteins and instead function as RNAs.

gene flow The transfer of alleles from one population to another, resulting from the movement of fertile individuals or their gametes.

gene pool The aggregate of all copies of every type of allele at all loci in every individual in a population. The term is also used in a more restricted sense as the aggregate of alleles for just one or a few loci in a population.

gene therapy The introduction of genes into an afflicted individual for therapeutic purposes.

genetic drift A process in which chance events cause unpredictable fluctuations in allele frequencies from one generation to the next. Effects of genetic drift are most pronounced in small populations.

genetic engineering The direct manipulation of genes for practical purposes.

genetic map An ordered list of genetic loci (genes or other genetic markers) along a chromosome.

genetic profile An individual's unique set of genetic markers, detected most often today by PCR or, previously, by electrophoresis and nucleic acid probes.

genetic recombination General term for the production of offspring with combinations of traits that differ from those found in either parent.

genetic variation Differences among individuals in the composition of their genes or other DNA sequences.

genetically modified organism (GMO) An organism that has acquired one or more genes by artificial means.

genetics The scientific study of heredity and hereditary variation.

genome (jē'-nōm) The genetic material of an organism or virus; the complete complement

of an organism's or virus's genes along with its noncoding nucleic acid sequences.

genome-wide association study (jē'-nōm)

A large-scale analysis of the genomes of many people having a certain phenotype or disease, with the aim of finding genetic markers that correlate with that phenotype or disease.

genomic imprinting (juh-nō'-mik) A phenomenon in which expression of an allele in offspring depends on whether the allele is inherited from the male or female parent.

genomics (juh-nō'-miks) The systematic study of whole sets of genes (or other DNA) and their interactions within a species, as well as genome comparisons between species.

genotype (jē'-nō-tip) The genetic makeup, or set of alleles, of an organism.

genus (jē'-nus) (plural, **genera**) A taxonomic category above the species level, designated by the first word of a species' two-part scientific name.

geologic record A standard time scale dividing Earth's history into time periods, grouped into four eons—Hadean, Archaean, Proterozoic, and Phanerozoic—and further subdivided into eras, periods, and epochs.

germ layer One of the three main layers in a gastrula that will form the various tissues and organs of an animal body.

gestation (jes-tā'-shun) Pregnancy; the condition of carrying one or more embryos in the uterus.

gibberellin (jib'-uh-rel'-in) Any of a class of related plant hormones that stimulate growth in the stem and leaves, trigger the germination of seeds and breaking of bud dormancy, and (with auxin) stimulate fruit development.

glans In humans, the rounded head of the penis (in males) or of the clitoris (in females); the glans is highly sensitive to stimulation.

glia (glial cells) Cells of the nervous system that support, regulate, and augment the functions of neurons.

global ecology The study of the functioning and distribution of organisms across the biosphere and how the regional exchange of energy and materials affects them.

glomeromycete (glō'-mer-ō-mī'-sēt) A member of the fungal phylum Glomeromycota, characterized by a distinct branching form of mycorrhizae called arbuscular mycorrhizae.

glomerulus (glō-mär'-yū-lus) A ball of capillaries surrounded by Bowman's capsule in the nephron and serving as the site of filtration in the vertebrate kidney.

glucocorticoid A steroid hormone that is secreted by the adrenal cortex and that influences glucose metabolism and immune function.

glucagon (glü'-kuh-gon) A hormone secreted by the pancreas that raises blood glucose levels. It promotes glycogen breakdown and release of glucose by the liver.

glyceraldehyde 3-phosphate (G3P) (glis'-er-al'-de-hid) A three-carbon carbohydrate that is the direct product of the Calvin cycle; it is also an intermediate in glycolysis.

glycogen (gli'-kō-jen) An extensively branched glucose storage polysaccharide found in the liver and muscle of animals; the animal equivalent of starch.

glycolipid A lipid with one or more covalently attached carbohydrates.

glycolysis (gli-kol'-uh-sis) A series of reactions that ultimately splits glucose into pyruvate. Glycolysis occurs in almost all living cells, serving as the starting point for fermentation or cellular respiration.

glycoprotein A protein with one or more covalently attached carbohydrates.

glycosidic linkage A covalent bond formed between two monosaccharides by a dehydration reaction.

gnathostome (na'-thu-stōm) Member of one of the two main clades of vertebrates; gnathostomes have jaws and include sharks and rays, ray-finned fishes, coelacanths, lungfishes, amphibians, reptiles, and mammals. *See also cyclostome.*

Golgi apparatus (gol'-jē) An organelle in eukaryotic cells consisting of stacks of flat membranous sacs that modify, store, and route products of the endoplasmic reticulum and synthesize some products, notably non-cellulose carbohydrates.

gonad (gō'-nad) A male or female gamete-producing organ.

G protein A GTP-binding protein that relays signals from a plasma membrane signal receptor, known as a G protein-coupled receptor, to other signal transduction proteins inside the cell.

G protein-coupled receptor (GPCR) A signal receptor protein in the plasma membrane that responds to the binding of a signaling molecule by activating a G protein. Also called a G protein-linked receptor.

graded potential An electrical response of a cell to a stimulus, consisting of a change in voltage across the membrane proportional to the stimulus strength.

Gram stain A staining method that distinguishes between two different kinds of bacterial cell walls; may be used to help determine medical response to an infection.

gram-negative Describing the group of bacteria that have a cell wall that is structurally more complex and contains less peptidoglycan than the cell wall of gram-positive bacteria. Gram-negative bacteria are often more toxic than gram-positive bacteria.

gram-positive Describing the group of bacteria that have a cell wall that is structurally less complex and contains more peptidoglycan than the cell wall of gram-negative bacteria. Gram-positive bacteria are usually less toxic than gram-negative bacteria.

grana (gran'-um) (plural, **grana**) A stack of membrane-bounded thylakoids in the chloroplast. Grana function in the light reactions of photosynthesis.

gravitropism (grav'-uh-trō'-pizm) A response of a plant or animal to gravity.

gray matter Regions of clustered neuron cell bodies within the CNS.

green alga A photosynthetic protist, named for green chloroplasts that are similar in structure and pigment composition to the chloroplasts of plants. Green algae are a paraphyletic group; some members are more closely related to plants than they are to other green algae.

greenhouse effect The warming of Earth due to the atmospheric accumulation of carbon dioxide and certain other gases, which absorb

reflected infrared radiation and reradiate some of it back toward Earth.

gross primary production (GPP) The total primary production of an ecosystem.

ground tissue Plant tissue that is neither vascular nor dermal, fulfilling a variety of functions, such as storage, photosynthesis, and support.

growth factor (1) A protein that must be present in the extracellular environment (culture medium or animal body) for the growth and normal development of certain types of cells. (2) A local regulator that acts on nearby cells to stimulate cell proliferation and differentiation.

growth hormone (GH) A hormone that is produced and secreted by the anterior pituitary and that has both direct (nontropic) and tropic effects on a wide variety of tissues.

guard cells The two cells that flank the stomatal pore and regulate the opening and closing of the pore.

gustation The sense of taste.

guttation The exudation of water droplets from leaves, caused by root pressure in certain plants.

gymnosperm (jim'-nō-sperm) A vascular plant that bears naked seeds—seeds not enclosed in protective chambers.

hagfish Marine jawless vertebrates that have highly reduced vertebrae and a skull made of cartilage; most hagfishes are bottom-dwelling scavengers.

hair cell A mechanosensory cell that alters output to the nervous system when hairlike projections on the cell surface are displaced.

half-life The amount of time it takes for 50% of a sample of a radioactive isotope to decay.

halophile *See* extreme halophile.

Hamilton's rule The principle that for natural selection to favor an altruistic act, the benefit to the recipient, devalued by the coefficient of relatedness, must exceed the cost to the altruist.

haploid cell (hap'-loyd) A cell containing only one set of chromosomes (n).

Hardy-Weinberg equilibrium The state of a population in which frequencies of alleles and genotypes remain constant from generation to generation, provided that only Mendelian segregation and recombination of alleles are at work.

heart A muscular pump that uses metabolic energy to elevate the hydrostatic pressure of the circulatory fluid (blood or hemolymph). The fluid then flows down a pressure gradient through the body and eventually returns to the heart.

heart attack The damage or death of cardiac muscle tissue resulting from prolonged blockage of one or more coronary arteries.

heart murmur A hissing sound that most often results from blood squirting backward through a leaky valve in the heart.

heart rate The frequency of heart contraction (in beats per minute).

heat Thermal energy in transfer from one body of matter to another.

heat of vaporization The quantity of heat a liquid must absorb for 1 g of it to be converted from the liquid to the gaseous state.

heat-shock protein A protein that helps protect other proteins during heat stress.

- Heat-shock proteins** are found in plants, animals, and microorganisms.
- heavy chain** One of the two types of polypeptide chains that make up an antibody molecule and B cell receptor; consists of a variable region, which contributes to the antigen-binding site, and a constant region.
- helicase** An enzyme that untwists the double helix of DNA at replication forks, separating the two strands and making them available as template strands.
- helper T cell** A type of T cell that, when activated, secretes cytokines that promote the response of B cells (humoral response) and cytotoxic T cells (cell-mediated response) to antigens.
- hemocoel** A body cavity lined by tissue derived from mesoderm and by tissue derived from endoderm.
- hemoglobin** (hē'-mō-glō'-bin) An iron-containing protein in red blood cells that reversibly binds oxygen.
- hemolymph** (hē'-mō-limf') In invertebrates with an open circulatory system, the body fluid that bathes tissues.
- hemophilia** (hē'-muh-fil'-ē-uh) A human genetic disease caused by a sex-linked recessive allele resulting in the absence of one or more blood-clotting proteins; characterized by excessive bleeding following injury.
- hepatic portal vein** A large vessel that conveys nutrient-laden blood from the small intestine to the liver, which regulates the blood's nutrient content.
- herbivore** (hur'-bi-vör') An animal that mainly eats plants or algae.
- herbivory** A +/- ecological interaction in which an organism eats part of a plant or alga.
- heredity** The transmission of traits from one generation to the next.
- hermaphrodite** (hur-maf'-ruh-dit') An individual that functions as both male and female in sexual reproduction by producing both sperm and eggs.
- hermaphroditism** (hur-maf'-rō-dī-tizm) A condition in which an individual has both female and male gonads and functions as both a male and a female in sexual reproduction by producing both sperm and eggs.
- heterochromatin** (het'-er-ō-krō'-muh-tin) Eukaryotic chromatin that remains highly compacted during interphase and is generally not transcribed.
- heterochrony** (het'-uh-rok'-ruh-nē) Evolutionary change in the timing or rate of an organism's development.
- heterocyst** (het'-er-ō-sist) A specialized cell that engages in nitrogen fixation in some filamentous cyanobacteria; also called a heterocyte.
- heterokaryon** (het'-er-ō-kār'-ē-un) A fungal mycelium that contains two or more haploid nuclei per cell.
- heteromorphic** (het'-er-ō-mōr'-fik) Referring to a condition in the life cycle of plants and certain algae in which the sporophyte and gametophyte generations differ in morphology.
- heterosporous** (het-er-os'-pōr-us) Referring to a plant species that has two kinds of spores: microspores, which develop into male gametophytes, and megasporangia, which develop into female gametophytes.
- heterotroph** (het'-er-ō-trōf) An organism that obtains organic food molecules by eating other organisms or substances derived from them.
- heterozygote** An organism that has two different alleles for a gene (encoding a character).
- heterozygote advantage** Greater reproductive success of heterozygous individuals compared with homozygotes; tends to preserve variation in a gene pool.
- heterozygous** (het'-er-ō-zī'-gus) Having two different alleles for a given gene.
- hibernation** A long-term physiological state in which metabolism decreases, the heart and respiratory system slow down, and body temperature is maintained at a lower level than normal.
- high-density lipoprotein (HDL)** A particle in the blood made up of thousands of cholesterol molecules and other lipids bound to a protein. HDL scavenges excess cholesterol.
- hindbrain** One of three ancestral and embryonic regions of the vertebrate brain; develops into the medulla oblongata, pons, and cerebellum.
- histamine** (his'-tuh-mēn) A substance released by mast cells that causes blood vessels to dilate and become more permeable in inflammatory and allergic responses.
- histogram** A variant of a bar graph that is made for numeric data by first grouping, or "binning," the variable plotted on the x-axis into intervals of equal width. The "bins" may be integers or ranges of numbers. The height of each bar shows the percent or number of experimental subjects whose characteristics can be described by one of the intervals plotted on the x-axis.
- histone** (his'-tōn) A small protein with a high proportion of positively charged amino acids that binds to the negatively charged DNA and plays a key role in chromatin structure.
- histone acetylation** (his'-tōn) The attachment of acetyl groups to certain amino acids of histone proteins.
- HIV (human immunodeficiency virus)** The infectious agent that causes AIDS. HIV is a retrovirus.
- holdfast** A rootlike structure that anchors a seaweed.
- homeobox** (hō'-mē-ō-boks') A 180-nucleotide sequence within homeotic genes and some other developmental genes that is widely conserved in animals. Related sequences occur in plants and yeasts.
- homeostasis** (hō'-mē-ō-stā'-sis) The steady-state physiological condition of the body.
- homeotic gene** (hō'-mē-ō'-tik) Any of the master regulatory genes that control placement and spatial organization of body parts in animals, plants, and fungi by controlling the developmental fate of groups of cells.
- hominin** (hō'-mi-nin) A group consisting of humans and the extinct species that are more closely related to us than to chimpanzees.
- homologous chromosomes (or homologs)** (hō'-mol'-uh-gus) A pair of chromosomes of the same length, centromere position, and staining pattern that possess genes for the same characters at corresponding loci. One homologous chromosome is inherited from the organism's father, the other from the mother. Also called a homologous pair.
- homologous pair** See homologous chromosomes.
- homologous structures** (hō'-mol'-uh-gus) Structures in different species that are similar because of common ancestry.
- homologs** See homologous chromosomes.
- homology** (hō'-mol'-ō-jē) Similarity in characteristics resulting from a shared ancestry.
- homoplasy** (hō'-muh-play'-zē) A similar (analogous) structure or molecular sequence that has evolved independently in two species.
- homosporous** (hō'-mos'-puh-rus) Referring to a plant species that has a single kind of spore, which typically develops into a bisexual gametophyte.
- homozygote** An organism that has a pair of identical alleles for a gene (encoding a character).
- homozygous** (hō'-mō-zī'-gus) Having two identical alleles for a given gene.
- horizontal gene transfer** The transfer of genes from one genome to another through mechanisms such as transposable elements, plasmid exchange, viral activity, and perhaps fusions of different organisms.
- hormone** In multicellular organisms, one of many types of secreted chemicals that are formed in specialized cells, travel in body fluids, and act on specific target cells in other parts of the organism, changing the target cells' functioning.
- hornwort** A small, herbaceous, nonvascular plant that is a member of the phylum Anthocerophyta.
- host** The larger participant in a symbiotic relationship, often providing a home and food source for the smaller symbiont.
- host range** The limited number of species whose cells can be infected by a particular virus.
- Human Genome Project** An international collaborative effort to map and sequence the DNA of the entire human genome.
- human immunodeficiency virus (HIV)** The infectious agent that causes AIDS (acquired immunodeficiency syndrome). HIV is a retrovirus.
- humoral immune response** (hyū'-mer-ul) The branch of adaptive immunity that involves the activation of B cells and that leads to the production of antibodies, which defend against bacteria and viruses in body fluids.
- humus** (hyū'-mus) Decomposing organic material that is a component of topsoil.
- Huntington's disease** A human genetic disease caused by a dominant allele; characterized by uncontrollable body movements and degeneration of the nervous system; usually fatal 10 to 20 years after the onset of symptoms.
- hybrid** Offspring that results from the mating of individuals from two different species or from two true-breeding varieties of the same species.
- hybrid zone** A geographic region in which members of different species meet and mate, producing at least some offspring of mixed ancestry.
- hybridization** In genetics, the mating, or crossing, of two true-breeding varieties.
- hydration shell** The sphere of water molecules around a dissolved ion.
- hydrocarbon** An organic molecule consisting only of carbon and hydrogen.

hydrogen bond A type of weak chemical bond that is formed when the slightly positive hydrogen atom of a polar covalent bond in one molecule is attracted to the slightly negative atom of a polar covalent bond in another molecule or in another region of the same molecule.

hydrogen ion A single proton with a charge of $1+$. The dissociation of a water molecule (H_2O) leads to the generation of a hydroxide ion (OH^-) and a hydrogen ion (H^+); in water, H^+ is not found alone but associates with a water molecule to form a hydronium ion.

hydrolysis (hi-drol'-uh-sis) A chemical reaction that breaks bonds between two molecules by the addition of water; functions in disassembly of polymers to monomers.

hydronium ion A water molecule that has an extra proton bound to it; H_3O^+ , commonly represented as H^+ .

hydrophilic (hi'-drō-fil'-ik) Having an affinity for water.

hydrophobic (hi'-drō-fō'-bik) Having no affinity for water; tending to coalesce and form droplets in water.

hydrophobic interaction (hi'-drō-fō'-bik) A type of weak chemical interaction caused when molecules that do not mix with water coalesce to exclude water.

hydroponic culture A method in which plants are grown in mineral solutions rather than in soil.

hydrostatic skeleton A skeletal system composed of fluid held under pressure in a closed body compartment; the main skeleton of most cnidarians, flatworms, nematodes, and annelids.

hydrothermal vent An area on the seafloor where heated water and minerals from Earth's interior gush into the seawater, producing a dark, hot, oxygen-deficient environment. The producers in a hydrothermal vent community are chemoautotrophic prokaryotes.

hydroxide ion A water molecule that has lost a proton; OH^- .

hydroxyl group (hi-drok'-sil) A chemical group consisting of an oxygen atom joined to a hydrogen atom. Molecules possessing this group are soluble in water and are called alcohols.

hyperpolarization A change in a cell's membrane potential such that the inside of the membrane becomes more negative relative to the outside. Hyperpolarization reduces the chance that a neuron will transmit a nerve impulse.

hypersensitive response A plant's localized defense response to a pathogen, involving the death of cells around the site of infection.

hypertension A disorder in which blood pressure remains abnormally high.

hypertonic Referring to a solution that, when surrounding a cell, will cause the cell to lose water.

hypha (plural, **hyphae**) (hi'-fuh, hi'-fē) One of many connected filaments that collectively make up the mycelium of a fungus.

hypocotyl (hi'-puh-cot'-ul) In an angiosperm embryo, the embryonic axis below the point of attachment of the cotyledon(s) and above the radicle.

hypothalamus (hi'-pō-thal'-uh-mus) The ventral part of the vertebrate forebrain; functions

in maintaining homeostasis, especially in coordinating the endocrine and nervous systems; secretes hormones of the posterior pituitary and releasing factors that regulate the anterior pituitary.

hypothesis (hi-poth'-uh-sis) A testable explanation for a set of observations based on the available data and guided by inductive reasoning. A hypothesis is narrower in scope than a theory.

hypotonic Referring to a solution that, when surrounding a cell, will cause the cell to take up water.

imbibition The uptake of water by a seed or other structure, resulting in swelling.

immigration The influx of new individuals into a population from other areas.

immune system An organism's system of defenses against agents that cause disease.

immunization The process of generating a state of immunity by artificial means. In vaccination, an inactive or weakened form of a pathogen is administered, inducing B and T cell responses and immunological memory. In passive immunization, antibodies specific for a particular pathogen are administered, conferring immediate but temporary protection.

immunoglobulin (Ig) (im'-yū-nō-glob'-yū-lin) See antibody.

imprinting In animal behavior, the formation at a specific stage in life of a long-lasting behavioral response to a specific individual or object. See also genomic imprinting.

inclusive fitness The total effect an individual has on proliferating its genes by producing its own offspring and by providing aid that enables other close relatives to increase production of their offspring.

incomplete dominance The situation in which the phenotype of heterozygotes is intermediate between the phenotypes of individuals homozygous for either allele.

incomplete flower A flower in which one or more of the four basic floral organs (sepals, petals, stamens, or carpels) are either absent or nonfunctional.

incomplete metamorphosis A type of development in certain insects, such as grasshoppers, in which the young (called nymphs) resemble adults but are smaller and have different body proportions. The nymph goes through a series of molts, each time looking more like an adult, until it reaches full size.

independent variable A factor whose value is manipulated or changed during an experiment to reveal possible effects on another factor (the dependent variable).

indeterminate cleavage A type of embryonic development in deuterostomes in which each cell produced by early cleavage divisions retains the capacity to develop into a complete embryo.

indeterminate growth A type of growth characteristic of plants, in which the organism continues to grow as long as it lives.

induced fit Caused by entry of the substrate, the change in shape of the active site of an enzyme so that it binds more snugly to the substrate.

inducer A specific small molecule that binds to a bacterial repressor protein and changes the repressor's shape so that it cannot bind to an operator, thus switching an operon on.

induction A process in which a group of cells or tissues influences the development of another group through close-range interactions.

inductive reasoning A type of logic in which generalizations are based on a large number of specific observations.

inflammatory response An innate immune defense triggered by physical injury or infection of tissue involving the release of substances that promote swelling, enhance the infiltration of white blood cells, and aid in tissue repair and destruction of invading pathogens.

inflorescence A group of flowers tightly clustered together.

ingestion The first stage of food processing in animals: the act of eating.

ingroup A species or group of species whose evolutionary relationships are being examined in a given analysis.

inhibitory postsynaptic potential (IPSP)

(IPSP) An electrical change (usually hyperpolarization) in the membrane of a postsynaptic neuron caused by the binding of an inhibitory neurotransmitter from a presynaptic cell to a postsynaptic receptor; makes it more difficult for a postsynaptic neuron to generate an action potential.

innate behavior Animal behavior that is developmentally fixed and under strong genetic control. Innate behavior is exhibited in virtually the same form by all individuals in a population despite internal and external environmental differences during development and throughout their lifetimes.

innate immunity A form of defense common to all animals that is active immediately upon exposure to a pathogen and that is the same whether or not the pathogen has been encountered previously.

inner cell mass An inner cluster of cells at one end of a mammalian blastocyst that subsequently develops into the embryo proper and some of the extraembryonic membranes.

inner ear One of the three main regions of the vertebrate ear; includes the cochlea (which in turn contains the organ of Corti) and the semicircular canals.

inositol trisphosphate (IP₃) (in-ō'-suh-tol)

A second messenger that functions as an intermediate between certain signaling molecules and a subsequent second messenger, Ca^{2+} , by causing a rise in cytoplasmic Ca^{2+} concentration.

inquiry The search for information and explanation, often focusing on specific questions.

insertion A mutation involving the addition of one or more nucleotide pairs to a gene.

in situ hybridization A technique using nucleic acid hybridization with a labeled probe to detect the location of a specific mRNA in an intact organism.

insulin (in'-suh-lin) A hormone secreted by pancreatic beta cells that lowers blood glucose levels. It promotes the uptake of glucose by most body cells and the synthesis and storage of glycogen in the liver and also stimulates protein and fat synthesis.

integral protein A transmembrane protein with hydrophobic regions that extend into and often completely span the hydrophobic interior of the membrane and with

hydrophilic regions in contact with the aqueous solution on one or both sides of the membrane (or lining the channel in the case of a channel protein).

integrin (in'-tuh-grin) In animal cells, a transmembrane receptor protein with two subunits that interconnects the extracellular matrix and the cytoskeleton.

integument (in-teg'-yū-mēnt) Layer of sporophyte tissue that contributes to the structure of an ovule of a seed plant.

integumentary system The outer covering of a mammal's body, including skin, hair, and nails, claws, or hooves.

interferon (in'-ter-fēr'-ōn) A protein that has antiviral or immune regulatory functions. For example, interferons secreted by virus-infected cells help nearby cells resist viral infection.

intermediate disturbance hypothesis The concept that moderate levels of disturbance can foster greater species diversity than low or high levels of disturbance.

intermediate filament A component of the cytoskeleton that includes filaments intermediate in size between microtubules and microfilaments.

interneuron An association neuron; a nerve cell within the central nervous system that forms synapses with sensory and/or motor neurons and integrates sensory input and motor output.

internode A segment of a plant stem between the points where leaves are attached.

interphase The period in the cell cycle when the cell is not dividing. During interphase, cellular metabolic activity is high, chromosomes and organelles are duplicated, and cell size may increase. Interphase often accounts for about 90% of the cell cycle.

intersexual selection A form of natural selection in which individuals of one sex (usually the females) are choosy in selecting their mates from the other sex; also called mate choice.

interspecific interaction A relationship between individuals of two or more species in a community.

interstitial fluid The fluid filling the spaces between cells in most animals.

intertidal zone The shallow zone of the ocean adjacent to land and between the high- and low-tide lines.

intrasexual selection A form of natural selection in which there is direct competition among individuals of one sex for mates of the opposite sex.

intrinsic rate of increase (*r*) In population models, the per capita rate at which an exponentially growing population increases in size at each instant in time.

introduced species A species moved by humans, either intentionally or accidentally, from its native location to a new geographic region; sometimes called a non-native species, exotic species, or invasive species.

intron (in'-tron) A noncoding, intervening sequence within a primary transcript that is removed from the transcript during RNA processing; also refers to the region of DNA from which this sequence was transcribed.

inversion An aberration in chromosome structure resulting from reattachment of a

chromosomal fragment in a reverse orientation to the chromosome from which it originated.

invertebrate An animal without a backbone. Invertebrates make up 95% of animal species.

in vitro fertilization (IVF) (vē'-trō) Fertilization of oocytes in laboratory containers followed by artificial implantation of the early embryo in the mother's uterus.

in vitro mutagenesis A technique used to discover the function of a gene by cloning it, introducing specific changes into the cloned gene's sequence, reinserting the mutated gene into a cell, and studying the phenotype of the mutant.

ion (ī'-ōn) An atom or group of atoms that has gained or lost one or more electrons, thus acquiring a charge.

ion channel (ī'-ōn) A transmembrane protein channel that allows a specific ion to diffuse across the membrane down its concentration or electrochemical gradient.

ionic bond (ī-on'-ik) A chemical bond resulting from the attraction between oppositely charged ions.

ionic compound (ī-on'-ik) A compound resulting from the formation of an ionic bond; also called a salt.

iris The colored part of the vertebrate eye, formed by the anterior portion of the choroid.

isomer (ī'-sō-mer) One of two or more compounds that have the same numbers of atoms of the same elements but different structures and hence different properties.

isomorphic Referring to alternating generations in plants and certain algae in which the sporophytes and gametophytes look alike, although they differ in chromosome number.

isotonic (ī'-sō-ton'-ik) Referring to a solution that, when surrounding a cell, causes no net movement of water into or out of the cell.

isotope (ī'-sō-tōp') One of several atomic forms of an element, each with the same number of protons but a different number of neutrons, thus differing in atomic mass.

iteroparity Reproduction in which adults produce offspring over many years; also called repeated reproduction.

jasmonate Any of a class of plant hormones that regulate a wide range of developmental processes in plants and play a key role in plant defense against herbivores.

joule (J) A unit of energy: 1 J = 0.239 cal; 1 cal = 4.184 J.

juxtaglomerular apparatus (JGA) (juks'-tuh-glüh-mär'-yü-lər) A specialized tissue in nephrons that releases the enzyme renin in response to a drop in blood pressure or volume.

juxtaglomerular nephron In mammals and birds, a nephron with a loop of Henle that extends far into the renal medulla.

karyogamy (kär'-ē-og'-uh-mē) In fungi, the fusion of haploid nuclei contributed by the two parents; occurs as one stage of sexual reproduction, preceded by plasmogamy.

karyotype (kär'-ē-ō-tip) A display of the chromosome pairs of a cell arranged by size and shape.

keystone species A species that is not necessarily abundant in a community yet exerts strong control on community structure by the nature of its ecological role or niche.

kidney In vertebrates, one of a pair of excretory organs where blood filtrate is formed and processed into urine.

kilocalorie (kcal) A thousand calories; the amount of heat energy required to raise the temperature of 1 kg of water by 1°C.

kinetic energy (kuh-net'-ik) The energy associated with the relative motion of objects. Moving matter can perform work by imparting motion to other matter.

kinetochore (kuh-net'-uh-kör) A structure of proteins attached to the centromere that links each sister chromatid to the mitotic spindle.

kinetoplastid A protist, such as a trypanosome, that has a single large mitochondrion that houses an organized mass of DNA.

kingdom A taxonomic category, the second broadest after domain.

kin selection Natural selection that favors altruistic behavior by enhancing the reproductive success of relatives.

K-selection Selection for life history traits that are sensitive to population density.

labia majora A pair of thick, fatty ridges that enclose and protect the rest of the vulva.

labia minora A pair of slender skin folds that surround the openings of the vagina and urethra.

lacteal (lak'-tē-ul) A tiny lymph vessel extending into the core of an intestinal villus and serving as the destination for absorbed chylomicrons.

lactic acid fermentation Glycolysis followed by the reduction of pyruvate to lactate, regenerating NAD⁺ with no release of carbon dioxide.

lagging strand A discontinuously synthesized DNA strand that elongates by means of Okazaki fragments, each synthesized in a 5' → 3' direction away from the replication fork.

lamprey Any of the jawless vertebrates with highly reduced vertebrae that live in freshwater and marine environments. Almost half of extant lamprey species are parasites that feed by clamping their round, jawless mouth onto the flank of a live fish; nonparasitic lampreys are suspension feeders that feed only as larvae.

lancelet A member of the clade Cephalochordata, small blade-shaped marine chordates that lack a backbone.

landscape An area containing several different ecosystems linked by exchanges of energy, materials, and organisms.

landscape ecology The study of how the spatial arrangement of habitat types affects the distribution and abundance of organisms and ecosystem processes.

large intestine The portion of the vertebrate alimentary canal between the small intestine and the anus; functions mainly in water absorption and the formation of feces.

larva (lar'-vuh) (plural, **larvae**) A free-living, sexually immature form in some animal life cycles that may differ from the adult animal in morphology, nutrition, and habitat.

larynx (lär'-inks) The portion of the respiratory tract containing the vocal cords; also called the voice box.

lateralization Segregation of functions in the cortex of the left and right cerebral hemispheres.

lateral line system A mechanoreceptor system consisting of a series of pores and receptor units along the sides of the body in fishes and aquatic amphibians; detects water movements made by the animal itself and by other moving objects.

lateral meristem (mär'-uh-stem) A meristem that thickens the roots and shoots of woody plants. The vascular cambium and cork cambium are lateral meristems.

lateral root A root that arises from the pericycle of an established root.

law of conservation of mass A physical law stating that matter can change form but cannot be created or destroyed. In a closed system, the mass of the system is constant.

law of independent assortment Mendel's second law, stating that each pair of alleles segregates, or assorts, independently of each other pair during gamete formation; applies when genes for two characters are located on different pairs of homologous chromosomes or when they are far enough apart on the same chromosome to behave as though they are on different chromosomes.

law of segregation Mendel's first law, stating that the two alleles in a pair segregate (separate from each other) into different gametes during gamete formation.

leading strand The new complementary DNA strand synthesized continuously along the template strand toward the replication fork in the mandatory 5' → 3' direction.

leaf The main photosynthetic organ of vascular plants.

leaf primordium (plural, **primordia**) A finger-like projection along the flank of a shoot apical meristem, from which a leaf arises.

learning The modification of behavior as a result of specific experiences.

lens The structure in an eye that focuses light rays onto the photoreceptors.

lenticel (len'-tē-sel) A small raised area in the bark of stems and roots that enables gas exchange between living cells and the outside air.

lepidosaur (leh-pid'-uh-sōr) A member of the reptilian group that includes lizards, snakes, and two species of New Zealand animals called tuatara.

leukocyte (lü'-kō-sīt') A blood cell that functions in fighting infections; also called a white blood cell.

lichen The mutualistic association between a fungus and a photosynthetic alga or cyanobacterium.

life cycle The generation-to-generation sequence of stages in the reproductive history of an organism.

life history The traits that affect an organism's schedule of reproduction and survival.

life table A summary of the age-specific survival and reproductive rates of individuals in a population.

ligament A fibrous connective tissue that joins bones together at joints.

ligand (lig'-und) A molecule that binds specifically to another molecule, usually a larger one.

ligand-gated ion channel (lig'-und) A transmembrane protein containing a pore that opens or closes as it changes shape in response to a signaling molecule (ligand), allowing or

blocking the flow of specific ions; also called an ionotropic receptor.

light chain One of the two types of polypeptide chains that make up an antibody molecule and B cell receptor; consists of a variable region, which contributes to the antigen-binding site, and a constant region.

light-harvesting complex A complex of proteins associated with pigment molecules (including chlorophyll *a*, chlorophyll *b*, and carotenoids) that captures light energy and transfers it to reaction-center pigments in a photosystem.

light microscope (LM) An optical instrument with lenses that refract (bend) visible light to magnify images of specimens.

light reactions The first of two major stages in photosynthesis (preceding the Calvin cycle). These reactions, which occur on the thylakoid membranes of the chloroplast or on membranes of certain prokaryotes, convert solar energy to the chemical energy of ATP and NADPH, releasing oxygen in the process.

lignin (lig'-nin) A strong polymer embedded in the cellulose matrix of the secondary cell walls of vascular plants that provides structural support in terrestrial species.

limiting nutrient An element that must be added for production to increase in a particular area.

limnetic zone In a lake, the well-lit, open surface waters far from shore.

linear electron flow A route of electron flow during the light reactions of photosynthesis that involves both photosystems (I and II) and produces ATP, NADPH, and O₂. The net electron flow is from H₂O to NADP⁺.

line graph A graph in which each data point is connected to the next point in the data set with a straight line.

linkage map A genetic map based on the frequencies of recombination between markers during crossing over of homologous chromosomes.

linked genes Genes located close enough together on a chromosome that they tend to be inherited together.

lipid (lip'-id) Any of a group of large biological molecules, including fats, phospholipids, and steroids, that mix poorly, if at all, with water.

littoral zone In a lake, the shallow, well-lit waters close to shore.

liver A large internal organ in vertebrates that performs diverse functions, such as producing bile, maintaining blood glucose level, and detoxifying poisonous chemicals in the blood.

liverwort A small, herbaceous, nonvascular plant that is a member of the phylum Hepaticophyta.

loam The most fertile soil type, made up of roughly equal amounts of sand, silt, and clay.

lobe-fin Member of a clade of osteichthyans having rod-shaped muscular fins. The group includes coelacanths, lungfishes, and tetrapods.

local regulator A secreted molecule that influences cells near where it is secreted.

locomotion Active motion from place to place.

locus (plural, **loci**), (lö'-kus), (lö'-sī) A specific place along the length of a chromosome where a given gene is located.

logistic population growth Population growth that levels off as population size approaches carrying capacity.

long-day plant A plant that flowers (usually in late spring or early summer) only when the light period is longer than a critical length.

long noncoding RNA (lncRNA) An RNA between 200 and hundreds of thousands of nucleotides in length that does not code for protein but is expressed at significant levels.

long-term memory The ability to hold, associate, and recall information over one's lifetime.

long-term potentiation (LTP) An enhanced responsiveness to an action potential (nerve signal) by a receiving neuron.

loop of Henle (hen'-lē) The hairpin turn, with a descending and ascending limb, between the proximal and distal tubules of the vertebrate kidney; functions in water and salt reabsorption.

lophophore (lof'-uh-fōr) In some lophotrochozoan animals, including brachiopods, a crown of ciliated tentacles that surround the mouth and function in feeding.

Lophotrochozoa (lo-phah'-truh-kō-zō'-uh) One of the three main lineages of bilaterian animals; lophotrochozoans include organisms that have lophophores or trophophore larvae. See also Deuterostomia and Ecdysozoa.

low-density lipoprotein (LDL) A particle in the blood made up of thousands of cholesterol molecules and other lipids bound to a protein. LDL transports cholesterol from the liver for incorporation into cell membranes.

lung An infolded respiratory surface of a terrestrial vertebrate, land snail, or spider that connects to the atmosphere by narrow tubes.

luteinizing hormone (LH) (lü'-tē-uh-nī'-zing) A tropic hormone that is produced and secreted by the anterior pituitary and that stimulates ovulation in females and androgen production in males.

lycophyte (lü'-kuh-fit) An informal name for a member of the phylum Lycophyta, which includes club mosses, spike mosses, and quillworts.

lymph The colorless fluid, derived from interstitial fluid, in the lymphatic system of vertebrates.

lymph node An organ located along a lymph vessel. Lymph nodes filter lymph and contain cells that attack viruses and bacteria.

lymphatic system A system of vessels and nodes, separate from the circulatory system, that returns fluid, proteins, and cells to the blood.

lymphocyte A type of white blood cell that mediates immune responses. The two main classes are B cells and T cells.

lysogenic cycle (li'-sō-jen'-ik) A type of phage replicative cycle in which the viral genome becomes incorporated into the bacterial host chromosome as a prophage, is replicated along with the chromosome, and does not kill the host.

lysosome (li'-suh-sōm) A membrane-enclosed sac of hydrolytic enzymes found in the cytoplasm of animal cells and some protists.

lysozyme (li'-sō-zim) An enzyme that destroys bacterial cell walls; in mammals, it is found in sweat, tears, and saliva.

lytic cycle (lit'-ik) A type of phage replicative cycle resulting in the release of new phages by lysis (and death) of the host cell.

macroevolution Evolutionary change above the species level. Examples of macroevolutionary change include the origin of a new group of organisms through a series of speciation events and the impact of mass extinctions on the diversity of life and its subsequent recovery.

macromolecule A giant molecule formed by the joining of smaller molecules. Polysaccharides, proteins, and nucleic acids are macromolecules.

macronutrient An essential element that an organism must obtain in relatively large amounts. *See also* micronutrient.

macrophage (mak'-rō-fāj) A phagocytic cell present in many tissues that functions in innate immunity by destroying microorganisms and in acquired immunity as an antigen-presenting cell.

magnoliid A member of the angiosperm clade that is most closely related to the combined eudicot and monocot clades. Extant examples are magnolias, laurels, and black pepper plants.

major depressive disorder A mood disorder characterized by feelings of sadness, lack of self-worth, emptiness, or loss of interest in nearly all things.

major histocompatibility complex (MHC)

molecule A host protein that functions in antigen presentation. Foreign MHC molecules on transplanted tissue can trigger T cell responses that may lead to rejection of the transplant.

malignant tumor A cancerous tumor containing cells that have significant genetic and cellular changes and are capable of invading and surviving in new sites. Malignant tumors can impair the functions of one or more organs.

Malpighian tubule (mal-pig'-ē-un) A unique excretory organ of insects that empties into the digestive tract, removes nitrogenous wastes from the hemolymph, and functions in osmoregulation.

mammal A member of the clade Mammalia, amniotes that have hair and mammary glands (glands that produce milk).

mammary gland An exocrine gland that secretes milk for nourishing the young. Mammary glands are characteristic of mammals.

mantle One of the three main parts of a mollusc; a fold of tissue that drapes over the mollusc's visceral mass and may secrete a shell. *See also* foot and visceral mass.

mantle cavity A water-filled chamber that houses the gills, anus, and excretory pores of a mollusc.

map unit A unit of measurement of the distance between genes. One map unit is equivalent to a 1% recombination frequency.

marine benthic zone The ocean floor.

mark-recapture method A sampling technique used to estimate the size of animal populations.

marsupial (mar-sū'-pē-ul) A mammal, such as a koala, kangaroo, or opossum, whose young complete their embryonic development inside a maternal pouch called the marsupium.

mass extinction The elimination of a large number of species throughout Earth, the result of global environmental changes.

mass number The total number of protons and neutrons in an atom's nucleus.

mast cell Immune system cell that secretes histamine; plays role in inflammatory response and allergies.

mate-choice copying Behavior in which individuals in a population copy the mate choice of others, apparently due to social learning.

maternal effect gene A gene that, when mutant in the mother, results in a mutant phenotype in the offspring, regardless of the offspring's genotype. Maternal effect genes, also called egg-polarity genes, were first identified in *Drosophila melanogaster*.

matter Anything that takes up space and has mass.

maximum likelihood As applied to DNA sequence data, a principle that states that when considering multiple phylogenetic hypotheses, one should take into account the hypothesis that reflects the most likely sequence of evolutionary events, given certain rules about how DNA changes over time.

maximum parsimony The principle that when considering multiple explanations for an observation, one should first investigate the simplest explanation that is consistent with the facts.

mean The sum of all data points in a data set divided by the number of data points.

mechanoreceptor A sensory receptor that detects physical deformation in the body's environment associated with pressure, touch, stretch, motion, or sound.

medulla oblongata (meh-dul'-uh ob'-long-go'-tuh) The lowest part of the vertebrate brain, commonly called the medulla; a swelling of the hindbrain anterior to the spinal cord that controls autonomic, homeostatic functions, including breathing, heart and blood vessel activity, swallowing, digestion, and vomiting.

medusa (muh-dü'-suh) (plural, **medusae**) The floating, mouth-down form of the cnidarian body plan. The alternate form is the polyp.

megapascal (MPa) (meg'-uh-pas-kal') A unit of pressure equivalent to about 10 atmospheres of pressure.

megaphyll (meh'-guh-fil) A leaf with a highly branched vascular system, found in almost all vascular plants other than lycophytes. *See also* microphyll.

megaspore A spore from a heterosporous plant species that develops into a female gametophyte.

meiosis (miō'-sis) A modified type of cell division in sexually reproducing organisms consisting of two rounds of cell division but only one round of DNA replication. It results in cells with half the number of chromosome sets as the original cell.

meiosis I (miō'-sis) The first division of a two-stage process of cell division in sexually reproducing organisms that results in cells with half the number of chromosome sets as the original cell.

meiosis II (miō'-sis) The second division of a two-stage process of cell division in sexually reproducing organisms that results in cells with half the number of chromosome sets as the original cell.

melanocyte-stimulating hormone (MSH) A hormone produced and secreted by the anterior pituitary with multiple activities, including regulating the behavior of pigment-containing cells in the skin of some vertebrates.

melatonin A hormone that is secreted by the pineal gland and that is involved in the regulation of biological rhythms and sleep.

membrane potential The difference in electrical charge (voltage) across a cell's plasma membrane due to the differential distribution of ions. Membrane potential affects the activity of excitable cells and the transmembrane movement of all charged substances.

memory cell One of a clone of long-lived lymphocytes, formed during the primary immune response, that remains in a lymphoid organ until activated by exposure to the same antigen that triggered its formation. Activated memory cells mount the secondary immune response.

menopause The cessation of ovulation and menstruation marking the end of a human female's reproductive years.

menstrual cycle (men'-strū-ul) In humans and certain other primates, the periodic growth and shedding of the uterine lining that occurs in the absence of pregnancy.

menstruation The shedding of portions of the endometrium during a uterine (menstrual) cycle.

meristem (mär'-uh-stem) Plant tissue that remains embryonic as long as the plant lives, allowing for indeterminate growth.

mesoderm (mez'-ō-derm) The middle primary germ layer in a triploblastic animal embryo; develops into the notochord, the lining of the coelom, muscles, skeleton, gonads, kidneys, and most of the circulatory system in species that have these structures.

mesohyl (mez'-ō-hil) A gelatinous region between the two layers of cells of a sponge.

mesophyll (mez'-ō-fil) Leaf cells specialized for photosynthesis. In C₃ and CAM plants, mesophyll cells are located between the upper and lower epidermis; in C₄ plants, they are located between the bundle-sheath cells and the epidermis.

messenger RNA (mRNA) A type of RNA, synthesized using a DNA template, that attaches to ribosomes in the cytoplasm and specifies the primary structure of a protein. (In eukaryotes, the primary RNA transcript must undergo RNA processing to become mRNA.)

metabolic pathway A series of chemical reactions that either builds a complex molecule (anabolic pathway) or breaks down a complex molecule to simpler molecules (catabolic pathway).

metabolic rate The total amount of energy an animal uses in a unit of time.

metabolism (muh-tab'-uh-lizm) The totality of an organism's chemical reactions, consisting of catabolic and anabolic pathways, which manage the material and energy resources of the organism.

metagenomics The collection and sequencing of DNA from a group of species, usually an environmental sample of microorganisms. Computer software sorts partial sequences and assembles them into genome sequences of individual species making up the sample.

metamorphosis (met'-uh-môr'-fuh-sis) A developmental transformation that turns an animal larva into either an adult or an adult-like stage that is not yet sexually mature.

metanephridium (met'-uh-nuh-frid'-ē-um) (plural, **metanephridia**) An excretory organ found in many invertebrates that typically consists of tubules connecting ciliated internal openings to external openings.

metaphase The third stage of mitosis, in which the spindle is complete and the chromosomes, attached to microtubules at their kinetochores, are all aligned at the metaphase plate.

metaphase plate An imaginary structure located at a plane midway between the two poles of a cell in metaphase on which the centromeres of all the duplicated chromosomes are located.

metapopulation A group of spatially separated populations of one species that interact through immigration and emigration.

metastasis (muh-tas'-tuh-sis) The spread of cancer cells to locations distant from their original site.

methanogen (meth-an'-ō-jen) An organism that produces methane as a waste product of the way it obtains energy. All known methanogens are in domain Archaea.

methyl group A chemical group consisting of a carbon bonded to three hydrogen atoms. The methyl group may be attached to a carbon or to a different atom.

microbiome The collection of microorganisms living in or on an organism's body, along with their genetic material.

microclimate Climate patterns on a very fine scale, such as the specific climatic conditions underneath a log.

microevolution Evolutionary change below the species level; change in the allele frequencies in a population over generations.

microfilament A cable composed of actin proteins in the cytoplasm of almost every eukaryotic cell, making up part of the cytoskeleton and acting alone or with myosin to cause cell contraction; also called an actin filament.

micronutrient An essential element that an organism needs in very small amounts. *See also* macronutrient.

microphyll (mī'-krō-fil) A small, usually spine-shaped leaf supported by a single strand of vascular tissue, found only in lycophytes.

microplastic A plastic particle less than 5 mm in size; microplastics have contaminated all of the world's oceans as well as freshwater and terrestrial ecosystems.

micropyle A pore in the integuments of an ovule.

microRNA (miRNA) A small, single-stranded RNA molecule, generated from a double-stranded RNA precursor. The miRNA associates with one or more proteins in a complex that can degrade or prevent translation of an mRNA with a complementary sequence.

microspore A spore from a heterosporous plant species that develops into a male gametophyte.

microsporidian A member of the fungal phylum Microsporidia, unicellular parasites of

protists and animals; microsporidians and their sister taxon (cryptomycetes) are a basal fungal lineage.

microtubule A hollow rod composed of tubulin proteins that makes up part of the cytoskeleton in all eukaryotic cells and is found in cilia and flagella.

microvillus (plural, **microvilli**) One of many fine, finger-like projections of the epithelial cells in the lumen of the small intestine that increase its surface area.

midbrain One of three ancestral and embryonic regions of the vertebrate brain; develops into sensory integrating and relay centers that send sensory information to the cerebrum.

middle ear One of three main regions of the vertebrate ear; in mammals, a chamber containing three small bones (the malleus, incus, and stapes) that convey vibrations from the eardrum to the oval window.

middle lamella (luh-mel'-uh) In plants, a thin layer of adhesive extracellular material, primarily pectins, found between the primary walls of adjacent young cells.

migration A regular, long-distance change in location.

mineral In nutrition, a simple nutrient that is inorganic and therefore cannot be synthesized in the body.

mineralocorticoid A steroid hormone secreted by the adrenal cortex that regulates salt and water homeostasis.

minimum viable population (MVP) The smallest population size at which a species is able to sustain its numbers and survive.

mismatch repair The cellular process that uses specific enzymes to remove and replace incorrectly paired nucleotides.

missense mutation A nucleotide-pair substitution that results in a codon that codes for a different amino acid.

mitochondrial matrix The compartment of the mitochondrion enclosed by the inner membrane and containing enzymes and substrates for the citric acid cycle, as well as ribosomes and DNA.

mitochondrion (mī'-tō-kon'-drē-un) (plural, **mitochondria**) An organelle in eukaryotic cells that serves as the site of cellular respiration; uses oxygen to break down organic molecules and synthesize ATP.

mitosis (mī-tō'-sis) A process of nuclear division in eukaryotic cells conventionally divided into five stages: prophase, prometaphase, metaphase, anaphase, and telophase. Mitosis conserves chromosome number by allocating replicated chromosomes equally to each of the daughter nuclei.

mitotic (M) phase The phase of the cell cycle that includes mitosis and cytokinesis.

mitotic spindle An assemblage of microtubules and associated proteins that is involved in the movement of chromosomes during mitosis.

mixotroph An organism that is capable of both photosynthesis and heterotrophy.

model A physical or conceptual representation of a natural phenomenon.

model organism A particular species chosen for research into broad biological principles because it is representative of a larger group and usually easy to grow in a lab.

molarity A common measure of solute concentration, referring to the number of moles of solute per liter of solution.

mold Informal term for a fungus that grows as a filamentous fungus, producing haploid spores by mitosis and forming a visible mycelium.

mole (mol) The number of grams of a substance that equals its molecular or atomic mass in daltons; a mole contains Avogadro's number of the molecules or atoms in question.

molecular clock A method for estimating the time required for a given amount of evolutionary change, based on the observation that some regions of genomes evolve at constant rates.

molecular mass The sum of the masses of all the atoms in a molecule; sometimes called molecular weight.

molecule Two or more atoms held together by covalent bonds.

molting A process in ecdysozoans in which the exoskeleton is shed at intervals, allowing growth by the production of a larger exoskeleton.

monilophyte An informal name for a member of the phylum Monilophyta, which includes ferns, horsetails, and whisk ferns and their relatives.

monoclonal antibody (mon'-ō-klōn'-ul)

Any of a preparation of antibodies that have been produced by a single clone of cultured cells and thus are all specific for the same epitope.

monocot A member of a clade consisting of flowering plants that have one embryonic seed leaf, or cotyledon.

monogamous (muh-nog'-uh-mus) Referring to a type of relationship in which one male mates with just one female.

monohybrid An organism that is heterozygous with respect to a single gene of interest. All the offspring from a cross between parents homozygous for different alleles are monohybrids. For example, parents of genotypes *AA* and *aa* produce a monohybrid of genotype *Aa*.

monohybrid cross A cross between two organisms that are heterozygous for the character being followed (or the self-pollination of a heterozygous plant).

monomer (mon'-uh-mer) The subunit that serves as the building block of a polymer.

monophyletic (mon'-ō-fi-let'-ik) Pertaining to a group of taxa that consists of a common ancestor and all of its descendants. A monophyletic taxon is equivalent to a clade.

monosaccharide (mon'-ō-sak'-uh-rid) The simplest carbohydrate, active alone or serving as a monomer for disaccharides and polysaccharides. Also called simple sugars, monosaccharides have molecular formulas that are generally some multiple of CH_2O .

monosomic Referring to a diploid cell that has only one copy of a particular chromosome instead of the normal two.

monotreme An egg-laying mammal, such as a platypus or echidna. Like all mammals, monotremes have hair and produce milk, but they lack nipples.

morphogen A substance, such as Bicoid protein in *Drosophila*, that provides positional

- information** in the form of a concentration gradient along an embryonic axis.
- morphogenesis** (mōr'-fō-jēn'-uh-sis) The development of the form of an organism and its structures.
- morphological species concept** Definition of a species in terms of measurable anatomical criteria.
- moss** A small, herbaceous, nonvascular plant that is a member of the phylum Bryophyta.
- motor neuron** A nerve cell that transmits signals from the brain or spinal cord to muscles or glands.
- motor protein** A protein that interacts with cytoskeletal elements and other cell components, producing movement of the whole cell or parts of the cell.
- motor system** An efferent branch of the vertebrate peripheral nervous system composed of motor neurons that carry signals to skeletal muscles in response to external stimuli.
- motor unit** A single motor neuron and all the muscle fibers it controls.
- movement corridor** A series of small clumps or a narrow strip of quality habitat (usable by organisms) that connects otherwise isolated patches of quality habitat.
- MPF** Maturation-promoting factor (or M-phase-promoting factor); a protein complex required for a cell to progress from late interphase to mitosis. The active form consists of cyclin and a protein kinase.
- mucoromycete** A member of the fungal phylum Mucromycota, characterized by the formation of a sturdy structure called a zygosporangium during sexual reproduction.
- mucus** A viscous and slippery mixture of glycoproteins, cells, salts, and water that moistens and protects the membranes lining body cavities that open to the exterior.
- Müllerian mimicry** (myū-lär'-ē-un mim'-uh-kṛē) Reciprocal mimicry by two unpalatable species.
- multifactorial** Referring to a phenotypic character that is influenced by multiple genes and environmental factors.
- multigene family** A collection of genes with similar or identical sequences, presumably of common origin.
- multiple fruit** A fruit derived from an entire inflorescence.
- multiplication rule** A rule of probability stating that the probability of two or more independent events occurring together can be determined by multiplying their individual probabilities.
- muscle tissue** Tissue consisting of long muscle cells that can contract, either on its own or when stimulated by nerve impulses.
- mutagen** (myū'-tuh-jen) A chemical or physical agent that interacts with DNA and can cause a mutation.
- mutation** (myū-tā'-shun) A change in the nucleotide sequence of an organism's DNA or in the DNA or RNA of a virus.
- mutualism** (myū'-chū-ul-izm) A +/+ ecological interaction that benefits individuals of both interacting species.
- mycelium** (mī-sē'-lē-um) (plural, **mycelia**) The densely branched network of hyphae in a fungus.
- mycorrhiza** (plural, **mycorrhizae**) (mī'-kōr-ī'-zuh, mī'-kōr-ī'-zē) A mutualistic association of plant roots and fungus.
- mycosis** (mī-kō'-sis) General term for a fungal infection.
- myelin sheath** (mī'-uh-lin) Wrapped around the axon of a neuron, an insulating coat of cell membranes from Schwann cells or oligodendrocytes. It is interrupted by nodes of Ranvier, where action potentials are generated.
- myofibril** (mī'-ō-fī'-bril) A longitudinal bundle in a muscle cell (fiber) that contains thin filaments of actin and regulatory proteins and thick filaments of myosin.
- myoglobin** (mī'-uh-glō'-bin) An oxygen-storing, pigmented protein in muscle cells.
- myosin** (mī'-uh-sin) A type of motor protein that associates into filaments that interact with actin filaments to cause cell contraction.
- myriapod** (mir'-ē-uh-pod') A terrestrial arthropod with many body segments and one or two pairs of legs per segment. Millipedes and centipedes are the two major groups of living myriapods.
- NAD⁺** The oxidized form of nicotinamide adenine dinucleotide, a coenzyme that can accept electrons, becoming NADH. NADH temporarily stores electrons during cellular respiration.
- NADH** The reduced form of nicotinamide adenine dinucleotide that temporarily stores electrons during cellular respiration. NADH acts as an electron donor to the electron transport chain.
- NADP⁺** The oxidized form of nicotinamide adenine dinucleotide phosphate, an electron carrier that can accept electrons, becoming NADPH. NADPH temporarily stores energized electrons produced during the light reactions.
- NADPH** The reduced form of nicotinamide adenine dinucleotide phosphate; temporarily stores energized electrons produced during the light reactions. NADPH acts as “reducing power” that can be passed along to an electron acceptor, reducing it.
- natural killer cell** A type of white blood cell that can kill tumor cells and virus-infected cells as part of innate immunity.
- natural selection** A process in which individuals that have certain inherited traits tend to survive and reproduce at higher rates than other individuals because of those traits.
- negative feedback** A form of regulation in which accumulation of an end product of a process slows the process; in physiology, a primary mechanism of homeostasis, whereby a change in a variable triggers a response that counteracts the initial change.
- negative pressure breathing** A breathing system in which air is pulled into the lungs.
- nematocyst** (nem'-uh-tuh-sist') In a cnidocyte of a cnidarian, a capsule-like organelle containing a coiled thread that when discharged can penetrate the body wall of the prey.
- nephron** (nef'-ron) The tubular excretory unit of the vertebrate kidney.
- neritic zone** The shallow region of the ocean overlying the continental shelf.
- nerve** A fiber composed primarily of the bundled axons of neurons.
- nervous system** In animals, the fast-acting internal system of communication involving sensory receptors, networks of nerve cells, and connections to muscles and glands that respond to nerve signals; functions in concert with the endocrine system to effect internal regulation and maintain homeostasis.
- nervous tissue** Tissue made up of neurons and supportive cells.
- net ecosystem production (NEP)** The gross primary production of an ecosystem minus the energy used by all autotrophs and heterotrophs for respiration.
- net primary production (NPP)** The gross primary production of an ecosystem minus the energy used by the producers for respiration.
- neural crest** In vertebrates, a region located along the sides of the neural tube where it pinches off from the ectoderm. Neural crest cells migrate to various parts of the embryo and form pigment cells in the skin and parts of the skull, teeth, adrenal glands, and peripheral nervous system.
- neural tube** A tube of infolded ectodermal cells that runs along the anterior-posterior axis of a vertebrate, just dorsal to the notochord. It will give rise to the central nervous system.
- neurohormone** A molecule that is secreted by a neuron, travels in body fluids, and acts on specific target cells, changing their functioning.
- neuron** (nyūr'-on) A nerve cell; the fundamental unit of the nervous system, having structure and properties that allow it to conduct signals by taking advantage of the electrical charge across its plasma membrane.
- neuronal plasticity** The capacity of a nervous system to change with experience.
- neuropeptide** A relatively short chain of amino acids that serves as a neurotransmitter.
- neurotransmitter** A molecule that is released from the synaptic terminal of a neuron at a chemical synapse, diffuses across the synaptic cleft, and binds to the postsynaptic cell, triggering a response.
- neutral variation** Genetic variation that does not provide a selective advantage or disadvantage.
- neutron** A subatomic particle having no electrical charge (electrically neutral), with a mass of about 1.7×10^{-24} g, found in the nucleus of an atom.
- neutrophil** The most abundant type of white blood cell. Neutrophils are phagocytic and tend to self-destruct as they destroy foreign invaders, limiting their life span to a few days.
- nitric oxide (NO)** A gas produced by many types of cells that functions as a local regulator and as a neurotransmitter.
- nitrogen cycle** The natural process by which nitrogen, either from the atmosphere or from decomposed organic material, is converted by soil bacteria to compounds assimilated by plants. This incorporated nitrogen is then taken in by other organisms and subsequently released, acted on by bacteria, and made available again to the nonliving environment.
- nitrogen fixation** The conversion of atmospheric nitrogen (N_2) to ammonia (NH_3). Biological nitrogen fixation is carried out by certain prokaryotes, some of which have mutualistic relationships with plants.

nociceptor (nō'-si-sep'-tur) A sensory receptor that responds to noxious or painful stimuli; also called a pain receptor.

node A point along the stem of a plant at which leaves are attached.

node of Ranvier (ron'-vē-ā') Gap in the myelin sheath of certain axons where an action potential may be generated. In saltatory conduction, an action potential is regenerated at each node, appearing to “jump” along the axon from node to node.

nodule A swelling on the root of a legume. Nodules are composed of plant cells that contain nitrogen-fixing bacteria of the genus *Rhizobium*.

noncompetitive inhibitor A substance that reduces the activity of an enzyme by binding to a location remote from the active site, changing the enzyme’s shape so that the active site no longer effectively catalyzes the conversion of substrate to product.

nondisjunction An error in meiosis or mitosis in which members of a pair of homologous chromosomes or a pair of sister chromatids fail to separate properly from each other.

nonequilibrium model A model that maintains that communities change constantly after being buffeted by disturbances.

nonpolar covalent bond A type of covalent bond in which electrons are shared equally between two atoms of similar electronegativity.

nonsense mutation A mutation that changes an amino acid codon to one of the three stop codons, resulting in a shorter and usually nonfunctional protein.

norepinephrine (nor-ep'-i-nef'-rin) A catecholamine that is chemically and functionally similar to epinephrine and acts as a hormone or neurotransmitter; also called noradrenaline.

northern coniferous forest A terrestrial biome characterized by long, cold winters and dominated by cone-bearing trees.

no-till agriculture A plowing technique that minimally disturbs the soil, thereby reducing soil loss.

notochord (nō'-tuh-kord') A longitudinal, flexible rod made of tightly packed mesodermal cells that runs along the anterior-posterior axis of a chordate in the dorsal part of the body.

nuclear envelope In a eukaryotic cell, the double membrane that surrounds the nucleus, perforated with pores that regulate traffic with the cytoplasm. The outer membrane is continuous with the endoplasmic reticulum.

nuclear lamina A netlike array of protein filaments that lines the inner surface of the nuclear envelope and helps maintain the shape of the nucleus.

nucleariid A member of a group of unicellular, amoeboid protists that are more closely related to fungi than they are to other protists.

nuclease An enzyme that cuts DNA or RNA, either removing one or a few bases or hydrolyzing the DNA or RNA completely into its component nucleotides.

nucleic acid (nū-klā'-ik) A polymer (poly-nucleotide) consisting of many nucleotide monomers; serves as a blueprint for proteins and, through the actions of proteins, for all cellular activities. The two types are DNA and RNA.

nucleic acid hybridization (nū-klā'-ik) The base pairing of one strand of a nucleic acid to the complementary sequence on a strand from another nucleic acid molecule.

nucleic acid probe (nū'-klā'-ik) In DNA technology, a labeled single-stranded nucleic acid molecule used to locate a specific nucleotide sequence in a nucleic acid sample. Molecules of the probe hydrogen-bond to the complementary sequence wherever it occurs; radioactive, fluorescent, or other labeling of the probe allows its location to be detected.

nucleoid (nū'-klē-oyd) A non-membrane-enclosed region in a prokaryotic cell where its chromosome is located.

nucleolus (nū'-klē'-ō-lus) (plural, **nucleoli**) A specialized structure in the nucleus, consisting of chromosomal regions containing ribosomal RNA (rRNA) genes along with ribosomal proteins imported from the cytoplasm; site of rRNA synthesis and ribosomal subunit assembly. *See also* ribosome.

nucleosome (nū'-klē-ō-sōm') The basic, bead-like unit of DNA packing in eukaryotes, consisting of a segment of DNA wound around a protein core composed of two copies of each of four types of histone.

nucleotide (nū'-klē-ō-tid') The building block of a nucleic acid, consisting of a five-carbon sugar covalently bonded to a nitrogenous base and one to three phosphate groups.

nucleotide excision repair (nū'-klē-ō-tid') A repair system that removes and then correctly replaces a damaged segment of DNA using the undamaged strand as a guide.

nucleotide-pair substitution (nū'-klē-ō-tid') A type of point mutation in which one nucleotide in a DNA strand and its partner in the complementary strand are replaced by another pair of nucleotides.

nucleus (1) An atom’s central core, containing protons and neutrons. (2) The organelle of a eukaryotic cell that contains the genetic material in the form of chromosomes, made up of chromatin. (3) A cluster of neurons.

nutrition The process by which an organism takes in and makes use of food substances.

obligate aerobe (ob'-lig-ēt ār'-ōb) An organism that requires oxygen for cellular respiration and cannot live without it.

obligate anaerobe (ob'-lig-ēt an'-uh-rōb) An organism that carries out only fermentation or anaerobic respiration. Such organisms cannot use oxygen and in fact may be poisoned by it.

ocean acidification The process by which the pH of the ocean is lowered (made more acidic) when excess CO₂ dissolves in seawater and forms carbonic acid (H₂CO₃).

oceanic pelagic zone Most of the ocean’s waters far from shore, constantly mixed by ocean currents.

odorant A molecule that can be detected by sensory receptors of the olfactory system.

Okazaki fragment (ō'-kah-zah'-kē) A short segment of DNA synthesized away from the replication fork on a template strand during DNA replication. Many such segments are joined together to make up the lagging strand of newly synthesized DNA.

olfaction The sense of smell.

oligodendrocyte A type of glial cell that forms insulating myelin sheaths around the axons of neurons in the central nervous system.

oligotrophic lake A nutrient-poor, clear lake with few phytoplankton.

ommatidium (ōm'-uh-tid'-ē-ūm) (plural, **ommatidia**) One of the facets of the compound eye of arthropods and some polychaete worms.

omnivore An animal that regularly eats animals as well as plants or algae.

oncogene (on'-kō-jēn) A gene found in viral or cellular genomes that is involved in triggering molecular events that can lead to cancer.

oocyte (ō'-uh-sīt) A cell in the female reproductive system that differentiates to form an egg.

oogenesis (ō'-uh-jen'-uh-sis) The process in the ovary that results in the production of female gametes.

oogonium (ō'-uh-gō'-nē-em) (plural, **oogonia**) A cell that divides mitotically to form oocytes.

open circulatory system A circulatory system in which fluid called hemolymph bathes the tissues and organs directly and there is no distinction between the circulating fluid and the interstitial fluid.

operator In bacterial and phage DNA, a sequence of nucleotides near the start of an operon to which an active repressor can attach. The binding of the repressor prevents RNA polymerase from attaching to the promoter and transcribing the genes of the operon.

operculum (ō-per'-kyuh-lum) In aquatic osteichthyans, a protective bony flap that covers and protects the gills.

operon (op'-er-on) A unit of genetic function found in bacteria and phages, consisting of a promoter, an operator, and a coordinately regulated cluster of genes whose products function in a common pathway.

opisthokont (uh-pis'-thuh-kont') A member of an extremely diverse clade of eukaryotes that includes fungi, animals, and several closely related groups of protists.

opposable thumb A thumb that can touch the ventral surface (fingerprint side) of the fingertip of all four fingers of the same hand with its own ventral surface.

opsin A membrane protein bound to a light-absorbing pigment molecule.

optimal foraging model The basis for analyzing behavior as a compromise between feeding costs and feeding benefits.

oral cavity The mouth of an animal.

orbital The three-dimensional space where an electron is found 90% of the time.

order In Linnaean classification, the taxonomic category above the level of family.

organ A specialized center of body function composed of several different types of tissues.

organelle (ōr-guh-nel') Any of several membrane-enclosed structures with specialized functions, suspended in the cytosol of eukaryotic cells.

organic chemistry The study of carbon compounds (organic compounds).

organism An individual living thing, consisting of one or more cells.

organismal ecology The branch of ecology concerned with the morphological, physiological, and behavioral ways in

which individual organisms meet the challenges posed by their biotic and abiotic environments.

organ of Corti (kor'-tē) The actual hearing organ of the vertebrate ear, located in the floor of the cochlear duct in the inner ear; contains the receptor cells (hair cells) of the ear.

organogenesis (ör-gan'-ō-jen'-uh-sis) The process in which organ rudiments develop from the three germ layers after gastrulation.

organ system A group of organs that work together in performing vital body functions.

origin of replication Site where the replication of a DNA molecule begins, consisting of a specific sequence of nucleotides.

orthologous genes Homologous genes that are found in different species because of speciation.

osculum (os'-kyuh-lum) A large opening in a sponge that connects the spongocoel to the environment.

osmoconformer An animal that is isoosmotic with its environment.

osmolarity (oz'-mō-lär'-uh-tē) Solute concentration expressed as molarity.

osmoregulation Regulation of solute concentrations and water balance by a cell or organism.

osmoregulator An animal that controls its internal osmolarity independent of the external environment.

osmosis (oz-mō'-sis) The diffusion of free water across a selectively permeable membrane.

osteichthyan (os'-tē-ik'-thē-an) A member of a vertebrate clade with jaws and mostly bony skeletons.

outer ear One of the three main regions of the ear in reptiles (including birds) and mammals; made up of the auditory canal and, in many birds and mammals, the pinna.

outgroup A species or group of species from an evolutionary lineage that is known to have diverged before the lineage that contains the group of species being studied. An outgroup is selected so that its members are closely related to the group of species being studied, but not as closely related as any study-group members are to each other.

oval window In the vertebrate ear, a membrane-covered gap in the skull bone, through which sound waves pass from the middle ear to the inner ear.

ovarian cycle (ö-vär'-ē-un) The cyclic recurrence of the follicular phase, ovulation, and the luteal phase in the mammalian ovary, regulated by hormones.

ovary (ö'-vuh-rē) (1) In flowers, the portion of a carpel in which the egg-containing ovules develop. (2) In animals, the structure that produces female gametes and reproductive hormones.

oviduct (ö'-vuh-duct) A tube passing from the ovary to the vagina in invertebrates or to the uterus in vertebrates, where it is also called a fallopian tube.

oviparous (ö-vip'-uh-rus) Referring to a type of development in which young hatch from eggs laid outside the mother's body.

ovoviviparous (ö'-vō-vī-vip'-uh-rus) Referring to a type of development in which young hatch from eggs that are retained in the mother's uterus.

ovulation The release of an egg from an ovary.

In humans, an ovarian follicle releases an egg during each uterine (menstrual) cycle.

ovule (ö'-vyü'l) A structure that develops within the ovary of a seed plant and contains the female gametophyte.

oxidation The complete or partial loss of electrons from a substance involved in a redox reaction.

oxidative phosphorylation (fos'-fōr-uh-lā'-shun) The production of ATP using energy derived from the redox reactions of an electron transport chain; the third major stage of cellular respiration.

oxidizing agent The electron acceptor in a redox reaction.

oxytocin (ok'-si-tō'-sen) A hormone produced by the hypothalamus and released from the posterior pituitary. It induces contractions of the uterine muscles during labor and causes the mammary glands to eject milk during nursing.

p53 gene A tumor-suppressor gene that codes for a specific transcription factor that promotes the synthesis of proteins that inhibit the cell cycle.

paedomorphosis (pē'-duh-mōr'-fuh-sis) The retention in an adult organism of the juvenile features of its evolutionary ancestors.

pain receptor A sensory receptor that responds to noxious or painful stimuli; also called a nociceptor.

paleoanthropology The study of human origins and evolution.

paleontology (pā'-lē-un-tol'-ō-jē) The scientific study of fossils.

pancreas (pan'-krē-us) A gland with exocrine and endocrine tissues. The exocrine portion functions in digestion, secreting enzymes and an alkaline solution into the small intestine via a duct; the ductless endocrine portion functions in homeostasis, secreting the hormones insulin and glucagon into the blood.

pancrustacean A member of a diverse arthropod clade that includes lobsters, crabs, barnacles and other crustaceans, as well as insects and their six-legged terrestrial relatives.

pandemic A global epidemic.

Pangaea (pan-jē'-uh) The supercontinent that formed near the end of the Paleozoic era, when plate movements brought all the landmasses of Earth together.

parabasalid A protist, such as a trichomonad, with modified mitochondria.

paracrine Referring to a secreted molecule that acts on a neighboring cell.

paralogous genes Homologous genes that are found in the same genome as a result of gene duplication.

paraphyletic (pär'-uh-fī-let'-ik) Pertaining to a group of taxa that consists of a common ancestor and some, but not all, of its descendants.

parareptile A basal group of reptiles, consisting mostly of large, stocky quadrupedal herbivores. Parareptiles died out in the late Triassic period.

parasite (pär'-uh-sit) An organism that feeds on the cell contents, tissues, or body fluids of another species (the host) while in or on the host organism. Parasites harm but usually do not kill their host.

parasitism (pär'-uh-sit-izm) A +/- ecological interaction in which one organism, the parasite, benefits by feeding upon another organism, the host, which is harmed; some parasites live within the host (feeding on its tissues), while others feed on the host's external surface.

parasympathetic division A division of the autonomic nervous system; generally enhances body activities that gain and conserve energy, such as digestion and reduced heart rate.

parathyroid gland One of four small endocrine glands, embedded in the surface of the thyroid gland, that secrete parathyroid hormone.

parathyroid hormone (PTH) A hormone secreted by the parathyroid glands that raises blood calcium level by promoting calcium release from bone and calcium retention by the kidneys.

parenchyma cell (puh-ren'-ki-muh) A relatively unspecialized plant cell type that carries out most of the metabolism, synthesizes and stores organic products, and develops into a more differentiated cell type.

parental type An offspring with a phenotype that matches one of the true-breeding parental (P generation) phenotypes; also refers to the phenotype itself.

Parkinson's disease A progressive brain disease characterized by difficulty in initiating movements, slowness of movement, and rigidity.

parthenogenesis (par'-thuh-nō'-jen'-uh-sis) A form of asexual reproduction in which females produce offspring from unfertilized eggs.

partial pressure The pressure exerted by a particular gas in a mixture of gases (for instance, the pressure exerted by oxygen in air).

passive immunity Short-term immunity conferred by the transfer of antibodies, as occurs in the transfer of maternal antibodies to a fetus or nursing infant.

passive transport The diffusion of a substance across a biological membrane with no expenditure of energy.

pathogen An organism or virus that causes disease.

pathogen-associated molecular pattern (PAMP) A molecular sequence that is specific to a certain pathogen.

pattern formation The development of a multicellular organism's spatial organization, the arrangement of organs and tissues in their characteristic places in three-dimensional space.

peat Extensive deposits of partially decayed organic material often formed primarily from the wetland moss *Sphagnum*.

pedigree A diagram of a family tree with conventional symbols, showing the occurrence of heritable characters in parents and offspring over multiple generations.

pelagic zone The open-water component of aquatic biomes.

penis The copulatory structure of male mammals.

PEP carboxylase An enzyme that adds CO₂ to phosphoenolpyruvate (PEP) to form oxaloacetate in mesophyll cells of C₄ plants. It acts prior to photosynthesis.

pepsin An enzyme present in gastric juice that begins the hydrolysis of proteins.

pepsinogen The inactive form of pepsin secreted by chief cells located in gastric pits of the stomach.

peptide bond The covalent bond between the carboxyl group on one amino acid and the amino group on another, formed by a dehydration reaction.

peptidoglycan (pep'-tid-o-gli'-kan) A type of polymer in bacterial cell walls consisting of modified sugars cross-linked by short polypeptides.

perception The interpretation of sensory system input by the brain.

pericycle The outermost layer in the vascular cylinder, from which lateral roots arise.

periderm (pär'-uh-derm') The protective coat that replaces the epidermis in woody plants during secondary growth, formed of the cork and cork cambium.

peripheral nervous system (PNS) The sensory and motor neurons that connect to the central nervous system.

peripheral protein A protein loosely bound to the surface of a membrane or to part of an integral protein and not embedded in the lipid bilayer.

peristalsis (pär'-uh-stal'-sis) (1) Alternating waves of contraction and relaxation in the smooth muscles lining the alimentary canal that push food along the canal. (2) A type of movement on land produced by rhythmic waves of muscle contractions passing from front to back, as in many annelids.

peristome (pär'-uh-stōmē) A ring of interlocking, tooth-like structures on the upper part of a moss capsule (sporangium), often specialized for gradual spore discharge.

peritubular capillary One of the tiny blood vessels that form a network surrounding the proximal and distal tubules in the kidney.

peroxisome (puh-rok'-suh-sōm') An organelle containing enzymes that transfer hydrogen atoms from various substrates to oxygen (O_2), producing and then degrading hydrogen peroxide (H_2O_2).

personalized medicine A type of medical care in which each person's specific genetic profile can provide information about diseases or conditions for which the person is especially at risk and help make health-care decisions.

petal A modified leaf of a flowering plant. Petals are the often colorful parts of a flower that advertise it to insects and other pollinators.

petiole (pet'-ē-ōl) The stalk of a leaf, which joins the leaf to a node of the stem.

P generation The true-breeding (homozygous) parent individuals from which F_1 hybrid offspring are derived in studies of inheritance. (P stands for parental.)

pH A measure of hydrogen ion concentration equal to $-\log[H^+]$ and ranging in value from 0 to 14.

phage (fāj) A virus that infects bacteria; also called a bacteriophage.

phagocytosis (fag'-ō-sī-tō'-sis) A type of endocytosis in which large particulate substances or small organisms are taken up by a cell. It is carried out by some protists and by certain

immune cells of animals (in mammals, mainly macrophages, neutrophils, and dendritic cells).

pharyngeal cleft (fuh-rin'-jē-ul) In chordate embryos, one of the grooves that separate a series of arches along the outer surface of the pharynx and may develop into a pharyngeal slit.

pharyngeal slit (fuh-rin'-jē-ul) In chordate embryos, one of the slits that form from the pharyngeal clefts and open into the pharynx, later developing into gill slits in many vertebrates.

pharynx (fār'-inks) (1) An area in the vertebrate throat where air and food passages cross. (2) In flatworms, the muscular tube that protrudes from the ventral side of the worm and ends in the mouth.

phase change (1) A shift from one developmental phase to another. (2) In plants, a morphological change that arises from a transition in shoot apical meristem activity.

phenotype (fē'-nō-tip) The observable physical and physiological traits of an organism, which are determined by its genetic makeup.

pheromone (fär'-uh-mōn) In animals and fungi, a small molecule released into the environment that functions in communication between members of the same species. In animals, it acts much like a hormone in influencing physiology and behavior.

phloem (flō'-em) Vascular plant tissue consisting of living cells arranged into elongated tubes that transport sugar and other organic nutrients throughout the plant.

phloem sap (flō'-em) The sugar-rich solution carried through a plant's sieve tubes.

phosphate group A chemical group consisting of a phosphorus atom bonded to four oxygen atoms; important in energy transfer.

phospholipid (fos'-fō-lip'-id) A lipid made up of glycerol joined to two fatty acids and a phosphate group. The hydrocarbon chains of the fatty acids act as nonpolar, hydrophobic tails, while the rest of the molecule acts as a polar, hydrophilic head. Phospholipids form bilayers that function as biological membranes.

phosphorylated intermediate (fos'-fō-uh-lā'-ted) A molecule (often a reactant) with a phosphate group covalently bound to it, making it more reactive (less stable) than the unphosphorylated molecule.

phosphorylation cascade (fos'-fō-uh-lā'-shun) A series of chemical reactions during cell signaling mediated by enzymes (kinases), in which each kinase in turn phosphorylates and activates another, ultimately leading to phosphorylation of many proteins.

photic zone (fō'-tic) The narrow top layer of an ocean or lake, where light penetrates sufficiently for photosynthesis to occur.

photoautotroph (fō'-tō-ot'-ō-trōf) An organism that harnesses light energy to drive the synthesis of organic compounds from carbon dioxide.

photoheterotroph (fō'-tō-het'-er-ō-trōf) An organism that uses light to generate ATP but must obtain carbon in organic form.

photomorphogenesis Effects of light on plant morphology.

photon (fō'-ton) A quantum, or discrete quantity, of light energy that behaves as if it were a particle.

photoperiodism (fō'-tō-pēr'-ē-ō-dizm) A physiological response to photoperiod, the interval in a 24-hour period during which an organism is exposed to light. An example of photoperiodism is flowering.

photophosphorylation (fō'-tō-fos'-fōr-uh-lā'-shun) The process of generating ATP from ADP and phosphate by means of chemiosmosis, using a proton-motive force generated across the thylakoid membrane of the chloroplast or the membrane of certain prokaryotes during the light reactions of photosynthesis.

photoreceptor An electromagnetic receptor that detects the radiation known as visible light.

photorespiration A metabolic pathway that consumes oxygen and ATP, releases carbon dioxide, and decreases photosynthetic output. Photorespiration generally occurs on hot, dry, bright days, when the stomata close and the O_2 : CO_2 ratio in the leaf increases, favoring the binding of O_2 rather than CO_2 by rubisco.

photosynthesis (fō'-tō-sin'-thi-sis) The conversion of light energy to chemical energy that is stored in sugars or other organic compounds; occurs in plants, algae, and certain prokaryotes.

photosystem A light-capturing unit located in the thylakoid membrane of the chloroplast or in the membrane of some prokaryotes, consisting of a reaction-center complex surrounded by numerous light-harvesting complexes. There are two types of photosystems, I and II; they absorb light best at different wavelengths.

photosystem I (PS I) A light-capturing unit in a chloroplast's thylakoid membrane or in the membrane of some prokaryotes; it has two molecules of P700 chlorophyll *a* at its reaction center.

photosystem II (PS II) One of two light-capturing units in a chloroplast's thylakoid membrane or in the membrane of some prokaryotes; it has two molecules of P680 chlorophyll *a* at its reaction center.

phototropism (fō'-tō-trō'-pizm) The bending of a plant or other organism in response to light, either toward the source of light (positive phototropism) or away from it (negative phototropism).

phylogenetic tree A branching diagram that represents a hypothesis about the evolutionary history of a group of organisms.

phylogeny (fi-loj'-uh-nē) The evolutionary history of a species or group of related species.

phylum (fi'-lum) (plural, **phylla**) In Linnaean classification, the taxonomic category above class.

physiology The processes and functions of an organism.

phytochromes (fi'-tuh-krōm) Plant pigments that absorb mostly red and far-red light and regulate many plant responses, such as seed germination and shade avoidance.

phytoremediation An emerging technology that seeks to reclaim contaminated areas by taking advantage of some plant species' ability to extract heavy metals and other pollutants from the soil and to concentrate them in easily harvested portions of the plant.

pilus (plural, **pili**) (pí'-lus, pí'-lē) In bacteria, a structure that links one cell to another at the start of conjugation; also called a sex pilus or conjugation pilus.

pineal gland (pí'-nē-äl) A small gland on the dorsal surface of the vertebrate forebrain that secretes the hormone melatonin.

pinocytosis (pí'-nō-sí-tō'-sis) A type of endocytosis in which the cell ingests extracellular fluid and its dissolved solutes.

pistil A single carpel (a simple pistil) or a group of fused carpels (a compound pistil).

pith Ground tissue that is internal to the vascular tissue in a stem; in many monocot roots, parenchyma cells that form the central core of the vascular cylinder.

pituitary gland (puh-tū'-uh-tār'-ē) An endocrine gland at the base of the hypothalamus; consists of a posterior lobe, which stores and releases two hormones produced by the hypothalamus, and an anterior lobe, which produces and secretes many hormones that regulate diverse body functions.

placenta (pluh-sen'-tuh) A structure in the uterus of a pregnant eutherian mammal that nourishes the fetus with the mother's blood supply; formed from the uterine lining and embryonic membranes.

placoderm A member of an extinct group of fishlike vertebrates that had jaws and were enclosed in a tough outer armor.

planarian A free-living flatworm found in ponds and streams.

plasma (plaz'-muh) The liquid matrix of blood in which the blood cells are suspended.

plasma membrane (plaz'-muh) The membrane at the boundary of every cell that acts as a selective barrier, regulating the cell's chemical composition.

plasmid (plaz'-mid) A small, circular, double-stranded DNA molecule that carries accessory genes separate from those of a bacterial chromosome; in DNA cloning, plasmids are used as vectors carrying up to about 10,000 base pairs (10 kb) of DNA. Plasmids are also found in some eukaryotes, such as yeasts.

plasmodesma (plaz'-mō-dez'-muh) (plural, **plasmodesmata**) An open channel through the cell wall that connects the cytoplasm of adjacent plant cells, allowing water, small solutes, and some larger molecules to pass between the cells.

plasmogamy (plaz-moh'-guh-mē) In fungi, the fusion of the cytoplasm of cells from two individuals; occurs as one stage of sexual reproduction, followed later by karyogamy.

plasmolysis (plaz-mol'-uh-sis) A phenomenon in walled cells in which the cytoplasm shrivels and the plasma membrane pulls away from the cell wall; occurs when the cell loses water to a hypertonic environment.

plastid One of a family of closely related organelles that includes chloroplasts, chromoplasts, and amyloplasts. Plastids are found in cells of photosynthetic eukaryotes.

plate tectonics The theory that the continents are part of great plates of Earth's crust that float on the hot, underlying portion of the mantle. Movements in the mantle cause the continents to move slowly over time.

platelet A pinched-off cytoplasmic fragment of a specialized bone marrow cell. Platelets

circulate in the blood and are important in blood clotting.

pleiotropy (plí'-o-truh-pé) The ability of a single gene to have multiple effects.

pluripotent Describing a cell that can give rise to many, but not all, parts of an organism.

point mutation A change in a single nucleotide pair of a gene.

polar covalent bond A covalent bond between atoms that differ in electronegativity. The shared electrons are pulled closer to the more electronegative atom, making it slightly negative and the other atom slightly positive.

polar molecule A molecule (such as water) with an uneven distribution of charges in different regions of the molecule.

polarity A lack of symmetry; structural differences in opposite ends of an organism or structure, such as the root end and shoot end of a plant.

pollen grain In seed plants, a structure consisting of the male gametophyte enclosed within a pollen wall.

pollen tube A tube that forms after germination of the pollen grain and that functions in the delivery of sperm to the ovule.

pollination (pol'-uh-nā'-shun) The transfer of pollen to the part of a seed plant containing the ovules, a process required for fertilization.

poly-A tail A sequence of 50–250 adenine nucleotides added onto the 3' end of a pre-mRNA molecule.

polygamous Referring to a type of relationship in which an individual of one sex mates with several of the other.

polygenic inheritance (pol'-ē-jen'-ik) An additive effect of two or more genes on a single phenotypic character.

polymer (pol'-uh-mer) A long molecule consisting of many similar or identical monomers linked together by covalent bonds.

polymerase chain reaction (PCR) (puh-lim'-uh-rās) A technique for amplifying DNA *in vitro* by incubating it with specific primers, a heat-resistant DNA polymerase, and nucleotides.

polynucleotide (pol'-ē-nū'-klē-ō-tid) A polymer consisting of many nucleotide monomers in a chain. The nucleotides can be those of DNA or RNA.

polyp The sessile variant of the cnidarian body plan. The alternate form is the medusa.

polypeptide (pol'-ē-pep'-tid) A polymer of many amino acids linked together by peptide bonds.

polyphyletic (pol'-ē-fi-let'-ik) Pertaining to a group of taxa that includes distantly related organisms but does not include their most recent common ancestor.

polyploid (pol'-ē-ploy'-dē) A chromosomal alteration in which the organism possesses more than two complete chromosome sets. It is the result of an accident of cell division.

polyribosome (polysome) (pol'-ē-ri'-buhs'-ōm') A group of several ribosomes attached to, and translating, the same messenger RNA molecule.

polysaccharide (pol'-ē-sak'-uh-rid) A polymer of many monosaccharides, formed by dehydration reactions.

polyspermy The fertilization of an egg by more than one sperm.

polytomy (puh-lit'-uh-mē) In a phylogenetic tree, a branch point from which more than two descendant taxa emerge. A polytomy indicates that the evolutionary relationships between the descendant taxa are not yet clear.

pons A portion of the brain that participates in certain automatic, homeostatic functions, such as regulating the breathing centers in the medulla.

population A group of individuals of the same species that live in the same area and interbreed, producing fertile offspring.

population dynamics The study of how complex interactions between biotic and abiotic factors influence variations in population size.

population ecology The study of populations in relation to their environment, including environmental influences on population density and distribution, age structure, and variations in population size.

positional information Molecular cues that control pattern formation in an animal or plant embryonic structure by indicating a cell's location relative to the organism's body axes. These cues elicit a response by genes that regulate development.

positive feedback A form of regulation in which an end product of a process speeds up that process; in physiology, a control mechanism in which a change in a variable triggers a response that reinforces or amplifies the change.

positive interaction A +/+ or +/0 ecological interaction between individuals of two species in which at least one individual benefits and neither is harmed; positive interactions include mutualism and commensalism.

positive pressure breathing A breathing system in which air is forced into the lungs.

posterior Pertaining to the rear, or tail end, of a bilaterally symmetrical animal.

posterior pituitary An extension of the hypothalamus composed of nervous tissue that secretes oxytocin and antidiuretic hormone made in the hypothalamus; a temporary storage site for these hormones.

postzygotic barrier (pōst'-zī-got'-ik) A reproductive barrier that prevents hybrid zygotes produced by two different species from developing into viable, fertile adults.

potential energy The energy that matter possesses as a result of its location or spatial arrangement (structure).

predation An interaction in which an individual of one species, the predator, kills and eats an individual of the other species, the prey.

prediction In deductive reasoning, a forecast that follows logically from a hypothesis. By testing predictions, experiments may allow certain hypotheses to be rejected.

pregnancy The condition of carrying one or more embryos in the uterus; also called gestation.

pressure potential (Ψ_p) A component of water potential that consists of the physical pressure on a solution, which can be positive, zero, or negative.

prezygotic barrier (prē'-zī-got'-ik) A reproductive barrier that impedes mating between species or hinders fertilization if interspecific mating is attempted.

- primary cell wall** In plants, a relatively thin and flexible layer that surrounds the plasma membrane of a young cell.
- primary consumer** An herbivore; an organism that eats plants or other autotrophs.
- primary electron acceptor** In the thylakoid membrane of a chloroplast or in the membrane of some prokaryotes, a specialized molecule that shares the reaction-center complex with a pair of chlorophyll *a* molecules and that accepts an electron from them.
- primary growth** Growth produced by apical meristems, lengthening stems and roots.
- primary immune response** The initial adaptive immune response to an antigen, which appears after a lag of about 10–17 days.
- primary meristems** The three meristematic derivatives (protoderm, procambium, and ground meristem) of an apical meristem.
- primary oocyte** (ō'-uh-sīt) An oocyte prior to completion of meiosis I.
- primary producer** An autotroph, usually a photosynthetic organism. Collectively, autotrophs make up the trophic level of an ecosystem that ultimately supports all other levels.
- primary production** The amount of light energy converted to chemical energy (organic compounds) by the autotrophs in an ecosystem during a given time period.
- primary structure** The level of protein structure referring to the specific linear sequence of amino acids.
- primary succession** A type of ecological succession that occurs in an area where there were originally no organisms present and where soil has not yet formed.
- primary transcript** An initial RNA transcript from any gene; also called pre-mRNA when transcribed from a protein-coding gene.
- primase** An enzyme that joins RNA nucleotides to make a primer during DNA replication, using the parental DNA strand as a template.
- primer** A short polynucleotide with a free 3' end, bound by complementary base pairing to the template strand and elongated with DNA nucleotides during DNA replication.
- prion** An infectious agent that is a misfolded version of a normal cellular protein. Prions appear to increase in number by converting correctly folded versions of the protein to more prions.
- problem solving** The cognitive activity of devising a method to proceed from one state to another in the face of real or apparent obstacles.
- producer** An organism that produces organic compounds from CO₂ by harnessing light energy (in photosynthesis) or by oxidizing inorganic chemicals (in chemosynthetic reactions carried out by some prokaryotes).
- product** A material resulting from a chemical reaction.
- production efficiency** The percentage of energy stored in assimilated food that is not used for respiration or eliminated as waste.
- progesterone** A steroid hormone that contributes to the menstrual cycle and prepares the uterus for pregnancy; the major progestin in mammals.
- progestin** Any steroid hormone with progesterone-like activity.

- prokaryote** A single-celled organism of the domain Bacteria or Archaea.
- prokaryotic cell** (prō'-kär'-ē-ot'-ik) A type of cell lacking a membrane-enclosed nucleus and membrane-enclosed organelles. Organisms with prokaryotic cells (bacteria and archaea) are called prokaryotes.
- prolactin** A hormone produced and secreted by the anterior pituitary with a great diversity of effects in different vertebrate species. In mammals, it stimulates growth of and milk production by the mammary glands.
- prometaphase** The second stage of mitosis, in which the nuclear envelope fragments and the spindle microtubules attach to the kinetochores of the chromosomes.
- promoter** A specific nucleotide sequence in the DNA of a gene that binds RNA polymerase, positioning it to start transcribing RNA at the appropriate place.
- prophage** (prō'-fāj) A phage genome that has been inserted into a specific site on a bacterial chromosome.
- prophase** The first stage of mitosis, in which the chromatin condenses into discrete chromosomes visible with a light microscope, the mitotic spindle begins to form, and the nucleolus disappears but the nucleus remains intact.
- prostaglandin** (pros'-tuh-glan'-din) One of a group of modified fatty acids that are secreted by virtually all tissues and that perform a wide variety of functions as local regulators.
- prostate gland** (pros'-tāt) A gland in human males that secretes an acid-neutralizing component of semen.
- protease** (prō'-tē-āz) An enzyme that digests proteins by hydrolysis.
- protein** (prō'-tēn) A biologically functional molecule consisting of one or more polypeptides folded and coiled into a specific three-dimensional structure.
- protein kinase** (prō'-tēn kī'-nās) An enzyme that transfers phosphate groups from ATP to a protein, thus phosphorylating the protein.
- protein phosphatase** (prō'-tēn fos'-fuh-tās) An enzyme that removes phosphate groups from (dephosphorylates) proteins, often functioning to reverse the effect of a protein kinase.
- proteoglycan** (prō'-tē-ō-gli'-kan) A large molecule consisting of a small core protein with many carbohydrate chains attached, found in the extracellular matrix of animal cells. A proteoglycan may consist of up to 95% carbohydrate.
- proteome** The entire set of proteins expressed by a given cell, tissue, or organism.
- proteomics** (prō'-tē-ō'-miks) The systematic study of sets of proteins and their properties, including their abundance, chemical modifications, and interactions.
- protist** An informal term applied to any eukaryote that is not a plant, animal, or fungus. Most protists are unicellular, though some are colonial or multicellular.
- protocell** An abiotic precursor of a living cell that had a membrane-like structure and that maintained an internal chemistry different from that of its surroundings.
- proton** (prō'-ton) A subatomic particle with a single positive electrical charge, with a mass of about 1.7×10^{-24} g, found in the nucleus of an atom.
- protoonema** (prō'-tuh-nē'-muh) (plural, **protoonemata**) A mass of green, branched, one-cell-thick filaments produced by germinating moss spores.
- protonephridium** (prō'-tō-nuh-frid'-ē-um) (plural, **protonephridia**) An excretory system, such as the flame bulb system of flatworms, consisting of a network of tubules lacking internal openings.
- proton-motive force** (prō'-ton) The potential energy stored in the form of a proton electrochemical gradient, generated by the pumping of hydrogen ions (H⁺) across a biological membrane during chemiosmosis.
- proton pump** (prō'-ton) An active transport protein in a cell membrane that uses ATP to transport hydrogen ions out of a cell against their concentration gradient, generating a membrane potential in the process.
- proto-oncogene** (prō'-tō-on'-kō-jēn) A normal cellular gene that has the potential to become an oncogene.
- protoplast** The living part of a plant cell, which also includes the plasma membrane.
- protostome development** In animals, a developmental mode distinguished by the development of the mouth from the blastopore; often also characterized by spiral cleavage and by the body cavity forming when solid masses of mesoderm split.
- provirus** A viral genome that is permanently inserted into a host genome.
- proximal tubule** In the vertebrate kidney, the portion of a nephron immediately downstream from Bowman's capsule that conveys and helps refine filtrate.
- pseudogene** (sū'-dō-jēn) A DNA segment that is very similar to a real gene but does not yield a functional product; a DNA segment that formerly functioned as a gene but has become inactivated in a particular species because of mutation.
- pseudopodium** (sū'-dō-pō'-dē-um) (plural, **pseudopodia**) A cellular extension of amoeboid cells used in moving and feeding.
- P site** One of a ribosome's three binding sites for tRNA during translation. The P site holds the tRNA carrying the growing polypeptide chain. (P stands for peptidyl tRNA.)
- pterosaur** Winged reptile that lived during the Mesozoic era.
- pulse** The rhythmic bulging of the artery walls with each heartbeat.
- punctuated equilibria** In the fossil record, long periods of apparent stasis, in which a species undergoes little or no morphological change, interrupted by relatively brief periods of sudden change.
- Punnett square** A diagram used in the study of inheritance to show the predicted genotypic results of random fertilization in genetic crosses between individuals of known genotype.
- pupil** The opening in the iris, which admits light into the interior of the vertebrate eye. Muscles in the iris regulate its size.
- purine** (pyū'-rēn) One of two types of nitrogenous bases found in nucleotides, characterized by a six-membered ring fused to a

five-membered ring. Adenine (A) and guanine (G) are purines.

pyrimidine (puh-rim'-uh-dēn) One of two types of nitrogenous bases found in nucleotides, characterized by a six-membered ring. Cytosine (C), thymine (T), and uracil (U) are pyrimidines.

quantitative character A heritable feature that varies continuously over a range rather than in an either-or fashion.

quaternary structure (kwot'-er-när'-ē) The particular shape of a complex, aggregate protein, defined by the characteristic three-dimensional arrangement of its constituent subunits, each a polypeptide.

radial cleavage A type of embryonic development in deuterostomes in which the planes of cell division that transform the zygote into a ball of cells are either parallel or perpendicular to the vertical axis of the embryo, thereby aligning tiers of cells one above the other.

radial symmetry Symmetry in which the body is shaped like a pie or barrel (lacking a left side and a right side) and can be divided into mirror-imaged halves by any plane through its central axis.

radicle An embryonic root of a plant.

radioactive isotope An isotope (an atomic form of a chemical element) that is unstable; the nucleus decays spontaneously, giving off detectable particles and energy.

radiolarian A protist, usually marine, with a shell generally made of silica and pseudopodia that radiate from the central body.

radiometric dating A method for determining the absolute age of rocks and fossils, based on the half-life of radioactive isotopes.

radula A straplike scraping organ used by many molluscs during feeding.

ras gene A gene that codes for Ras, a G protein that relays a growth signal from a growth factor receptor on the plasma membrane to a cascade of protein kinases, ultimately resulting in stimulation of the cell cycle.

ratite (rat'-it) A member of the group of flightless birds.

ray-finned fish A member of the clade Actinopterygii, aquatic osteichthyans with fins supported by long, flexible rays, including tuna, bass, and herring.

reabsorption In excretory systems, the recovery of solutes and water from filtrate.

reactant A starting material in a chemical reaction.

reaction-center complex A complex of proteins associated with a special pair of chlorophyll *a* molecules and a primary electron acceptor. Located centrally in a photosystem, this complex triggers the light reactions of photosynthesis. Excited by light energy, the pair of chlorophylls donates an electron to the primary electron acceptor, which passes an electron to an electron transport chain.

reading frame On an mRNA, the triplet grouping of ribonucleotides used by the translation machinery during polypeptide synthesis.

receptacle The base of a flower; the part of the stem that is the site of attachment of the floral organs.

reception In cellular communication, the first step of a signaling pathway in which a signaling molecule is detected by a receptor molecule on or in the cell.

receptor-mediated endocytosis (en'-dō-si-tō'-sis) The movement of specific molecules into a cell by the infolding of vesicles containing proteins with receptor sites specific to the molecules being taken in; enables a cell to acquire bulk quantities of specific substances.

receptor potential A graded potential occurring in a receptor cell.

receptor tyrosine kinase (RTK) A receptor protein spanning the plasma membrane, the cytoplasmic (intracellular) part of which can catalyze the transfer of a phosphate group from ATP to a tyrosine on another protein. Receptor tyrosine kinases often respond to the binding of a signaling molecule by dimerizing and then phosphorylating a tyrosine on the cytoplasmic portion of the other receptor in the dimer.

recessive allele An allele whose phenotypic effect is not observed in a heterozygote.

reciprocal altruism Altruistic behavior between unrelated individuals, whereby the altruistic individual benefits in the future when the beneficiary reciprocates.

recombinant chromosome A chromosome created when crossing over combines DNA from two parents into a single chromosome.

recombinant DNA molecule A DNA molecule made *in vitro* with segments from different sources.

recombinant type (recombinant) An offspring whose phenotype differs from that of the true-breeding P generation parents; also refers to the phenotype itself.

rectum The terminal portion of the large intestine, where the feces are stored prior to elimination.

red alga A photosynthetic protist, named for its color, which results from a red pigment that masks the green of chlorophyll. Most red algae are multicellular and marine.

redox reaction (rē'-doks) A chemical reaction involving the complete or partial transfer of one or more electrons from one reactant to another; short for reduction-oxidation reaction.

reducing agent The electron donor in a redox reaction.

reduction The complete or partial addition of electrons to a substance involved in a redox reaction.

reference genome A complete sequence that researchers agree best represents the genome of a given species, arrived at by sequencing multiple individuals.

reflex An automatic reaction to a stimulus, mediated by the spinal cord or lower brain.

refractory period (rē-frak'-tōr-ē) A period, immediately following a response to stimulation, during which a cell or organ is unresponsive to further stimulation.

regulator An animal for which mechanisms of homeostasis moderate internal changes in a particular variable in the face of external fluctuation of that variable.

regulatory gene A gene that codes for a protein, such as a repressor, that controls the transcription of another gene or group of genes.

reinforcement In evolutionary biology, a process in which natural selection strengthens prezygotic barriers to reproduction, thus reducing the chances of hybrid formation. Such a process is likely to occur only if hybrid offspring are less fit than members of the parent species.

relative abundance The proportional abundance of different species in a community.

relative fitness The contribution an individual makes to the gene pool of the next generation, relative to the contributions of other individuals in the population.

renal cortex The outer portion of the vertebrate kidney.

renal medulla The inner portion of the vertebrate kidney, beneath the renal cortex.

renal pelvis The funnel-shaped chamber that receives processed filtrate from the vertebrate kidney's collecting ducts and is drained by the ureter.

renin-angiotensin-aldosterone system

(RAAS) A hormone cascade pathway that helps regulate blood pressure and blood volume.

repetitive DNA Nucleotide sequences, usually noncoding, that are present in many copies in a eukaryotic genome. The repeated units may be short and arranged tandemly (in series) or long and dispersed in the genome.

replication fork A Y-shaped region on a replicating DNA molecule where the parental strands are being unwound and new strands are being synthesized.

repressor A protein that inhibits gene transcription. In prokaryotes, repressors bind to the DNA in or near the promoter. In eukaryotes, repressors may bind to control elements within enhancers, to activators, or to other proteins in a way that blocks activators from binding to DNA.

reproductive isolation The existence of biological factors (barriers) that impede members of two species from producing viable, fertile offspring.

reptile A member of the clade of amniotes that includes tuatars, lizards and snakes, turtles, crocodilians, and birds.

reservoir In biogeochemical cycles, location of a chemical element, consisting of either organic or inorganic materials that are either available for direct use by organisms or unavailable as nutrients.

residual volume The amount of air that remains in the lungs after forceful exhalation.

resource partitioning The division of environmental resources by coexisting species such that the niche of each species differs by one or more significant factors from the niches of all coexisting species.

respiratory pigment A protein that transports oxygen in blood or hemolymph.

response (1) In cellular communication, the change in a specific cellular activity brought about by a transduced signal from outside the cell. (2) In feedback regulation, a physiological activity triggered by a change in a variable.

resting potential The membrane potential characteristic of a nonconducting excitable cell, with the inside of the cell more negative than the outside.

restriction enzyme An endonuclease (type of enzyme) that recognizes and cuts DNA molecules foreign to a bacterium (such as phage genomes). The enzyme cuts at specific nucleotide sequences (restriction sites).

restriction fragment A DNA segment that results from the cutting of DNA by a restriction enzyme.

restriction site A specific sequence on a DNA strand that is recognized and cut by a restriction enzyme.

retina (ret'-i-nuh) The innermost layer of the vertebrate eye, containing photoreceptor cells (rods and cones) and neurons; transmits images formed by the lens to the brain via the optic nerve.

retinal The light-absorbing pigment in rods and cones of the vertebrate eye.

retrotransposon (re'-trō-trans-pō'-zon) A transposable element that moves within a genome by means of an RNA intermediate, a transcript of the retrotransposon DNA.

retrovirus (re'-trō-vī'-rus) An RNA virus that replicates by transcribing its RNA into DNA and then inserting the DNA into a cellular chromosome; an important class of cancer-causing viruses.

reverse transcriptase (tran-skrip'-tās) An enzyme encoded by certain viruses (retroviruses) that uses RNA as a template for DNA synthesis.

reverse transcriptase–polymerase chain reaction (RT-PCR) A technique for determining expression of a particular gene. It uses reverse transcriptase and DNA polymerase to synthesize cDNA from all the mRNA in a sample and then subjects the cDNA to PCR amplification using primers specific for the gene of interest.

rhizarians (rī'-zā'-rē-uhns) One of the three major subgroups for which the SAR eukaryotic supergroup is named. Many species in this clade are amoebas characterized by threadlike pseudopodia.

rhizobacterium A soil bacterium whose population size is much enhanced in the rhizosphere, the soil region close to a plant's roots.

rhizoid (rī'-zoyd) A long, tubular single cell or filament of cells that anchors bryophytes to the ground. Unlike roots, rhizoids are not composed of tissues, lack specialized conducting cells, and do not play a primary role in water and mineral absorption.

rhizosphere The soil region close to plant roots and characterized by a high level of microbial activity.

rhodopsin (rō-dop'-sin) A visual pigment consisting of retinal and opsin. Upon absorbing light, the retinal changes shape and dissociates from the opsin.

ribonucleic acid (RNA) (rī'-bō-nū-klā'-ik) A type of nucleic acid consisting of a polynucleotide made up of nucleotide monomers with a ribose sugar and the nitrogenous bases adenine (A), cytosine (C), guanine (G), and uracil (U); usually single-stranded; functions in protein synthesis, in gene regulation, and as the genome of some viruses.

ribose The sugar component of RNA nucleotides.

ribosomal RNA (rRNA) (rī'-buh-sō'-mul) RNA molecules that, together with proteins, make

up ribosomes; the most abundant type of RNA.

ribosome (rī'-buh-sōm) A complex of rRNA and protein molecules that functions as a site of protein synthesis in the cytoplasm; consists of a large and a small subunit. In eukaryotic cells, each subunit is assembled in the nucleolus. See also nucleolus.

ribozyme (rī'-buh-zim) An RNA molecule that functions as an enzyme, such as an intron that catalyzes its own removal during RNA splicing.

RNA interference (RNAi) A mechanism for silencing the expression of specific genes. In RNAi, double-stranded RNA molecules that match the sequence of a particular gene are processed into siRNAs that either block translation or trigger the degradation of the gene's messenger RNA. This happens naturally in some cells and can be carried out in laboratory experiments as well.

RNA polymerase An enzyme that links ribonucleotides into a growing RNA chain during transcription, based on complementary binding to nucleotides on a DNA template strand.

RNA processing Modification of RNA primary transcripts, including splicing out of introns, joining together of exons, and alteration of the 5' and 3' ends.

RNA sequencing (RNA-seq) (RNA-sēk) A method of analyzing large sets of RNAs that involves making cDNAs and sequencing them.

RNA splicing After synthesis of a eukaryotic primary RNA transcript, the removal of portions of the transcript (introns) that will not be included in the mRNA and the joining together of the remaining portions (exons).

rod A rodlike cell in the retina of the vertebrate eye, sensitive to low light intensity.

root An organ in vascular plants that anchors the plant and enables it to absorb water and minerals from the soil.

root cap A cone of cells at the tip of a plant root that protects the apical meristem.

root hair A tiny extension of a root epidermal cell, growing just behind the root tip and increasing surface area for absorption of water and minerals.

root pressure Pressure exerted in the roots of plants as the result of osmosis, causing exudation from cut stems and guttation of water from leaves.

root system All of a plant's roots, which anchor it in the soil, absorb and transport minerals and water, and store food.

rooted Describing a phylogenetic tree that contains a branch point (often, the one farthest to the left) representing the most recent common ancestor of all taxa in the tree.

rough ER That portion of the endoplasmic reticulum with ribosomes attached.

round window In the mammalian ear, the point of contact where vibrations of the stapes create a traveling series of pressure waves in the fluid of the cochlea.

R plasmid A bacterial plasmid carrying genes that confer resistance to certain antibiotics.

r-selection Selection for life history traits that maximize reproductive success in uncrowded environments.

rubisco (rū-bis'-kō) Ribulose bisphosphate (RuBP) carboxylase-oxygenase, the enzyme that normally catalyzes the first step of the Calvin cycle (the addition of CO₂ to RuBP). When excess O₂ is present or CO₂ levels are low, rubisco can bind oxygen, resulting in photorespiration.

ruminant (rūh'-muh-nent) A cud-chewing animal, such as a cow or sheep, with multiple stomach compartments specialized for an herbivorous diet.

salicylic acid (sal'-i-sil'-ik) A signaling molecule in plants that may be partially responsible for activating systemic acquired resistance to pathogens.

salivary gland A gland associated with the oral cavity that secretes substances that lubricate food and begin the process of chemical digestion.

salt A compound resulting from the formation of an ionic bond; also called an ionic compound.

saltatory conduction (sol'-tuh-tōr'-ē) Rapid transmission of a nerve impulse along an axon, resulting from the action potential jumping from one node of Ranvier to another, skipping the myelin-sheathed regions of membrane.

SAR One of four supergroups of eukaryotes proposed in a current hypothesis of the evolutionary history of eukaryotes. This supergroup contains a large, extremely diverse collection of protists from three major subgroups: stramenopiles, alveolates, and rhizarians. See also Excavata, Archaeplastida, and Unikonta.

sarcomere (sar'-kō-mēr) The fundamental, repeating unit of striated muscle, delimited by the Z lines.

sarcoplasmic reticulum (SR) (sar'-kō-plaz'-mik ruh-tik'-yū-lum) A specialized endoplasmic reticulum that regulates the calcium concentration in the cytosol of muscle cells.

saturated fatty acid A fatty acid in which all carbons in the hydrocarbon tail are connected by single bonds, thus maximizing the number of hydrogen atoms that are attached to the carbon skeleton.

savanna A tropical grassland biome with scattered individual trees and large herbivores and maintained by occasional fires and drought.

scaffolding protein A type of large relay protein to which several other relay proteins are simultaneously attached, increasing the efficiency of signal transduction.

scanning electron microscope (SEM) A microscope that uses an electron beam to scan the surface of a sample, coated with metal atoms, to study details of its topography.

scatter plot A graph in which each piece of data is represented by a point. A scatter plot is used when the data for all variables are numerical and continuous.

schizophrenia (skit'-suh-frē'-nē-uh) A severe mental disturbance characterized by psychotic episodes in which patients have a distorted perception of reality.

Schwann cell A type of glial cell that forms insulating myelin sheaths around the axons of neurons in the peripheral nervous system.

science An approach to understanding the natural world.

scion (sī'-un) The twig grafted onto the stock when making a graft.

- sclerenchyma cell** (skluh-ren'-kim-uh) A rigid, supportive plant cell type usually lacking a protoplast and possessing thick secondary walls strengthened by lignin at maturity.
- scrotum** A pouch of skin outside the abdomen that houses the testes; functions in maintaining the testes at the lower temperature required for spermatogenesis.
- second law of thermodynamics** The principle stating that every energy transfer or transformation increases the entropy of the universe. Usable forms of energy are at least partly converted to heat.
- second messenger** A molecule that relays messages in a cell from a receptor to a target where an action within the cell takes place.
- secondary cell wall** In plant cells, a strong and durable matrix that is often deposited in several laminated layers around the plasma membrane and provides protection and support.
- secondary consumer** A carnivore that eats herbivores.
- secondary endosymbiosis** A process in eukaryotic evolution in which a heterotrophic eukaryotic cell engulfed a photosynthetic eukaryotic cell, which survived in a symbiotic relationship inside the heterotrophic cell.
- secondary growth** Growth produced by lateral meristems, thickening the roots and shoots of woody plants.
- secondary immune response** The adaptive immune response elicited on second or subsequent exposures to a particular antigen. The secondary immune response is more rapid, of greater magnitude, and of longer duration than the primary immune response.
- secondary oocyte** (ō'-uh-sīt) An oocyte that has completed meiosis I.
- secondary production** The amount of chemical energy in consumers' food that is converted to their own new biomass during a given time period.
- secondary structure** Regions of repetitive coiling or folding of the polypeptide backbone of a protein due to hydrogen bonding between constituents of the backbone (not the side chains).
- secondary succession** A type of succession that occurs where an existing community has been cleared by some disturbance that leaves the soil or substrate intact.
- secretion** (1) The discharge of molecules synthesized by a cell. (2) The active transport of wastes and certain other solutes from the body fluid into the filtrate in an excretory system.
- seed** An adaptation of some terrestrial plants consisting of an embryo packaged along with a store of food within a protective coat.
- seed coat** A tough outer covering of a seed, formed from the outer coat of an ovule. In a flowering plant, the seed coat encloses and protects the embryo and endosperm.
- seedless vascular plant** An informal name for a plant that has vascular tissue but lacks seeds. Seedless vascular plants form a paraphyletic group that includes the phyla Lycophyta (club mosses and their relatives) and Monilophyta (ferns and their relatives).
- selective permeability** A property of biological membranes that allows them to regulate the passage of substances across them.

- self-incompatibility** The ability of a seed plant to reject its own pollen and sometimes the pollen of closely related individuals.
- semelparity** (sel'-mel-pär'-i-tē) Reproduction in which an organism produces all of its offspring in a single event; also called big-bang reproduction.
- semen** (sē'-mūn) The fluid that is ejaculated by the male during orgasm; contains sperm and secretions from several glands of the male reproductive tract.
- semicircular canals** A three-part chamber of the inner ear that functions in maintaining equilibrium.
- semiconservative model** Type of DNA replication in which the replicated double helix consists of one old strand, derived from the parental molecule, and one newly made strand.
- semilunar valve** A valve located at each exit of the heart, where the aorta leaves the left ventricle and the pulmonary artery leaves the right ventricle.
- seminal vesicle** (sem'-i-nul ves'-i-kul) A gland in males that secretes a fluid component of semen that lubricates and nourishes sperm.
- seminiferous tubule** (sem'-i-nif'-er-us) A highly coiled tube in the testis in which sperm are produced.
- senescence** (se-nes'-ens) The programmed death of certain cells or organs or the entire organism.
- sensitive period** A limited phase in an animal's development when learning of particular behaviors can take place; also called a critical period.
- sensor** In homeostasis, a receptor that detects a stimulus.
- sensory adaptation** The tendency of sensory neurons to become less sensitive when they are stimulated repeatedly.
- sensory neuron** A nerve cell that receives information from the internal or external environment and transmits signals to the central nervous system.
- sensory reception** The detection of a stimulus by sensory cells.
- sensory receptor** A specialized structure or cell that responds to a stimulus from an animal's internal or external environment.
- sensory transduction** The conversion of stimulus energy to a change in the membrane potential of a sensory receptor cell.
- sepal** (sē'-pul) A modified leaf in angiosperms that helps enclose and protect a flower bud before it opens.
- septum** (plural, **septa**) One of the cross-walls that divide a fungal hypha into cells. Septa generally have pores large enough to allow ribosomes, mitochondria, and even nuclei to flow from cell to cell.
- serial endosymbiosis** A hypothesis for the origin of eukaryotes consisting of a sequence of endosymbiotic events in which mitochondria, chloroplasts, and perhaps other cellular structures were derived from small prokaryotes that had been engulfed by larger cells.
- set point** In homeostasis in animals, a value maintained for a particular variable, such as body temperature or solute concentration.
- seta** (sē'-tuh) (plural, **setae**) The elongated stalk of a bryophyte sporophyte.
- sex chromosome** A chromosome responsible for determining the sex of an individual.
- sex-linked gene** A gene located on either sex chromosome. Most sex-linked genes are on the X chromosome and show distinctive patterns of inheritance; there are very few genes on the Y chromosome.
- sexual dimorphism** (di-mōr'-fizm) Differences between the secondary sex characteristics of males and females of the same species.
- sexual reproduction** Reproduction arising from fusion of two gametes.
- sexual selection** A process in which individuals with certain inherited characteristics are more likely than other individuals of the same sex to obtain mates.
- Shannon diversity index** An index of community diversity symbolized by H and represented by the equation $H = -(p_A \ln p_A + p_B \ln p_B + p_C \ln p_C + \dots)$, where A, B, C ... are species, p is the relative abundance of each species, and \ln is the natural logarithm.
- shared ancestral character** A character, shared by members of a particular clade, that originated in an ancestor that is not a member of that clade.
- shared derived character** An evolutionary novelty that is unique to a particular clade.
- shoot system** The aerial portion of a plant body, consisting of stems, leaves, and (in angiosperms) flowers.
- short tandem repeat (STR)** Simple sequence DNA containing multiple tandemly repeated units of two to five nucleotides. Variations in STRs act as genetic markers in STR analysis, used to prepare genetic profiles.
- short-day plant** A plant that flowers (usually in late summer, fall, or winter) only when the light period is shorter than a critical length.
- short-term memory** The ability to hold information, anticipations, or goals for a time and then release them if they become irrelevant.
- sickle-cell disease** A recessively inherited human blood disorder in which a single nucleotide change in the α -globin gene causes hemoglobin to aggregate, changing red blood cell shape and causing multiple symptoms in afflicted individuals.
- sieve plate** An end wall in a sieve-tube element, which facilitates the flow of phloem sap in angiosperm sieve tubes.
- sieve-tube element** A living cell that conducts sugars and other organic nutrients in the phloem of angiosperms; also called a sieve-tube member. Connected end to end, they form sieve tubes.
- sign stimulus** An external sensory cue that triggers a fixed action pattern by an animal.
- signal** Any kind of information sent from one organism to another, or from one place in an organism to another place.
- signal peptide** A sequence of about 20 amino acids at or near the leading (amino) end of a polypeptide that targets it to the endoplasmic reticulum or other organelles in a eukaryotic cell.
- signal-recognition particle (SRP)** A protein-RNA complex that recognizes a signal peptide as it emerges from a ribosome and helps direct the ribosome to the

endoplasmic reticulum (ER) by binding to a receptor protein on the ER.

signal transduction The linkage of a mechanical, chemical, or electromagnetic stimulus to a specific cellular response.

signal transduction pathway A series of steps linking a mechanical, chemical, or electrical stimulus to a specific cellular response.

silent mutation A nucleotide-pair substitution that has no observable effect on the phenotype; for example, within a gene, a mutation that results in a codon that codes for the same amino acid.

simple fruit A fruit derived from a single carpel or several fused carpels.

simple sequence DNA A DNA sequence that contains many copies of tandemly repeated short sequences.

single bond A single covalent bond; the sharing of a pair of valence electrons by two atoms.

single circulation A circulatory system consisting of a single pump and circuit, in which blood passes from the sites of gas exchange to the rest of the body before returning to the heart.

single-lens eye The camera-like eye found in some jellies, polychaete worms, spiders, and many molluscs.

single nucleotide polymorphism (SNP) (snip) A single base-pair site in a genome where nucleotide variation is found in at least 1% of the population.

single-strand binding protein A protein that binds to the unpaired DNA strands during DNA replication, stabilizing them and holding them apart while they serve as templates for the synthesis of complementary strands of DNA.

sinoatrial (SA) node (sī'-nō-ā'-trē-uhl) A region in the right atrium of the heart that sets the rate and timing at which all cardiac muscle cells contract; the pacemaker.

sister chromatids Two copies of a duplicated chromosome attached to each other by proteins at the centromere and, sometimes, along the arms. While joined, two sister chromatids make up one chromosome. Chromatids are eventually separated during mitosis or meiosis II.

sister taxa Groups of organisms that share an immediate common ancestor and hence are each other's closest relatives.

skeletal muscle A type of striated muscle that is generally responsible for the voluntary movements of the body.

sliding-filament model The idea that muscle contraction is based on the movement of thin (actin) filaments along thick (myosin) filaments, shortening the sarcomere, the basic unit of muscle organization.

slow-twitch fiber A muscle fiber that can sustain long contractions.

small interfering RNA (siRNA) One of multiple small, single-stranded RNA molecules generated by cellular machinery from a long, linear, double-stranded RNA molecule. The siRNA associates with one or more proteins in a complex that can degrade or prevent translation of an mRNA with a complementary sequence.

small intestine The longest section of the alimentary canal, so named because of its small

diameter compared with that of the large intestine; the principal site of the enzymatic hydrolysis of food macromolecules and the absorption of nutrients.

smooth ER That portion of the endoplasmic reticulum that is free of ribosomes.

smooth muscle A type of muscle lacking the striations of skeletal and cardiac muscle because of the uniform distribution of myosin filaments in the cells; responsible for involuntary body activities.

social learning Modification of behavior through the observation of other individuals.

sociobiology The study of social behavior based on evolutionary theory.

sodium-potassium pump A transport protein in the plasma membrane of animal cells that actively transports sodium out of the cell and potassium into the cell.

soil horizon A soil layer with physical characteristics that differ from those of the layers above or beneath.

solute (sol'ü-t) A substance that is dissolved in a solution.

solute potential (Ψ_s) A component of water potential that is proportional to the molarity of a solution and that measures the effect of solutes on the direction of water movement; also called osmotic potential, it can be either zero or negative.

solution A liquid that is a homogeneous mixture of two or more substances.

solvent The dissolving agent of a solution. Water is the most versatile solvent known.

somatic cell (sō-mat'ik) Any cell in a multicellular organism except a sperm or egg or their precursors.

somite One of a series of blocks of mesoderm that exist in pairs just lateral to the notochord in a vertebrate embryo.

soredium (suh-rē'-dē-um) (plural, **soredia**) In lichens, a small cluster of fungal hyphae with embedded algae.

sorus (plural, **sori**) A cluster of sporangia on a fern sporophyll. Sori may be arranged in various patterns, such as parallel lines or dots, which are useful in fern identification.

spatial learning The establishment of a memory that reflects the environment's spatial structure.

speciation (spē'-sē-ā'-shun) An evolutionary process in which one species splits into two or more species.

species (spē'-sēz) A population or group of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring but do not produce viable, fertile offspring with members of other such groups.

species-area curve (spē'-sēz) The biodiversity pattern that shows that the larger the geographic area of a community is, the more species it has.

species diversity (spē'-sēz) The number and relative abundance of species in a biological community.

species richness (spē'-sēz) The number of species in a biological community.

specific heat The amount of heat that must be absorbed or lost for 1 g of a substance to change its temperature by 1°C.

spectrophotometer An instrument that measures the proportions of light of different wavelengths absorbed and transmitted by a pigment solution.

sperm The male gamete.

spermatheca (sper'-muh-thē'-kuh) (plural, **spermathecae**) In many insects, a sac in the female reproductive system where sperm are stored.

spermatogenesis (sper-ma'-tō-gen'-uh-sis) The continuous and prolific production of mature sperm in the testis.

spermatogonium (sper-ma'-tō-gō'-nē-um) (plural, **spermatogonia**) A cell that divides mitotically to form spermatocytes.

phase The synthesis phase of the cell cycle; the portion of interphase during which DNA is replicated.

sphincter (sfink'-ter) A ringlike band of muscle fibers that controls the size of an opening in the body, such as the passage between the esophagus and the stomach.

spiral cleavage A type of embryonic development in protostomes in which the planes of cell division that transform the zygote into a ball of cells are diagonal to the vertical axis of the embryo. As a result, the cells of each tier sit in the grooves between cells of adjacent tiers.

spliceosome (splē'-sō-sōm) A large complex made up of proteins and RNA molecules that splices RNA by interacting with the ends of an RNA intron, releasing the intron and joining the two adjacent exons.

spongocoel (spon'-jō-sēl) The central cavity of a sponge.

spontaneous process A process that occurs without an overall input of energy; a process that is energetically favorable.

sporangium (spōr-an'-jē-um) (plural, **sporangia**) A multicellular organ in fungi and plants in which meiosis occurs and haploid cells develop.

spore (1) In the life cycle of a plant or alga undergoing alternation of generations, a haploid cell produced in the sporophyte by meiosis. A spore can divide by mitosis to develop into a multicellular haploid individual, the gametophyte, without fusing with another cell. (2) In fungi, a haploid cell, produced either sexually or asexually, that produces a mycelium after germination.

sporocyte (spō'-ruh-sit) A diploid cell within a sporangium that undergoes meiosis and generates haploid spores; also called a spore mother cell.

sporophyll (spō'-ruh-fil) A modified leaf that bears sporangia and hence is specialized for reproduction.

sporophyte (spō'-ruh-fit) In organisms (plants and some algae) that have alternation of generations, the multicellular diploid form that results from the union of gametes. Meiosis in the sporophyte produces haploid spores that develop into gametophytes.

sporopollenin (spōr-uh-pol'-eh-nin) A durable polymer that covers exposed zygotes of charophyte algae and forms the walls of plant spores, preventing them from drying out.

stability In evolutionary biology, a term referring to a hybrid zone in which hybrids continue to be produced; this causes the hybrid zone to be "stable" in the sense of persisting over time.

- stabilizing selection** Natural selection in which intermediate phenotypes survive or reproduce more successfully than do extreme phenotypes.
- stamen** (stā'men) The pollen-producing reproductive organ of a flower, consisting of an anther and a filament.
- standard deviation** A measure of the variation found in a set of data points.
- standard metabolic rate (SMR)** Metabolic rate of a resting, fasting, and nonstressed ectotherm at a particular temperature.
- starch** A storage polysaccharide in plants, consisting entirely of glucose monomers joined by glycosidic linkages.
- start point** In transcription, the nucleotide position on the promoter where RNA polymerase begins synthesis of RNA.
- statocyst** (stat'-uh-sist') A type of mechanoreceptor that functions in equilibrium in invertebrates by use of statoliths, which stimulate hair cells in relation to gravity.
- statolith** (stat'-uh-lith') (1) In plants, a specialized plastid that contains dense starch grains and may play a role in detecting gravity. (2) In invertebrates, a dense particle that settles in response to gravity and is found in sensory organs that function in equilibrium.
- stele** (stēl) The vascular tissue of a stem or root.
- stem** A vascular plant organ consisting of an alternating system of nodes and internodes that support the leaves and reproductive structures.
- stem cell** Any relatively unspecialized cell that can produce, during a single division, two identical daughter cells or two more specialized daughter cells that can undergo further differentiation, or one cell of each type.
- steroid** A type of lipid characterized by a carbon skeleton consisting of four fused rings with various chemical groups attached.
- sticky end** A single-stranded end of a double-stranded restriction fragment.
- stigma** (plural, **stigmata**) The sticky part of a flower's carpel, which receives pollen grains.
- stimulus** In feedback regulation, a fluctuation in a variable that triggers a response.
- stipe** A stemlike structure of a seaweed.
- stock** The plant that provides the root system when making a graft.
- stoma** (stō'muh) (plural, **stomata**) A microscopic pore surrounded by guard cells in the epidermis of leaves and stems that allows gas exchange between the environment and the interior of the plant.
- stomach** An organ of the digestive system that stores food and performs preliminary steps of digestion.
- stramenopiles** (strah'-men-ō'-pē-lēz) One of the three major subgroups for which the SAR eukaryotic supergroup is named. This clade arose by secondary endosymbiosis and includes diatoms and brown algae.
- stratum** (strah'-tum) (plural, **strata**) A rock layer formed when new layers of sediment cover older ones and compress them.
- strigolactone** Any of a class of plant hormones that inhibit shoot branching, trigger the germination of parasitic plant seeds, and stimulate the association of plant roots with mycorrhizal fungi.
- strobilus** (strō-bī'lus) (plural, **strobili**) The technical term for a cluster of sporophylls known commonly as a cone, found in most gymnosperms and some seedless vascular plants.
- stroke** The death of nervous tissue in the brain, usually resulting from rupture or blockage of arteries in the neck or head.
- stroke volume** The volume of blood pumped by a heart ventricle in a single contraction.
- stroma** (strō'muh) The dense fluid within the chloroplast surrounding the thylakoid membrane and containing ribosomes and DNA; involved in the synthesis of organic molecules from carbon dioxide and water.
- stromatolite** Layered rock that results from the activities of prokaryotes that bind thin films of sediment together.
- structural isomer** One of two or more compounds that have the same molecular formula but differ in the covalent arrangements of their atoms.
- style** The stalk of a flower's carpel, with the ovary at the base and the stigma at the top.
- substrate** The reactant on which an enzyme works.
- substrate feeder** An animal that lives in or on its food source, eating its way through the food.
- substrate-level phosphorylation** (fos'-fōr-uh-lā'shun) The enzyme-catalyzed formation of ATP by direct transfer of a phosphate group to ADP from an intermediate substrate in catabolism.
- sugar sink** A plant organ that is a net consumer or storer of sugar. Growing roots, buds, stems, and fruits are examples of sugar sinks supplied by phloem.
- sugar source** A plant organ in which sugar is being produced by either photosynthesis or the breakdown of starch. Mature leaves are the primary sugar sources of plants.
- sulfhydryl group** A chemical group consisting of a sulfur atom bonded to a hydrogen atom.
- summation** A phenomenon of neural integration in which the membrane potential of the postsynaptic cell is determined by the combined effect of EPSPs or IPSPs produced in rapid succession at one synapse or simultaneously at different synapses.
- suprachiasmatic nucleus (SCN)** (sūp'-ruh-kē'-as-ma-tik) A group of neurons in the hypothalamus of mammals that functions as a biological clock.
- surface tension** A measure of how difficult it is to stretch or break the surface of a liquid. Water has a high surface tension because of the hydrogen bonding of surface molecules.
- surfactant** A substance secreted by alveoli that decreases surface tension in the fluid that coats the alveoli.
- survivorship curve** A plot of the number of members of a cohort that are still alive at each age; one way to represent age-specific mortality.
- suspension feeder** An animal that feeds by removing suspended food particles from the surrounding medium by a capture, trapping, or filtration mechanism.
- sustainable agriculture** Long-term productive farming methods that are environmentally safe.
- sustainable development** Development that meets the needs of people today without limiting the ability of future generations to meet their needs.
- swim bladder** In aquatic osteichthyans, an air sac that enables the animal to control its buoyancy in the water.
- symbiont** (sim'bē-ont) The smaller participant in a symbiotic relationship, living in or on the host.
- symbiosis** An ecological relationship between organisms of two different species that live together in direct and intimate contact.
- sympathetic division** A division of the autonomic nervous system; generally increases energy expenditure and prepares the body for action.
- sympatric speciation** (sim-pat'-rik) The formation of new species in populations that live in the same geographic area.
- symplast** In plants, the continuum of cytosol connected by plasmodesmata between cells.
- synapse** (sin'-aps) The junction where a neuron communicates with another cell across a narrow gap via a neurotransmitter or an electrical coupling.
- synapsid** (si-nap'-sid) A member of an amniote clade distinguished by a single hole on each side of the skull. Synapsids include the mammals.
- synapsis** (si-nap'-sis) The pairing and physical connection of one duplicated chromosome to its homolog during prophase I of meiosis.
- synaptonemal complex** (si-nap'-tuh-nē'-muhl) A zipper-like structure composed of proteins, which connects a chromosome to its homolog tightly along their lengths during part of prophase I of meiosis.
- systematics** A scientific discipline focused on classifying organisms and determining their evolutionary relationships.
- systemic acquired resistance** A defensive response in infected plants that helps protect healthy tissue from pathogenic invasion.
- systemic circuit** The branch of the circulatory system that supplies oxygenated blood to and carries deoxygenated blood away from organs and tissues throughout the body.
- systems biology** An approach to studying biology that aims to model the dynamic behavior of whole biological systems based on a study of the interactions among the system's parts.
- systole** (sis'-tō-lē) The stage of the cardiac cycle in which a heart chamber contracts and pumps blood.
- systolic pressure** Blood pressure in the arteries during contraction of the ventricles.
- taproot** A main vertical root that develops from an embryonic root and gives rise to lateral (branch) roots.
- tastant** Any chemical that stimulates the sensory receptors in a taste bud.
- taste bud** A collection of modified epithelial cells on the tongue or in the mouth that are receptors for taste in mammals.
- TATA box** A DNA sequence in eukaryotic promoters crucial in forming the transcription initiation complex.
- taxis** (tak'-sis) An oriented movement toward or away from a stimulus.

taxon (plural, **taxa**) A named taxonomic unit at any given level of classification.

taxonomy (tak-son'-uh-mē) A scientific discipline concerned with naming and classifying the diverse forms of life.

Tay-Sachs disease A human genetic disease caused by a recessive allele for a dysfunctional enzyme, leading to accumulation of certain lipids in the brain. Seizures, blindness, and degeneration of motor and mental performance usually become manifest a few months after birth, followed by death within a few years.

T cells The class of lymphocytes that mature in the thymus; they include both effector cells for the cell-mediated immune response and helper cells required for both branches of adaptive immunity.

technology The application of scientific knowledge for a specific purpose, often involving industry or commerce but also including uses in basic research.

telomere (tel'-uh-mēr) The tandemly repetitive DNA at the end of a eukaryotic chromosome's DNA molecule. Telomeres protect the organism's genes from being eroded during successive rounds of replication. *See also* repetitive DNA.

telophase The fifth and final stage of mitosis, in which daughter nuclei are forming and cytokinesis has typically begun.

temperate broadleaf forest A biome located throughout midlatitude regions where there is sufficient moisture to support the growth of large, broadleaf deciduous trees.

temperate grassland A terrestrial biome that exists at midlatitude regions and is dominated by grasses and forbs.

temperate phage A phage that is capable of replicating by either a lytic or lysogenic cycle.

temperature A measure in degrees of the average kinetic energy (thermal energy) of the atoms and molecules in a body of matter.

template strand The DNA strand that provides the pattern, or template, for ordering, by complementary base pairing, the sequence of nucleotides in an RNA transcript.

tendon A fibrous connective tissue that attaches muscle to bone.

terminator In bacteria, a sequence of nucleotides in DNA that marks the end of a gene and signals RNA polymerase to release the newly made RNA molecule and detach from the DNA.

territoriality A behavior in which an animal defends a bounded physical space against encroachment by other individuals, usually of its own species.

tertiary consumer (ter'-shē-är'-ē) A carnivore that eats other carnivores.

tertiary structure (ter'-shē-är'-ē) The overall shape of a protein molecule due to interactions of amino acid side chains, including hydrophobic interactions, ionic bonds, hydrogen bonds, and disulfide bridges.

test In foram protists, a porous shell that consists of a single piece of organic material hardened with calcium carbonate.

testcross Breeding an organism of unknown genotype with a homozygous recessive individual to determine the unknown genotype. The ratio of phenotypes in the offspring reveals the unknown genotype.

testis (plural, **testes**) The male reproductive organ, or gonad, in which sperm and reproductive hormones are produced.

testosterone A steroid hormone required for development of the male reproductive system, spermatogenesis, and male secondary sex characteristics; the major androgen in mammals.

tetanus (tet'-uh-nus) The maximal, sustained contraction of a skeletal muscle, caused by a very high frequency of action potentials elicited by continual stimulation.

tetrapod A vertebrate clade whose members have limbs with digits. Tetrapods include mammals, amphibians, and birds and other reptiles.

thalamus (thal'-uh-mus) An integrating center of the vertebrate forebrain. Neurons with cell bodies in the thalamus relay neural input to specific areas in the cerebral cortex and regulate what information goes to the cerebral cortex.

theory An explanation that is broader in scope than a hypothesis, generates new hypotheses, and is supported by a large body of evidence.

thermal energy Kinetic energy due to the random motion of atoms and molecules; energy in its most random form. *See also* heat.

thermocline A narrow stratum of abrupt temperature change in the ocean and in many temperate-zone lakes.

thermodynamics (ther'-mō-dī-nam'-iks) The study of energy transformations that occur in a collection of matter. *See also* first law of thermodynamics and second law of thermodynamics.

thermophile *See* extreme thermophile.

thermoreceptor A receptor stimulated by either heat or cold.

thermoregulation The maintenance of internal body temperature within a tolerable range.

theropod A member of a group of dinosaurs that were bipedal carnivores.

thick filament A filament composed of staggered arrays of myosin molecules; a component of myofibrils in muscle fibers.

thigmomorphogenesis (thig'-mō-mor'-phō-gen'-uh-sis) A response in plants to chronic mechanical stimulation, resulting from increased ethylene production. An example is thickening stems in response to strong winds.

thigmotropism (thig-mō'-truh-pizm) A directional growth of a plant in response to touch.

thin filament A filament consisting of two strands of actin and two strands of regulatory protein coiled around one another; a component of myofibrils in muscle fibers.

threatened species A species that is considered likely to become endangered in the foreseeable future.

threshold The potential that an excitable cell membrane must reach for an action potential to be initiated.

thrombus (plural, **thrombi**) A fibrin-containing clot that forms in a blood vessel and blocks the flow of blood.

thylakoid (thī'-luh-koyd) A flattened, membranous sac inside a chloroplast. Thylakoids often exist in stacks called grana that are interconnected; their membranes contain molecular "machinery" used to convert light energy to chemical energy.

thymus (thī'-mus) A small organ in the thoracic cavity of vertebrates where maturation of T cells is completed.

thyroid gland An endocrine gland, located on the ventral surface of the trachea, that secretes two iodine-containing hormones, triiodothyronine (T_3) and thyroxine (T_4), as well as calcitonin.

thyroid hormone Either of two iodine-containing hormones (triiodothyronine and thyroxine) that are secreted by the thyroid gland and that help regulate metabolism, development, and maturation in vertebrates.

thyroxine (T_4) One of two iodine-containing hormones that are secreted by the thyroid gland and that help regulate metabolism, development, and maturation in vertebrates.

tidal volume The volume of air a mammal inhales and exhales with each breath.

tight junction A type of intercellular junction between animal cells that prevents the leakage of material through the space between cells.

tissue An integrated group of cells with a common structure, function, or both.

tissue system One or more tissues organized into a functional unit connecting the organs of a plant.

Toll-like receptor (TLR) A membrane receptor on a phagocytic white blood cell that recognizes fragments of molecules common to a set of pathogens.

tonicity The ability of a solution surrounding a cell to cause that cell to gain or lose water.

top-down control A situation in which the abundance of organisms at each trophic level is controlled by the abundance of consumers at higher trophic levels; thus, predators limit herbivores, and herbivores limit plants.

topoisomerase A protein that breaks, swivels, and rejoins DNA strands. During DNA replication, topoisomerase helps to relieve strain in the double helix ahead of the replication fork.

topsoil A mixture of particles derived from rock, living organisms, and decaying organic material (humus).

torpor A physiological state in which activity is low and metabolism decreases.

totipotent (tō'-tuh-pōt'-ent) Describing a cell that can give rise to all parts of the embryo and adult, as well as extraembryonic membranes in species that have them.

trace element An element indispensable for life but required in extremely minute amounts.

trachea (trā'-kē-uh) The portion of the respiratory tract that passes from the larynx to the bronchi; also called the windpipe.

tracheal system In insects, a system of branched, air-filled tubes that extends throughout the body and carries oxygen directly to cells.

tracheid (trā'-kē-id) A long, tapered water-conducting cell found in the xylem of nearly all vascular plants. Functioning tracheids are no longer living.

trait One of two or more detectable variants in a genetic character.

trans fat An unsaturated fat, formed artificially during hydrogenation of oils, containing one or more *trans* double bonds.

transcription The synthesis of RNA using a DNA template.

transcription factor A regulatory protein that binds to DNA and affects transcription of specific genes.

transcription initiation complex The completed assembly of transcription factors and RNA polymerase bound to a promoter.

transcription unit A region of DNA that is transcribed into an RNA molecule.

transduction A process in which phages (viruses) carry bacterial DNA from one bacterial cell to another. When these two cells are members of different species, transduction results in horizontal gene transfer. *See also* signal transduction pathway.

transfer RNA (tRNA) An RNA molecule that functions as a translator between nucleic acid and protein languages by picking up a specific amino acid and carrying it to the ribosome, where the tRNA recognizes the appropriate codon in the mRNA.

transformation (1) The process by which a cell in culture acquires the ability to divide indefinitely, similar to the division of cancer cells. (2) A change in genotype and phenotype due to the assimilation of external DNA by a cell. When the external DNA is from a member of a different species, transformation results in horizontal gene transfer.

transgene A gene that has been transferred naturally or by a genetic engineering technique from one organism to another.

transgenic Pertaining to an organism whose genome contains DNA introduced from another organism of the same or a different species.

translation The synthesis of a polypeptide using the genetic information encoded in an mRNA molecule. There is a change of “language” from nucleotides to amino acids.

translocation (1) An aberration in chromosome structure resulting from attachment of a chromosomal fragment to a nonhomologous chromosome. (2) During protein synthesis, the third stage in the elongation cycle, when the RNA carrying the growing polypeptide moves from the A site to the P site on the ribosome. (3) The transport of organic nutrients in the phloem of vascular plants.

transmembrane protein A type of integral protein that spans the entire membrane.

transmission electron microscope (TEM) A microscope that passes an electron beam through very thin sections stained with metal atoms and is primarily used to study the internal structure of cells.

transpiration The evaporative loss of water from a plant.

transport epithelium One or more layers of specialized epithelial cells that carry out and regulate solute movement.

transport protein A transmembrane protein that helps a certain substance or class of closely related substances to cross the membrane.

transport vesicle A small membranous sac in a eukaryotic cell's cytoplasm carrying molecules produced by the cell.

transposable element A segment of DNA that can move within the genome of a cell by means of a DNA or RNA intermediate; also called a transposable genetic element.

transposon A transposable element that moves within a genome by means of a DNA intermediate.

transverse (T) tubule An infolding of the plasma membrane of skeletal muscle cells.

triacylglycerol (trī-as'-ul-glis'-uh-rol) A lipid consisting of three fatty acids linked to one glycerol molecule; also called a fat or triglyceride.

trichome An epidermal cell that is a highly specialized, often hairlike outgrowth on a plant shoot.

triple response A plant growth maneuver in response to mechanical stress, involving slowing of stem elongation, thickening of the stem, and a curvature that causes the stem to start growing horizontally.

triplet code A genetic information system in which a series of three-nucleotide-long words specifies a sequence of amino acids for a polypeptide chain.

triploblastic Possessing three germ layers: the endoderm, mesoderm, and ectoderm. All bilaterian animals are triploblastic.

trisomic Referring to a diploid cell that has three copies of a particular chromosome instead of the normal two.

trochophore larva (trō'-kuh-för) Distinctive larval stage observed in some lophotrochozoan animals, including some annelids and molluscs.

trophic efficiency The percentage of production transferred from one trophic level to the next higher trophic level.

trophic level The position an organism occupies in a food chain.

trophic structure The different feeding relationships in an ecosystem, which determine the route of energy flow and the pattern of chemical cycling.

trophoblast The outer epithelium of a mammalian blastocyst. It forms the fetal part of the placenta, supporting embryonic development but not forming part of the embryo proper.

tropical dry forest A terrestrial biome characterized by relatively high temperatures and precipitation overall but with a pronounced dry season.

tropical rain forest A terrestrial biome characterized by relatively high precipitation and temperatures year-round.

tropics Latitudes between 23.5° north and south.

tropism A growth response that results in the curvature of whole plant organs toward or away from stimuli due to differential rates of cell elongation.

tropomyosin The regulatory protein that blocks the myosin-binding sites on actin molecules.

troponin complex The regulatory proteins that control the position of tropomyosin on the thin filament.

true-breeding Referring to organisms that produce offspring of the same variety over many generations of self-pollination.

tubal ligation A means of sterilization in which a woman's two oviducts (fallopian tubes) are tied closed and a segment of each is removed to prevent eggs from reaching the uterus.

tube foot One of numerous extensions of an echinoderm's water vascular system. Tube feet function in locomotion and feeding.

tumor-suppressor gene A gene whose protein product inhibits cell division, thereby preventing the uncontrolled cell growth that contributes to cancer.

tundra A terrestrial biome at the extreme limits of plant growth. At the northernmost limits, it is called arctic tundra, and at high altitudes, where plant forms are limited to low shrubby or matlike vegetation, it is called alpine tundra.

tunicate A member of the clade Urochordata, sessile marine chordates that lack a backbone.

turgid (ter'-jид) Swollen or distended, as in plant cells. (A walled cell becomes turgid if it has a lower water potential than its surroundings, resulting in entry of water.)

turgor pressure The force directed against a plant cell wall after the influx of water and swelling of the cell due to osmosis.

turnover The mixing of waters as a result of changing water-temperature profiles in a lake.

tympanic membrane Another name for the eardrum, the membrane between the outer and middle ear.

Unikonta (yū'-ni-kon'-tuh) One of four supergroups of eukaryotes proposed in a current hypothesis of the evolutionary history of eukaryotes. This clade, which is supported by studies of myosin proteins and DNA, consists of amoebozoans and opisthokonts. *See also* Excavata, SAR, and Archaeplastida.

unsaturated fatty acid A fatty acid that has one or more double bonds between carbons in the hydrocarbon tail. Such bonding reduces the number of hydrogen atoms attached to the carbon skeleton.

urban ecology The study of organisms and their environment in urban and suburban settings.

urea A soluble nitrogenous waste produced in the liver by a metabolic cycle that combines ammonia with carbon dioxide.

ureter (yū-rē'-ter) A duct leading from the kidney to the urinary bladder.

urethra (yū-rē'-thrū) A tube that releases urine from the mammalian body near the vagina in females and through the penis in males; also serves in males as the exit tube for the reproductive system.

uric acid A product of protein and purine metabolism and the major nitrogenous waste product of insects, land snails, and many reptiles. Uric acid is relatively nontoxic and largely insoluble in water.

urinary bladder The pouch where urine is stored prior to elimination.

uterine cycle The cyclic changes in the endometrium (uterine lining) of mammals that occur in the absence of pregnancy. In certain primates, including humans, the uterine cycle is a menstrual cycle.

uterus A female organ where eggs are fertilized and/or development of the young occurs.

vaccine A harmless variant or derivative of a pathogen that stimulates a host's immune system to mount defenses against the pathogen.

vacuole (vak'-yü-ōl') A membrane-bound vesicle whose specialized function varies in different kinds of cells.

vagina Part of the female reproductive system between the uterus and the outside opening; the birth canal in mammals. During

- copulation**, the vagina accommodates the male's penis and receives sperm.
- valence** The bonding capacity of a given atom; the number of covalent bonds that an atom can form, which usually equals the number of unpaired electrons in its outermost (valence) shell.
- valence electron** An electron in the outermost electron shell.
- valence shell** The outermost energy shell of an atom, containing the valence electrons involved in the chemical reactions of that atom.
- van der Waals interactions** Weak attractions between molecules or parts of molecules that result from transient local partial charges.
- variable** A factor that varies in an experiment.
- variation** Differences between members of the same species.
- vas deferens** In mammals, the tube in the male reproductive system in which sperm travel from the epididymis to the urethra.
- vasa recta** The capillary system in the kidney that serves the loop of Henle.
- vascular cambium** A cylinder of meristematic tissue in woody plants that adds layers of secondary vascular tissue called secondary xylem (wood) and secondary phloem.
- vascular plant** A plant with vascular tissue. Vascular plants include all living plant species except liverworts, mosses, and hornworts.
- vascular tissue** Plant tissue consisting of cells joined into tubes that transport water and nutrients throughout the plant body.
- vasectomy** The cutting and sealing of each vas deferens to prevent sperm from entering the urethra.
- vasoconstriction** A decrease in the diameter of blood vessels caused by contraction of smooth muscles in the vessel walls.
- vasodilation** An increase in the diameter of blood vessels caused by relaxation of smooth muscles in the vessel walls.
- vasopressin** See antidiuretic hormone (ADH).
- vector** An organism that transmits pathogens from one host to another.
- vegetal pole** The point at the end of an egg in the hemisphere where most yolk is concentrated; opposite of animal pole.
- vegetative propagation** Asexual reproduction in plants that is facilitated or induced by humans.
- vegetative reproduction** Asexual reproduction in plants.
- vein** (1) In animals, a vessel that carries blood toward the heart. (2) In plants, a vascular bundle in a leaf.
- ventilation** The flow of air or water over a respiratory surface.
- ventral** In an animal with bilateral symmetry, pertaining to the underside (in most animals) or front (in animals with upright posture) of the body.
- ventricle** (ven'-tri-kul) (1) A heart chamber that pumps blood out of the heart. (2) A space in the vertebrate brain, filled with cerebrospinal fluid.
- venule** (ven'-yü'l) A vessel that conveys blood between a capillary bed and a vein.
- vernization** The use of cold treatment to induce a plant to flower.
- vertebrate** A chordate animal with vertebrae, the series of bones that make up the backbone.
- vesicle** (ves'-i-kul) A membrane-bound sac in or outside a cell.
- vessel** A continuous water-conducting micro-pipe found in most angiosperms and a few nonflowering vascular plants.
- vessel element** A short, wide, water-conducting cell found in the xylem of most angiosperms and a few nonflowering vascular plants. Dead at maturity, vessel elements are aligned end to end to form micropipes called vessels.
- vestigial structure** A feature of an organism that is a historical remnant of a structure that served a function in the organism's ancestors.
- villus** (plural, **villi**) (1) A finger-like projection of the inner surface of the small intestine. (2) A finger-like projection of the chorion of the mammalian placenta. Large numbers of villi increase the surface areas of these organs.
- viral envelope** A membrane, derived from membranes of the host cell, that cloaks the capsid, which in turn encloses a viral genome.
- virulent phage** A phage that replicates only by a lytic cycle.
- virus** An infectious particle incapable of replicating outside of a cell, consisting of an RNA or DNA genome surrounded by a protein coat (capsid) and, for some viruses, a membranous envelope.
- visceral mass** One of the three main parts of a mollusc; the part containing most of the internal organs. *See also* foot and mantle.
- visible light** That portion of the electromagnetic spectrum that can be detected as various colors by the human eye, ranging in wavelength from about 380 nm to about 740 nm.
- vital capacity** The maximum volume of air that a mammal can inhale and exhale with each breath.
- vitamin** An organic molecule required in the diet in very small amounts. Many vitamins serve as coenzymes or parts of coenzymes.
- viviparous** (vi-vip'-uh-rus) Referring to a type of development in which the young are born alive after having been nourished in the uterus by blood from the placenta.
- voltage-gated ion channel** A specialized ion channel that opens or closes in response to changes in membrane potential.
- vulva** Collective term for the female external genitalia.
- water potential (ψ)** The physical property predicting the direction in which water will flow, governed by solute concentration and applied pressure.
- water vascular system** A network of hydraulic canals unique to echinoderms that branches into extensions called tube feet, which function in locomotion and feeding.
- wavelength** The distance between crests of waves, such as those of the electromagnetic spectrum.
- wetland** A habitat that is inundated by water at least some of the time and that supports plants adapted to water-saturated soil.
- white matter** Tracts of axons within the CNS.
- whole-genome shotgun approach** Procedure for genome sequencing in which the genome is randomly cut into many overlapping short segments that are sequenced; computer software then assembles the complete sequence.
- wild type** The phenotype most commonly observed in natural populations; also refers to the individual with that phenotype.
- wilting** The drooping of leaves and stems as a result of plant cells becoming flaccid.
- wobble** Flexibility in the base-pairing rules in which the nucleotide at the 5' end of a tRNA anticodon can form hydrogen bonds with more than one kind of base in the third position (3' end) of a codon.
- xerophyte** (zir'-ö-fit') A plant adapted to an arid climate.
- X-linked gene** A gene located on the X chromosome; such genes show a distinctive pattern of inheritance.
- X-ray crystallography** A technique used to study the three-dimensional structure of molecules. It depends on the diffraction of an X-ray beam by the individual atoms of a crystallized molecule.
- xylem** (zi'-lum) Vascular plant tissue consisting mainly of tubular dead cells that conduct most of the water and minerals upward from the roots to the rest of the plant.
- xylem sap** (zi'-lum) The dilute solution of water and minerals carried through vessels and tracheids.
- yeast** Single-celled fungus. Yeasts reproduce asexually by binary fission or by the pinching of small buds off a parent cell. Many fungal species can grow both as yeasts and as a network of filaments; relatively few species grow only as yeasts.
- yolk** Nutrients stored in an egg.
- zero population growth (ZPG)** A period of stability in population size, when additions to the population through births and immigration are balanced by subtractions through deaths and emigration.
- zona pellucida** The extracellular matrix surrounding a mammalian egg.
- zoned reserve** An extensive region that includes areas relatively undisturbed by humans surrounded by areas that have been changed by human activity and are used for economic gain.
- zone of polarizing activity (ZPA)** A block of mesoderm located just under the ectoderm where the posterior side of a limb bud is attached to the body; required for proper pattern formation along the anterior-posterior axis of the limb.
- zoonotic pathogen** A disease-causing agent that is transmitted to humans from other animals.
- zoopagomycete** A member of the fungal phylum Zoopagomycota, multicellular parasites or commensal symbionts of animals; sexual reproduction, where known, involves the formation of a sturdy structure called a zygosporangium.
- zoospore** Flagellated spore found in chytrid fungi and some protists.
- zygomycete** (zi'-guh-mi'-sët) A member of the fungal phylum Zygomycota, characterized by the formation of a sturdy structure called a zygosporangium during sexual reproduction.
- zygosporangium** (zi'-guh-spör-an'-jë-um) (plural, **zygosporangia**) In zygomycete fungi, a sturdy multinucleate structure in which karyogamy and meiosis occur.
- zygote** (zi'-göt) The diploid cell produced by the union of haploid gametes during fertilization; a fertilized egg.

NOTE: A page number in regular type indicates where a topic is discussed in the text; a **bold** page number indicates where a term is bold and defined; an *f* following a page number indicates a figure (the topic may also be discussed in the text on that page); a *t* following a page number indicates a table (the topic may also be discussed in the text on that page).

2,4-dichlorophenoxyacetic acid (2,4-D), 849
3' end (sugar-phosphate backbone), 85*f*, 345*f*, 348*f*
3-phosphoglycerate, 201, 202*f*
5' cap, 345*f*, 348*f*
5' end (sugar-phosphate backbone), 85*f*
5-methylcytosine, 63*f*
10-nm fibers, DNA, 330*f*–331*f*, 332
30-nm fibers, DNA, 330*f*

A

a (yeast mating type), 213*f*, 214, 217
ABC hypothesis, flower formation, 780*f*
abd-A gene, 706*f*
Abdomen, insect, 710*f*
Abiotic factors, 1169
 microclimate and, 1169–1170
 in pollination, 824*f*
 in species distributions, 1178, 1183*f*–1186*f*
Abiotic stresses, plant, 862–863, 864*f*, 865
Abiotic synthesis, organic molecule, 57*f*, 58,
 526*f*–527*f*
Abnormal chromosome number disorders, 307*f*
ABO blood groups, 280*f*, 292, 969–970
Abomasum, 914*f*
Abortion, 1039
 spontaneous, 306
Abscisic acid (ABA), 798, 846*t*, 852*f*, 863
Abscission, leaf, 852, 854*f*
Absorption, 904
 in animal food processing, 904, 905*f*
 of carbon dioxide, 1245
 in large intestine, 910
 of light energy and primary production, 1242*f*
 of nutrients, 895*f*
 plant and animal, 895*f*
 in small intestine, 909^f–910*f*
 of water and mineral by root cells, 792
Absorption spectrum, 193*f*
Abstinence, 1037, 1038*f*
Abstract thinking, 1146
Abyssal zone, 1177*f*
Acacia trees, 10*f*, 1220*f*
Acanthocephalans, 687*f*, 698*f*, 1220
Acanthodians, 726
Accessory fruits, 831*f*
Accessory glands, male reproductive, 1025*f*, 1026
Acclimatization, 883*f*, 888
Accommodation, visual, 1122*f*
Acetic acid, 63*f*
Acetone, 63*f*
Acetylation, histone, 371*f*
Acetylcholine, 1080, 1081*t*, 1128, 1129*f*
Acetylcholinesterase, 1080
Acetyl CoA (acetyl coenzyme A), 171*f*–173*f*
Acetylsalicylic acid, 651
Achillea lanulosa, 1189
Achondroplasia, 287*f*
Acid bogs, 529*f*
Acid growth hypothesis, 848, 849*f*
Acid rain, 55
Acidification, ocean, 53*f*, 54
Acid precipitation, 821, 1265, 1266*f*
Acid reflux, 908
Acids, 51
 acid precipitation and, 821, 1265, 1266*f*
 amino acids as, 76, 77*f*
 buffers and, 52–53
 hydrogen ions, bases, and, 51

ocean acidification and, 53*f*, 54
pH scale and, 51, 52*f*
Acinetobacter baumannii, 913
Acoela, 683*f*, 687*f*
Acorn woodpeckers (*Melanerpes formicivorus*), 1162
Acorn worms, 689*f*
Acquired immunodeficiency, 971, 972*f*, 973. *See also AIDS*
Acquired traits, noninheritance of, 471*f*
Acromegaly, 1010
Acrosomal reactions, 1044*f*, 1045
Acrosomes, 1028*f*, 1044*f*, 1045
Actias luna, 43
Actin, 76*f*, 115, 241, 879*f*
Actin filaments, 113*t*, 1056*f*, 1125, 1126*f*–1127*f*.
 See also Microfilaments
Actinistia, 719*f*, 729*f*
Actinomycetes, 584*f*
Actinopterygii (ray-finned fishes), 719*f*, 728*f*–729*f*
Action potentials, neuron, 1073
 adaptations of axon structure for, 1076*f*–1077*f*
 conduction of, 1075*f*, 1076
 evolution of, 1084
 generation of, 1073, 1074*f*, 1075
 graded potentials, voltage-gated ion channels, and, 1073, 1074*f*
 hyperpolarization and depolarization of membrane potentials and, 1072*f*–1073*f*
 in long-term potentiation, 1101*f*
 in sensory systems, 1109*f*
Action potentials, plant, 862
Action spectrum, 193, 194*f*, 855
Activation, allosteric, 160*f*, 161
Activation, egg, 1046
Activation energy, 153, 154*f*–155*f*
Activators, 160*f*, 369*f*, 374*f*–375*f*, 397
Active immunity, 968
Active sites, enzyme, 155*f*–156*f*
Active transport, 126, 136
 ATP as energy for, 137*f*
 cotransport in, 138*f*, 139
 maintenance of membrane potential by ion pumps in, 137, 138*f*
 passive transport vs., 137*f*
 in plant cells, 209*f*
 of solutes across plant plasma membranes, 788, 789*f*
Activity, animal metabolic rate and, 891–892
Actual range, 1184
Acyclovir, 409
Adaptation, sensory, 1109–1110
Adaptations, 472. *See also* Evolution; Natural selection
 in amniote development, 1053*f*, 1054
 axon width and myelination as, 1076*f*–1077*f*
 evolution and, 2*f*, 14*f*–16*f*, 472, 473*f*–476*f*
 as evolutionary compromises, 501*f*
 floral, to prevent self-fertilization, 834, 835*f*
 gas exchange, 947*f*–949*f*
 for heat exchange in animals, 873*f*, 885*f*–889*f*
 against herbivory, 1219–1220
 mycorrhizae as plant, 817
 of pathogens to evade immune systems, 957, 971–972, 973*f*, 973*t*, 974, 976
 of plants and animals to life challenges, 894*f*–895*f*
 of plants to global climate change, 204–205
 of plants to terrestrial life, 203
 of plants to toxic elements, 30*f*
 predator and prey, 1217, 1218*f*–1219*f*, 1237
 prokaryotic, 573*f*–577*f*, 578, 581*t*, 582*f*
 as property of life, 3*f*
 to reduce terrestrial nutrient limitations, 1244
 of seed plants, 653
 sexual reproduction patterns as, 1022
 of smooth muscles, 1132
 terrestrial, of fungi and plants, 619*f*, 621, 660
 terrestrial, of seed plants, 637*f*–638*f*, 639
 of vertebrate digestive systems, 911*f*–914*f*
Adaptive evolution, 494, 498, 499*f*, 501. *See also Evolution; Natural selection*

Adaptive immunity, 953
 active and passive immunity in, 968
 antigen recognition by B cells and antibodies of, 958*f*–959*f*
 antigen recognition by T cells, 959*f*–960*f*
 B cell and T cell development of, 960, 961*f*–963*f*
 B cell and T cell proliferation in, 961, 962*f*
 B cells and antibodies in responses of, 964, 965*f*–966*f*
 cytotoxic T cells in responses of, to infected cells, 966*f*, 967
 helper T cells in responses of, 963, 964*f*
 immune rejection and, 969–970
 immunization and, 968*f*, 976
 immunological memory of, 960, 962, 963*f*
 medical tools using antibodies of, 969*f*
 molecular recognition by, 957*f*
 overview of, 957*f*, 967*f*
 pathogen recognition in, 952*f*, 957*f*–958*f*
 self-tolerance in, 961
Adaptive radiations, 15*f*–16*f*, 525, 542, 543*f*, 544, 736, 1183, 1184*f*
Addition rule, 277*f*, 278
Adélie penguin, 892
Adenine, 84, 85*f*, 86, 317*f*, 318, 341*f*, 850
Adenomatous polyposis coli (APC), 391*f*, 394
Adenosine diphosphate. *See* ADP
Adenosine triphosphate. *See* ATP
Adenoviruses, 400*f*
Adenyl cyclase, 223*f*–224*f*
Adhesion, 46*f*, 795–796
Adhesive chemicals, echinoderm, 713, 714*f*
Adipose tissue, 878*f*, 915, 918
ADP (adenosine diphosphate)
 as enzyme activator, 160
 hydrolysis of ATP to, 151*f*
 in sliding-filament model of muscle contraction, 1126, 1127*f*
 synthesis of ATP from, 153*f*, 169, 175, 176*f*, 177–178
Adrenal cortex, 1004*f*, 1013–1014
Adrenal glands, 1012
 epinephrine and. *See* Epinephrine (adrenaline)
 in human endocrine system, 1004*f*
 responses of, to stress, 1012*f*–1013*f*, 1014
 smooth ER and, 104
Adrenaline. *See* Epinephrine
Adrenal medulla, 1004*f*, 1012*f*–1013*f*
Adrenocorticotrophic hormone (ACTH), 1004*f*, 1008*f*, 1012*f*, 1013–1014
Adult stem cells, 430, 431*f*
Adventitious roots, 760*f*
Adventitious shoots, 833*f*
Aerial roots, 760*f*
Aerobic prokaryotes, 577*f*
Aerobic respiration, 165, 179–181
Afferent arteriole, 987*f*
Afferent neurons, 1088*f*, 1108*f*
Africa, human population in, 1208, 1209*f*
African-Americans, sickle-cell disease in, 286*f*, 287
African buffalo, 1221*f*
African elephants (*Loxodonta africana*), 474*f*, 1197*f*, 1265*f*
African golden mole, 558*f*, 559
African grey parrots, 1099
Africans
 genomes of, 462–463
 sickle-cell disease in, 286*f*, 287
African sleeping sickness, 713
Agave, 1200, 1201*f*
Age-related macular degeneration (AMD), 432
Age structure, human population, 1208, 1209*f*
Aggregate fruits, 831*f*
Aging, 233, 289
Aglaophyton major, 628*f*, 660
Agonistic behavior, 1153*f*
agouti gene, 372*f*
Agriculture. *See also* Crop plants
 allopolyploidy in, 514*f*–515*f*

- biotechnology in, 437–439
C₃ plants in, 203
C₄ plants in, 203
 climate change and, 863
 community disturbances by, 1231
 effects of atmospheric carbon dioxide on
 productivity of, 205
 fertilizing in. *See* Fertilization, soil
 fungal food products of, 670
 global human population size and, 1211
 importance of insects to, 713
 importance of mycorrhizae to, 818
 nematode pests in, 705
 nitrogen fixation and, 817
 nutrient pollution from, 1274, 1275f
 plant biotechnology and genetic engineering in,
 836f–838f, 839–840
 plant breeding in, 823, 835–837
 plant cloning in, 428
 plant control systems in, 871
 seed plants in, 651
 soil conservation and sustainable, 807f–809f, 1273
 vegetative propagation of plants in, 835–836
- Agrobacterium tumefaciens*, 422, 595, 837
- Aguirre-Jarquin, Clemente, 24f
- AIDS (acquired immunodeficiency syndrome), **406**, **973**f. *See also* HIV
- cell-surface proteins and blocking HIV to prevent, 130f
- drug cocktails in treatment of, 489
- emergence of, 410
- G protein-coupled receptors and, 217f
- HIV and, 398f, 406, 407f
- host range of, 401
- Aigarchaeota clade, 586
- Ailuropoda melanoleuca*, 448t
- Ain, Michael C., 287f
- Air circulation patterns, global, 1166f
- Air roots, 760f
- Air sacs, 942f–945f
- Alanine, 77f
- Alarm calls, 1148f
- Albatross, 977f, 1277f
- Albinism, 285f, 335f, 336–337
- Albumen, 735f
- Albumin, 377f, 934f
- Albuterol, 62f
- Alcohol compounds, 63f
- Alcohol dehydrogenase, 66f
- Alcohol fermentation, **180**f
- Alcoholic beverages, 670
- Aldehyde compounds, 63f
- Alder, 1230f–1231f
- Aldoses, 68f
- Aldosterone, 220, 221f, 995, 996f, 1014
- Algae, **596**
- alternation of generations in, 258f, 259
 - blooms of, 1227f, 1242, 1243f
 - brown, 602, 603f, 604
 - chloroplasts in, 110, 111f
 - DNA identification of, 1222
 - as earliest multicellular eukaryotes, 535f
 - evolution of plants from green, 617, 618, 619f, 621
 - evolution of photosynthetic, 596f–597f
 - fossils of, 529f, 533f
 - fungi and, as lichens, 663, 668f–669f
 - green, 101f, 596f–597f, 610f–611f, 614, 617, 618, 619f, 621
 - horizontal gene transfer in, 569f
 - photosynthesis in, 188f
 - as protists, 599f
 - red, 596f–597f, 609f, 610
 - structure and organelles of cells of, 101f
- Algin, 603
- Alimentary canals, 688f, **697**f, 704f, **905**f, 912f
- Alkaline vents, **526**f
- Alkaloids, 868f
- Alkaptonuria, 293, 336
- Allantois, 735f, 1053f, 1054
- Alleles, **272**. *See also* Genes
- combination predictions of, 268
 - correlating behavior of chromosome pairs with, 295, 296f–297f
 - degrees of dominance of, and phenotypes, 279f, 280
 - dominant, in genetic disorders, 287f
 - dominant vs. recessive, in Mendelian inheritance, 272, 273f–276f, 293
- frequencies of, in gene pools of populations, 490f
- genetic markers for disease-causing, 427f
- genetic variation from recombination of, 305.
- See also* Recombination
- genetic variation preserved in recessive, 500
- genomic imprinting of maternal or paternal, 372
- as information, 293
- microevolution as alteration in frequencies of, in populations, 487f, 493, 494f–497f
- multiple, and pleiotropy, 280f
- mutations as sources of, 265, 488–489
- recessive, in genetic disorders, 285f–286f, 287
- in sexual life cycles, 259
- sickle-cell, 502f–503f
- testing populations for frequencies of, 490, 491f, 492–493
- transmission of, 269
- Allergens, 839, 970f, 971
- Allergies, 438, 970f, 971
- Alliaria petiolata*, 818
- Alligator mississippiensis*. *See* American alligator
- Alligators, 737f, 738, 925
- Allohexaploid, 514–515, 524
- Allolactose, 368f–396f, 370
- Allopatric populations, character displacement in, 1216, 1217f
- Allopatric speciation, **511**f–512f, 513, 539–540
- Allopolyploids, **514**f–515f
- All-or-none responses, 1073
- Allosteric regulation, **160**f–161f
- α (yeast mating type), 213f, 214, 217
- α chain, 959f
- α -globin gene family, 453f
- α helix, **80**f
- α -lactalbumin, 456, 457f
- Alpha (α) carbon, 75
- Alpha cells, 916f
- Alpha proteobacteria, 584f, 596
- Alpheus* species, 512f, 513
- Alpine chickweed, 1281f
- Alpine pennycress (*Thlaspi caerulescens*), 809
- Alpine tundra, 1176f
- Alpine wood sorrel, 835f
- Alternate phyllotaxy, 786f
- Alternation of generations, **258**f, **603**f, 604, **620**f, 621
- Alternative RNA splicing, **347**f, **378**f, 449
- Altruism, **1156**f–1159f, 1162
- Alu* elements, 452, 459
- Aluminum toxicity, plant, 809
- Alveolates, 599f, **604**f–606f
- Alveoli, 604f, **943**f–944f
- Alzheimer's disease, 83, 231, 311, 361, 413, 433, 435, **1103**, 1104f
- Amacrine cells, 1118f
- Amazon rain forest, 1271f
- Amber, fossils in, 529f
- Amborella trichopoda*, 648f, 650f, 653
- Amebic dysentery, 613
- American alligator (*Alligator mississippiensis*), 737f
- American beech trees (*Fagus grandifolia*), 1170f
- American chestnut trees, 1226, 1234
- American Dust Bowl, 807f
- American flamingo, 14f
- American pika (*Ochotona princeps*), 1280f
- American pokeweed, 830f
- Amine compounds, 63f
- Amines, 1001f
- Amino acids
- abiotic synthesis of, 526f–527f
 - activation of, in eukaryotic cells, 356f
 - deamination of, for catabolism, 182
 - in DNA-binding proteins, 91
 - in enzymatic catalysis, 156
 - essential, 899f
 - in evolution of enzymes, 159f
 - in genetic code, 340f–342f
 - human dietary deficiencies in, 901
 - as neurotransmitters, 1081t
 - in nitrogen cycle, 1251f
 - in polypeptides and proteins, 67, 75, 76f–78f.
- See also* Polypeptides; Proteins
- in proteins, 75, 77f
- sequences of, 444, 445f, 446, 458
- sickle-cell disease and, 82f
- specified by nucleotide triplets in translation, 347f–350f
- structure of, 91
- using sequences of, to test hypothesis on horizontal gene transfer, 570
- Amino acid sequence identity tables, reading, in Scientific Skills Exercise, 458
- Amino acid sequences, 444, 445f, 446, 458
- Aminoacyl tRNA, 349f
- Aminoacyl-tRNA synthetases, **349**f
- Amino end. *See* N-terminus
- Amino group, 63f
- Amitochondriate protists, 597
- Ammonia, **982**
- as base, 51
 - hydrogen bonds and, 39f
 - as nitrogenous waste, 982f, 983, 988
- Ammonites, **702**
- Ammonium, in nitrogen cycle, 1251f
- Amniocentesis, **288**, 289f, 1039–1040
- Amnion, 480, 735f, 1053f
- Amniotes, **734**, **1053**
- derived characters of, 734, 735f
 - developmental adaptations of, 1053f, 1054
 - evolution of, 678
 - fossils and early evolution of, 735f
 - mammals as, 741
 - phylogeny of, 734f
 - reptiles, 735f–740f
- Amniotic egg, 718, **734**, 735f
- Amoebas, 117f, 235f, 449, 599f, **606**
- Amoebocytes, **690**f, 691
- Amoeboid movement, 117f
- Amoebozoans, **612**f–613f
- Amorphea, 599, 611
- AMP (adenosine monophosphate), 183f, 184, 349f
- AMPA receptors, 1101f
- Amphetamines, 1102, 1103f
- Amphibians, **731**
- adaptations of kidneys of, 992
 - axis formation in, 1060f
 - brains of, 1091f
 - breathing in, 925, 944
 - cell developmental potential in, 1060, 1061f
 - cell fate and pattern formation by inductive signals in, 1062f
 - cleavage in, 1048f, 1049
 - diversity of, 732f–733f
 - double circulation in, 924f, 925
 - evolution of, 678
 - external fertilization in, 1022f
 - fungal parasites of, 669, 670f
 - gastrulation in, 1051f, 1052
 - hearing and equilibrium in, 1116f
 - neurulation in, 1054f, 1055
 - parental care in, 1151
 - phylogeny of, 719f
 - species distributions of, 1164f, 1185
 - vaccine for, 733
- Amphipathic molecules, **127**
- Amplification, sensory, **1109**–1110
- Amplification, signal, 221, 226–227
- Ampulla, sea star, 714f
- Amygdala, 1095f–**1096**f
- Amylase, **906**
- Amyloid plaques, 1104f
- Amylopectin, 70f
- Amyloplasts, 111
- Amylose, 70f, 111
- Amyotrophic lateral sclerosis (ALS), 1129
- Anabaena*, 582f
- Anableps anableps*, 365f
- Anabolic pathways, **144**, 183
- Anabolic steroids, 1014
- Anabrus simplex*, 449, 712f, 1112f
- Anaerobic respiration, 165, 179–182, **582**
- Analyses, **558**f
- Analogous structures, **481**
- Anaphase, 252
- Anaphase (mitosis), **237**, 239f, 241f, 243f, 263f
- Anaphase I, 260f, 263f, 266f
- Anaphase II, 261f, 266f
- Anaphylactic shock, 971
- Anatomical homologies, 479f, 480
- Anatomy, 873f–**874**. *See also* Animal form and function; Morphology; Plant structure
- Ancestral characters, shared, **560**, 561f
- Ancestry, common, 15f–16f, 479f–481f, 555, 556f–560f, 648
- Anchorage dependence, **247**, 248f

- Anchoring junctions, 120f
 Androgens, 1004f, **1014**, 1015f, 1030, 1031f
 Anemia, 936
 Anesthetics, 1084
 Aneuploidies, **307**, 308f, 309
 Angiosperm reproduction
 asexual, 833f–836f
 breeding and genetic engineering in, 836f–838f, 839–840
 flower pollination in, 824f–825f
 flower structure and function in, 823f–824f, 830
 fruit structure and function in, 830f–831f
 life cycle of, 646f, 647, 653, 826, 827f, 828
 mutualisms in, 825f
 seeds in, 828f–830f
 Angiosperms, **623f**
 bulk flow in sugar translocation in, 800, 801f
 characteristics of, 644f–646f, 647
 evolutionary mystery of, for C. Darwin, 477
 evolution of, 647f–649f
 evolution of seeds in, 639
 flowers of, 644f
 fruits of, 644, 645f
 gametophyte-sporophyte relationships in, 637f, 638
 life cycle of, 646f, 647, 653, 826, 827f, 828
 G. Mendel's techniques of crossing, 270f–271f
 origin of, 533f
 phylogeny of, 622t, 648f–650f, 653
 reproduction of. *See* Angiosperm reproduction
 Angiotensin II, 995, 996f
 Anhydrobiosis, **979**, 980f
 Animal behavior, 1140
 cerebral cortex information processing and, 1097f, 1098
 genetics, altruism, and inclusive fitness in evolution of, 1154, 1155f–1159f, 1160
 hormones and, 999f
 learning and, 1144f, 1145f–1148f
 stimuli for simple and complex, 1140f–1143f
 survival and reproductive success in evolution of, 1148, 1149f–1154f, 1161
 in thermoregulation, 873f, 887f
 Animal cells. *See also* Eukaryotic cells
 apoptosis in, 230f–231f
 cell junctions of, 120f
 cellular respiration in. *See* Cellular respiration
 cytokinesis in, 241, 242f
 endocytosis in, 140f
 extracellular matrix of, 118, 119f
 local and long-distance cell signaling in, 215f, 216
 meiosis in, 260f–261f
 nuclear transplantation of differentiated, 428, 429f–430f
 stem cells, 430f–431f
 structure and organelles of, 100f
 structure and specialization of, 674
 water balance of, 134f–135f
 Animal development. *See also* Embryonic development
 adaptations of, 894f
 animal phylogeny and, 682, 683f, 684
 cell fate specification in, 1057, 1058f–1064f
 comparing processes of, 463f–464f
 developmental biology and, 1057
 fertilization and cleavage in, 1044f–1048f, 1049
 morphogenesis in, 1049, 1050f–1057f
 protostome vs. deuterostome, 681, 682f
 reproduction and embryonic, 674f, 675
 Animal form and function
 anatomy and physiology as, 873f–874
 bioenergetics of, 889, 890f–893f
 body plans, 679, 680f–682f
 correlation of, at all levels of organization, 874f–880f, 876f
 evolution of body size and shape in, 874f
 exchange with environment in, 874, 875f, 876
 feedback regulation of homeostasis in, 881f–883f
 hierarchical organization of body plans in, 876t, 877f–879f
 mammalian organ systems in, 876t
 regulation of, by endocrine and nervous systems, 880f
 thermoregulation in, 884f–889f
 Animal hormones, **880**, **1000**. *See also* Endocrine systems; Hormones
 behavior and, 999f
 birth control, **1038f**, 1039
 cascade pathways of, 1008, 1009f, 1010, 1014
 cellular response pathways of, 1002f–1003f
 chemical classes of, 1002f, 1003
 as chemical signals of endocrine system, 1000f–1004f
 in childbirth and labor, 1037f
 embryonic, 1035
 endocrine system glands and, 1003, 1004f
 endocrine systems and, in cell signaling, 880f
 erythropoietin, 936
 evolution of, 1015f, 1016
 feedback regulation of, 1005–1006
 in fight-or-flight responses, 212
 multiple effects of single, 1003
 in neuroendocrine signaling, 1000f, 1001, 1006f–1008f. *See also* Neuroendocrine signaling
 plant hormones vs., 216, 894f
 receptors for, 1000f–1004f, 1018
 regulation of appetite and consumption by, 917f, 918
 in regulation of digestive systems, 915f
 in regulation of mammalian reproduction, 1030, 1031f–1032f, 1033–1034
 in regulatory functions of endocrine glands, 1011f–1015f, 1016
 in sex determination, 1030
 in simple endocrine pathway, 1004, 1005f
 in simple neuroendocrine pathway, 1005f
 Animalia kingdom, **12f**, 568
 Animal nutrition. *See also* Human nutrition
 adaptations of vertebrate digestive systems for diets in, 911f–914f
 compartmentalized processing in, 898
 diets and requirements for, 899f–902f, 900t–901t
 digestive systems and, 905, 906f–911f
 feedback regulation of digestion, energy storage, and appetite in, 914, 915f–917f, 918
 feeding mechanisms in, 902, 903f
 food processing stages in, 902, 903f–905f
 nutritional modes in, 673f, 674, 894f
 Animal pole, **1048f**
 Animal reproduction. *See also* Human reproduction
 amphibian, 732f–733f
 asexual, 266, 267f, 1020
 development and, 674f, 675
 different ways of, 1019f
 evolution of sexual, 1021, 1022f
 fertilization mechanisms in, 1022f–1024f
 of fish, 728
 hormonal regulation of mammalian, 1030, 1031f–1032f, 1033–1034
 reproductive cycles in, 1021f
 sexual life cycles in, 258f. *See also* Sexual life cycles
 Animals. *See also* Animal behavior; Animal development; Animal form and function; Animal hormones; Animal nutrition; Animal reproduction
 aquatic. *See* Aquatic animals
 catabolic pathways in, 182f, 183
 cells of, 6f. *See also* Animal cells
 cell structure and specialization of tissues of, 674
 cellular respiration in hibernating, 178
 circulatory and gas exchange systems of. *See* Cardiovascular systems; Circulatory systems; Gas exchange
 climate change and, 11f, 1280f–1281f
 cloning of, 428, 429f–430f
 as consumers and predators, 673f
 correlation of diversity of miRNAs with complexity of, 678
 defense mechanisms of, 28f
 in domain Eukarya, 12f
 in ecosystem interaction, 10f, 11
 endangered or threatened, 1261, 1262f, 1288
 in energy flow and chemical cycling, 9f
 evolutionary history of, 675f–677f, 678–679
 evolutionary links between plants and, 648, 649f
 extinctions of, 702f
 flower pollination by, 824f–825f
 fruit and seed dispersal by, 832f
 fungal mutualisms with, 668f
 fungal parasites of, 669f–670f
 glycogen as storage polysaccharide for, 70f, 71
 herbivore adaptations in, 477f, 478
 immune systems of. *See* Immune systems
 kingdom and domain mutualisms with, 813f
 land colonization by, 533f, 536, 537f
 latitude and size of, 897
 life challenges and solutions for, 894f–895f
 maximizing body surface area of, 695f
 microevolution of populations of. *See* Microevolution
 neurons and nervous systems of. *See* Nervous systems; Neurons
 nutrition of, 12f, 13
 as opisthokonts, 613
 osmoregulation and excretion of. *See* Excretory systems; Osmoregulation
 osmoregulation in, 978f–980f, 981
 phylogeny of, 682f, 683f, 684, 686
 plant recruitment of, as herbivore defense, 869f
 protein production by "pharm" transgenic, 436f
 relationship of, to unikont protists, 611–612
 reproduction and development of, 674f, 675
 seed dispersal by, 645f
 sensory and motor systems of. *See* Motor systems; Sensory systems
 tropical deforestation and extinctions of, 651f, 652
 zoonotic pathogens and, 1234, 1235f
 Animal viruses
 classes of, 406f
 as pathogens, 407f–413f
 replicative cycles of, 404, 405f, 406t, 407f
 Anions, **37**, 38f, 806, 807f, 1070t
 Ankle bones, 481f
 Annelids, 688f, 703f–704f, 705, 923f, 985f, 1086f
 Annual human population growth rates, 1207f, 1208
 Annuals, 766
 Antagonistic functions, autonomic nervous system, 1089f
 Antagonistic muscle pairs, 1132f
 Antarctica, 1224f
 Antarctic Circumpolar Current, 1168f
 Antennae, 43, 1110, 1111f, 1123
 Anterior pituitary gland, 1004f, **1007f**–1008f, 1016, 1030, 1031f–1032f
 Anterior-posterior axis, 1055, 1060f
Antherea polyphemus, 1001
 Antheridia, 624f, **625**, 630f
 Anthers, **644f**, **823f**
 Anthocerophyta (hornworts), 623, 626f
 Anthophyta. *See* Angiosperms
 Anthozoans, 692f–693f
 Anthrax, 575f, 584f
 Anthropoids, **746f**–747f
 Anti-aging effects, 850
 Antibiotic drugs
 bacteria and, 349
 bacterial resistance to, 213, 581, 588f–589f
 for cystic fibrosis, 286
 as enzyme inhibitors, 158–159
 evolution of resistance to, 478f, 592
 fungal, 670
 gram-positive bacteria and, 584f
 peptidoglycan and, 574–575
 prokaryotic ribosomes and, 577
 from soil bacteria, 590
 sponges and, 691
 viruses and, 409
 Antibodies, **958**
 in allergic reactions, 970f, 971
 antigen recognition by, 958f–959f
 gene rearrangement by, 960, 961f
 in humoral immune response, 963, 964f–967f
 immunological memory, 963f
 as medical tools, 969f
 as proteins, 76f, 79f
 in responses to extracellular pathogens, 964, 965f–966f
 Anticodons, **348f**–349f
 Antidiuretic hormone (ADH), 994f–995f, 1004f, **1007f**, **1155f**
 Antifreeze proteins, 865, 888
 Antigen fragments, 959f–960f
 Antigenic variation, 972–973
 Antigen presentation, **959f**–**960f**
 Antigen-presenting cells, **963**, 964f
 Antigen receptors, **958f**–**961f**
 Antigens, **958**, 963f–967f
 in allergic reactions, 970f, 971
 B cell recognition of, 958f–959f
 T cell recognition of, 959f–960f

- Antihistamines, 971
 Anti-inflammatory drugs, 1013–1014
 Antimicrobial peptides, 953–954, 955f, 956–957
 Antioxidants, 195
 Antiparallel DNA sugar-phosphate backbones, 86f, 317f–320f, 318, 324, 325f–327f
 Antithrombin, 436f
 Antivenin, 968
 Antiviral drugs, 409
 Ants, 28f, 298f, 485, 668f, 712f, 813f, 832f, 1001f, 1220f
 Anurans, 732f–733f
 Anus, 911
 Aorta, 926f, 930f
 Apes, 746f–747f
 Aphids, 570, 801f
 Aphotic zone, 1177f
 Apical buds, 761
 Apical dominance, 770, 850f
 Apical ectodermal ridge (AER), 1062f, 1063f
 Apical meristems, 621f, 766f–767f
 Apical surface, epithelial, 877f
 Apicomplexans, 605, 606f
 Apicoplasts, 606f
 Apodans, 732f
 Apomixis, 833
 Apoplast, 787, 788f, 800f
 Apoplastic route, 788f, 793f
 Apoptosis, 229
 cell-signaling pathways of, 230, 231f
 cytotoxic T cell response and, 966f, 967
 emergent properties of, 233
 ethylene in response to senescence and, 853–854
 in immune cells, 233
 molecular mechanisms of, 230f
 in morphogenesis, 1056–1057
 p53 gene and, 390f
 plant response to flooding with, 864f
 as programmed cell death, 229f, 230
 self-tolerance vs., 961
 Aposematic coloration, 1218f, 1219
 Appendages, arthropod, 706, 707f, 708–709
 Appendix, 911f
 Appetite regulation, 917f, 918
 Apple fruit, 831f
 Apple maggot fly (*Rhagoletis pomonella*), 508f, 515–516
Aptenodytes forsteri, 873f
Aptenodytes patagonicus, 740f, 884f, 1192f
 Aquaporins, 132, 790, 989
 cellular membrane selective permeability and, 132f
 facilitated diffusion and, 135f
 in kidney regulation, 994f–995f
 mutations in, as causes of diabetes insipidus, 995f
 water diffusion and role of, 790–791
 Aquatic animals
 adaptations of kidneys of, 992, 993f
 gills for gas exchange in, 921f, 940f–941f
 ice and, 44
 nitrogenous wastes of, 982f
 osmoregulation in, 979f–980f
 Aquatic biomes
 acid precipitation in, 1265, 1266f
 biodiversity hot spots in, 1272f
 coral reefs, 1182f
 decomposition in, 1248–1249
 estuaries, 1180f
 eutrophication of, 1275f
 food chains in, 1224f
 habitat loss in, 1264
 intertidal zones, 1181f
 lakes, 1179f
 locomotion in, 1135
 marine benthic zones, 1182f
 nutrient cycling in, 1250f–1251f
 oceanic pelagic zones, 1181f
 plastic waste in, 1277f
 primary production in, 1242, 1243f, 1243t
 protists as producers in, 614, 615f
 streams and rivers, 1180f
 thermoregulation in, 881f
 wetlands, 1179f
 zonation in, 1177f–1178f
 Aqueous humor, 1118f
 Aqueous solutions, 49
 acidic and basic conditions of, 51, 52f–53f, 54
 solvents, solutes, and, 49f, 50
 Aquifers, 808
- Arabidopsis thaliana* (mustard plant)
 altering gene expression of, with touch, 862f
 genome size of, 448f
 as model organism, 22, 774, 776f, 783
 triple response in, 853f
 Arachnids, 689f, 708f
 Arbuscular mycorrhizae, 656, 660, 663, 817, 818f
 Arbuscule, 537f, 656f
 Archaea, 12f
 domain, 12f, 568, 569f, 585t, 586
 genome sizes and number of genes for, 448t, 449
 prokaryotic cells of, 6f, 97. *See also* Prokaryotes;
 Prokaryotic cells
 Archaean eon, 530f, 532f–533f
Archaefructus sinensis, 533f, 647f
Archaeoglobus fulgidus, 448t
 Archaeognatha (bristletails), 712f
 Archaeology, peat moss and, 627f
Archaeopteris, 641
Archaeopteryx, 739f
 Archaeoplastida, 599f, 609f–610f
 Archegonia, 624f, 625, 630f
 Archenterons, 682f, 1050f
Architeuthis dux, 702
 Archosaurs, 736
 Arctic, 48f
 Arctic fox, 1238f, 1244, 1256f
 Arctic ground squirrel (*Spermophilus parryii*), 893
 Arctic sea ice, 1279
 Arctic tundra ecosystem, 1238f, 1244, 1256f–1257f
Ardipithecus ramidus, 748f–749f
 Area effects, community diversity and, 1232f
 Arginine, 77f, 336f–338f
 Argo complex, 954f
Argyroneta aquatica, 951
 Arid conditions, 142, 203, 204f–206f, 1166f, 1168
 Aristotle, 470
 Armenian oak, 650f
 Arms, chromatid, 236, 264
 Arousal
 autonomic, 1096
 brain functions in sleep and, 1094f
 human sexual, 1034, 1081
 Arsenic, 29
 Art, humans and, 754f
 Arteries, 924f–926f, 929f–931f, 937f, 939
 Arterioles, 924f, 929f–932f
 Arthropophyes, 632f
 Arthropods, 706. *See also* Ecdysozoans
 chelicerates, 707, 708f
 chitin as structural polysaccharide for, 72f
 compound eyes of, 1117f, 1118
 crustaceans and insects as pancrustaceans, 709f–712f, 713
 evolution of, 678
 exoskeletons of, 1133
 general characteristics of, 707f, 708
 Hox genes and body plan of, 706f, 707
 land colonization by, 536–537
 Malpighian tubules of, 985f
 myriapods, 707–708, 709f
 nervous systems of, 1086f
 origins of, 706f, 707
 phylogeny of, 689f, 709f
 Artificial corridors, 1271f, 1272
 Artificial selection, 474, 475f, 476, 651, 823, 836f, 837
 Artiodactyls, 745f
 Ascending limb, loop of Henle, 988f, 989
 Asci, 663
 Ascocarps, 663f
 Ascomycetes, 660f, 663f–664f, 665t, 671f
 Asexual reproduction, 255, 833, 1020
 in angiosperms, 833f–836f
 in bryophytes, 625
 evolution of, in animals, 266, 267f
 in fungi, 658f–659f
 inheritance in, 255f
 in lichens, 668f–669f
 mechanisms of, 1020
 in protists, 594
 in rotifers, 697–698
 sexual reproduction vs., 255f, 833–834, 1021, 1022f. *See also* Sexual reproduction
 switch to, 268
 of triploid organisms, 268
 Asian army ants (*Leptogenys distinguenda*), 1001f
 Asian elephant, 474f
 Asian ladybird beetles, 475f
- A site (aminoacyl-tRNA binding site), 350f, 352f–353f
 A soil horizon, 806f
 Asparagine, 77f
 Aspartic acid, 77f
 Aspen trees (*Populus tremuloides*), 791f, 833f
 Aspirin, 651, 1001, 1013–1014, 1112
 Assassin bugs, 712f
 Assembly stage, phage lytic cycle, 402f
 Association areas, cerebral cortex, 1096
 Associative learning, 1146f
 Asteroidea, 713, 714f
 Aster, 238f, 240f
 Asthma, 62, 217, 933, 1012
Astragalus bones, 481f
 Astrobiologists, 50
 Astrocytes, 1090f
 Asymmetrical cell division, 777f
 Asymmetric carbon, 61f–62f, 68, 75
 Asymmetry, body, 1059–1060, 1061f, 1064f
 Atherosclerosis, 74, 75, 139, 141, 937f, 938–939
 Athletes
 abuse of anabolic steroids by, 1014
 blood doping by, 936
 Athlete's foot, 670
 Atlantic lobster (*Homarus americanus*), 979
 Atlantic salmon (*Salmo salar*), 89
 Atmosphere
 animal evolution and oxygen in, 677
 carbon dioxide in, 11
 Earth's early, 526f–527f
 global climate change and carbon dioxide in, 1278f, 1279, 1282, 1283f
 ozone in, 1283f, 1284
 photosynthesis and oxygen in, 533, 534f
 Atomic mass, 31
 Atomic mass unit (amu), 31
 Atomic nucleus, 30f, 31
 Atomic number, 31
 Atoms, 30f–36f, 37
 ATP (adenosine triphosphate), 64, 150
 in bioenergetics, 890f
 catabolic pathways and production of, 165
 conversion of, to cyclic AMP, 223f–224f
 in DNA replication, 324
 energy coupling and, 150, 151f–153f
 as energy for active transport, 137f
 as energy for membrane proteins, 130f
 as energy source for cellular processes, 64
 in feedback regulation of cellular respiration, 183f, 184
 in muscle fiber contraction speed, 1131
 phosphofructokinase and, 186
 in photosynthesis, 191f, 192, 197f–200f, 201, 206, 207f
 regeneration of, in ATP cycle, 153f
 regulation of regeneration of, 160
 in sliding-filament model of muscle contraction, 1126, 1127f, 1128
 synthesis of, by cellular respiration, 164f, 165, 169. *See also* Cellular respiration
 synthesis of, by fermentation and anaerobic respiration, 179, 180f, 181
 thylakoids and production of, 211
 in translation, 349f
 work as hydrolysis of, 151f, 152
 yield of, at each stage of cellular respiration, 177f, 178
 ATP synthase, 175f–176f, 177, 186, 311
 Atria, heart, 924f–927f
 Atrial natriuretic peptide (ANP), 996
 Atrioventricular (AV) nodes, 928f
 Atrioventricular (AV) valves, 927f
 Attachment function, membrane protein, 130f
 Attachment stage, phage lytic cycle, 402f
 Auditory communication, 1141–1142
Aurea mutant tomato, 844f, 845
 Australia, 481f, 539–540, 605f, 742–744
 Australian moles, 558f, 559
 Australian thorny devil lizard (*Moloch horridus*), 737f
 Australopiths, 749, 750f
 Autism spectrum disorder, 1100
 Autocrine signaling, 1000f, 1001f
 Autoimmune diseases, 971f
 Autonomic arousal, 1096
 Autonomic nervous system, 1088f–1089f
 Autophagy, 107f, 108
 Autopolyploids, 514f
 Autosomes, 257

- Autotrophs, **188f**, 581*t*, 586, 889, 894*f*, 1240*f*
 Auxin, 845, 846*f*, 847*f*, **848f**, 849*f*, 850, 854*f*, 861
 Avery, Mary Ellen, 943, 944*f*
 Avery, Oswald, 315
 Avian flu, 410, 1234, 1235*f*
 Avogadro's number, 50
 Axel, Richard, 1124
 Axillary buds, **761**
 Axis formation, 385*f*–386*f*, 387, 1059, 1060*f*
 Axolotls, 544, 545*f*, 921*f*
 Axons, 879*f*, 1067, **1068f**, 1076*f*–1077*f*, 1084,
 1086–1087, 1089*f*, 1090
 Azidothymidine (AZT), 409
Azolla, 813*f*, 817
- B**
- Bacillus anthracis*, 575*f*, 584*f*
Bacillus thuringiensis, 837, 838*f*
 Backbone, nucleic acid, 86*f*
 Backbone, polypeptide, 78*f*
 Bacteria, **12f**
 alcohol fermentation by, 180*f*
 anaerobic respiration in, 179–180
 antibiotic drugs and, 349
 antibiotic resistance in, 478*f*, 581
 binary fission in, 242, 243*f*
 bioremediation using, 1255*f*
 Cas9 protein of, 360, 361*f*
 cell signaling in, 213*f*, 214
 cell structure of, 97*f*
 cellular integration and, 121*f*
 cholera and, 224
 conjugation in, 579, 580*f*, 581
 as decomposers, 1240*f*
 in digestive systems, 912, 913*f*–914*f*
 diversity of, 1223*f*
 as DNA cloning vectors, 418*f*, 419
 DNA packing in chromosomes of, 330–331
 DNA replication in, 322*f*–327*f*
 domain, 12*f*, 568, 569*f*, 583*f*–584*f*, 585*t*
 evidence for DNA in research on, 315*f*–316*f*, 317
 evolution of cell division in, 242, 243*f*
 evolution of glycolysis in, 182
 expressing cloned eukaryotic genes in, 422–423
 flagellum, movement of, 993*f*
 genome sizes and number of genes for, 448*f*, 449
 G proteins and infections by, 218*f*
 Gram staining of, 574, 575*f*
 immune system recognition of, 952*f*
 land colonization by, 536
 as model organism. *See Escherichia coli*
 mutualistic and pathogenic, 587, 588*f*, 813*f*
 nitrogen-fixing, and plants, 814*f*–816*f*, 817, 1244
 nutrient limitations and, 1244
 origin of photosynthesis in, 533, 534*f*
 origins of mitochondria and chloroplasts, 109,
 110*f*
 in Permian mass extinction, 540
 photosynthesis of, 188*f*, 189, 199
 phylogeny of, 583*f*–584*f*, 585
 plant defenses against, 866
 in polymerase chain reaction, 421, 422*f*
 prokaryotic cells of, 6*f*, 97. *See also Prokaryotes;*
 Prokaryotic cells
 regulation of transcription in, 365*f*–369*f*, 370
 relatedness of, to mitochondria, 595
 reproduction rate of, 592
 root mutualism with, 592
 soil, 807
 transcription and translation in, 339*f*, 355*f*
 transcription in, 342, 343*f*–344*f*
 translation in. *See Translation*
 viral infections of. *See Phages*
- Bacteriophages (phages), **315, 401**
 capsids of, 400*f*, 401
 Cas9 protein and, 360, 361*f*
 defense against, 404*f*
 in DNA research, 315*f*–316*f*, 317
 in fighting infections, 872, 931
 prophages and temperate, 402, 403*f*
 replicative cycles of, 402*f*–404*f*
 in transduction, 579*f*
 virulent, 402*f*
 Bacteriorhodopsin, 129*f*
Bacteroides thetaiotaomicron, 587
 Bacteroids, **816f**, 817
 Bada, Jeffrey, 58
- Bait-and-switch defense, 600–601
 Baker, C. S., 557*f*
 Baker's yeast. *See Saccharomyces cerevisiae*
 Balance, body, 1112*f*–1116*f*, 1135
 Balancer, 1066
 Balancing selection, **500**, 501*f*–503*f*
Balanus balanoides, 1216*f*
 Baleen, 903*f*
 Ball-and-socket joints, 1134*f*
 Ball-and-stick models, 39*f*, 59*f*
 Ballooning, spider, 708
 Ball pythons, 892
 Banana, 268, 313
 Banana slugs, 1155, 1156*f*
 Barbiturates, 104–105
 Barbs, 645*f*
 Bar graphs in Scientific Skills Exercises, 23, 179, 376,
 483, 590, 629, 700, 762, 864, 1150, 1186, 1217
 Bark, **774**
 Bark beetles, 1244*f*, 1245, 1280*f*
 Barley, 650*f*, 851*f*
 Barnacles, 708–709, 710*f*, 1216*f*
 Barr, Murray, 300
 Barr body, **300f**, 309
 Barrier contraceptives, 1038*f*
 Barrier defenses, 953–954
 Barrier reefs, 1182*f*
 Basal angiosperms, **649**, 650*f*
 Basal animals, 682, 683*f*, 684, 690
 Basal body, **115**, 116*f*
 Basal cells, 828*f*
 Basal lamina, 929*f*
 Basal-like breast cancer, 393*f*
 Basal metabolic rate (BMR), **890f**–891*f*, 892
 Basal nuclei, 1093*f*
 Basal surface, epithelial, 877*f*
 Basal taxon, 556*f*, **557**
 Base pairing, DNA and RNA, 86*f*, 319*f*–321*f*
 Bases, **51**
 amino acids as, 76, 77*f*
 buffers and, 52–53
 hydrogen ions, acids, and, 51
 pH scale and, 51, 52*f*
 Basidiocarps, **666f**
 Basidiomycetes, 657, 660*f*, **665f**–667*f*
 Basidiospores, 666*f*
 Basidium, **665**
 Basilar membrane, 1113*f*
 Basin wetlands, 1179*f*
 Basking, reptilian, 735–736
 Basophils, 934*f*–935*f*
 Bass fishes, 881*f*
 Bassham, James, 191
 Batesian mimicry, 1218*f*, **1219**, 1237
Batrachochytrium dendrobatidis, 669, 670*f*
 Bats, 15*f*, 717, 825*f*, 991*f*, 992, 1262*f*
 Bautista, Diana, 92
 B cells, **958f**–960, 961*f*–966*f*
 DNA of, 976
 Bdelloid rotifers, 266, 267*f*, 698
 Beach mouse (*Peromyscus polionotus*), 2*f*, 20*f*–21*f*
 Beadle, George, 336*f*–338*f*
Beagle, HMS, C. Darwin's voyage on, 471, 472*f*
 Beaks
 finch, 473*f*, 486*f*–487*f*
 shapes of bird, 740*f*
 soapberry bug, 477*f*, 478
 Beans, 829*f*–830*f*, 858*f*, 899
 Bears, 145*f*, 510*f*, 1268*f*, 1269
 Beavers, 1226*f*
 Bed bugs, 712*f*
 Beech trees, 1170*f*
 Bees, 298*f*, 712*f*, 824*f*, 887
 Beetles, 475*f*, 712*f*, 717, 1244*f*, 1245, 1259, 1280*f*
 Behavior, **1140**. *See also Animal behavior*
 Behavioral ecology, **1140**
 Behavioral isolation, 508*f*
 Beijerinck, Martinus, 399
 Belding's ground squirrels, 1156, 1158, 1159*f*, 1193*t*,
 1194*f*, 1195, 1213
 Beluga whales, 1111*f*
 Benign tumors, **249**
 Bennettittales, 648*f*
 Benson, Andrew, 191
 Benthic zone, **1177f**
 Benthos, **1177**
 Bergmann, Christian, 897
- Berthold, Peter, 1157*f*
 β_2 -adrenergic receptor, 217*f*, 220
 β -amyloid, 1104
 β chain, 959*f*
 β -galactosidase, 159*f*, 368*f*
 β -globin, 87, 89, 357*f*, 358, 364
 β -globin gene family, 453*f*
 β -keratin, bird feathers and, 738*f*, 739
 β pleated sheet, **80f**
 Beta-carotene, 838*f*
 Beta cells, 916*f*
 Beta oxidation, **183**
 BGI (formerly Beijing Genome Institute), 444
bicoid gene, 386*f*–387*f*, 463
 Biennials, 766
 Big-bang reproduction, 1200
 Bilateral symmetry
 animal, 679, 680*f*, 683
 axis formation and, 1059, 1060*f*
 flower, 644*f*, 649*f*
 Bilaterians, **677**
 chordates, 719*f*
 Deuterostomia, 713
 Ecdysozoans, 705
 invertebrates, 686*f*
 Lophotrochozoans, 694
 origin of, 677
 phylogeny of, 683*f*, 717
 Bilayers, phospholipid. *See Phospholipid bilayers*
 Bile, **909**, 915*f*
 Binary fission, **242**, 243*f*, 577–578, 606, 607*f*
 Binding sites, ribosome, 350*f*
 Binomials (nomenclature), 470, **554**, 555*f*
 Biochemical pathways. *See Metabolic pathways*
 Biochemistry, 96
 Biodiversity
 angiosperm, 649f–650f. *See also Angiosperms*
 animal. *See Animals*
 of bacteria and archaea. *See Archaea; Bacteria*
 cellular structures and, 125
 classification of, 470
 climate change effects on, 1279
 conservation biology and, 1261. *See also Conservation biology*
 current crisis of, 1260f–1262f
 effects of mass extinctions on, 540f–542f
 evolution and, 14f–16f, 473. *See also Evolution of fungi. See Fungi*
 gymnosperm, 641, 642f–643f
 habitat loss and fragmentation and, 1263, 1264f
 human welfare and, 1262, 1263f
 invertebrate. *See Invertebrates*
 landscape ecology and regional conservation to
 sustain, 1270, 1271f–1274f
 levels of, 1261f–1262f
 plant. *See Plants*
 protection of, 1260
 protist. *See Protists*
 resurrection of, 1266
 within species, 507f
 sustainable development and, 1284,
 1285f, 1286
 taxonomy and classification of, 12f–13f
 threats to, 1260f, 1261, 1263, 1264f–1266f
 tree of life and, 15f–16f. *See also Phylogenetic trees; Phylogenies; Tree of life*
 tropical deforestation as threat to, 651f, 652
 unity in, 13f–14f, 26, 469, 473
 vertebrate. *See Vertebrates*
 Biodiversity hot spots, **1272f**
 Bioenergetics, **144**, **889**. *See also Metabolism*
 energy allocation and use in, 889, 890f
 energy budgets in, 892
 energy costs of foraging in, 1149
 influences on metabolic rate in, 891f, 892
 of locomotion, 1136
 metabolic rates and thermoregulation in, 890–891
 of osmoregulation, 980
 principles of, 163
 thyroid regulation of, 1009
 torpor, hibernation, and energy conservation in,
 892, 893f
 of urea and uric acid wastes, 983
 Biofilms, 213, **582f**
 Biofortification, 838*f*
 Biofuels, 671*f*, **838**
 Biogenic amines, 1081*f*

- Biogeochemical cycles, 1249f–1252f. *See also* Energy flow and chemical cycling
- Biogeographic factors, community diversity and, 1231, 1232f–1234f
- Biogeography, 482f, 483
- Bioinformatics, 9, 87, 443
- in analysis of protein structure, 83
 - centralized resources of, for genome analysis, 444, 445f
 - genome analysis using genomics and, 443
 - genomics, proteomics, and, 86, 87f
 - identifying protein-coding genes using gene annotation in, 445–446
 - in study of genomes, 9
 - systems biology and proteomics in study of genes and gene expression in, 446, 447f–448f
- Biological augmentation, 1255
- Biological clocks, 857, 858f–860f, 1094–1095. *See also* Circadian rhythms
- Biological Dynamics of Forest Fragments Project, 1271f
- Biological magnification, 1275, 1276f
- Biological molecules. *See also* Organic compounds
- analyzing polypeptide sequence data of, 87, 89
 - carbohydrates as. *See* Carbohydrates
 - four classes of, 66
 - genomics and proteomics in study of, 86, 87f
 - lipids as, 72, 73f–75f
 - macromolecules as polymers of monomers and, 66f–67f
 - as measures of evolution, 87, 89
 - nucleic acids as, 84, 85f–86f
 - proteins as. *See* Proteins
- Biological species concept, 507f–510f
- Biology, 3
- astrobiology in, 50f
 - biodiversity in. *See* Animals; Biodiversity; Plants
 - biophilia and, 1285f
 - cells in. *See* Cells
 - classification in. *See* Cladistics; Phylogenies; Systematics; Taxonomy
 - connection of, to chemistry. *See* Chemistry
 - conservation biology in. *See* Conservation biology
 - developmental biology in, 1057
 - ecology in. *See* Ecology
 - emergent properties at levels of biological organization in, 4–6, 4f–5f
 - evolutionary developmental (evo-devo) biology in, 387, 463, 544
 - evolution as theme of, 2, 3, 11, 12f–16f. *See also* Evolution
 - expression and transmission of genetic information in, 6, 7f–8f. *See also* Genetics
 - genomics and proteomics in, 86, 87f
 - interactions in biological systems in, 10f–11f. *See also* Interactions
 - molecular biology in. *See* Molecular biology
 - organization in, 4f–5f, 6
 - science of, 3, 16, 17f–24f. *See also* Case studies; Inquiry Figures; Research Method Figures; Scientific Skills Exercises
 - sociobiology in, 1159–1160
 - systems biology in, 5–6, 446, 447f–448f
 - transfer and transformation of energy and matter in, 9f. *See also* Energy
 - unifying themes of, 2f–11f
- Bioluminescence, 143f
- Biomass, 838, 1223, 1241–1242
- Biomass pyramid, 1247f, 1248
- Biomes, 1171. *See also* Aquatic biomes; Biosphere; Global ecology; Terrestrial biomes
- aquatic, 1177f–1182f
 - terrestrial, 1171f–1176f, 1189
- Biophilia, 1262, 1285f
- Bioremediation, 591f, 809, 1253
- ecosystem restoration using, 1253, 1255f
- Biorhythms, melatonin and, 1015
- Biosphere, 4f, 1165f. *See also* Earth
- aquatic biomes of, 1177f–1182f
 - biomes of. *See* Aquatic biomes; Terrestrial biomes
 - climate of, 1166f–1170f
 - ecological role of prokaryotes in, 586f–587f
 - future of, 1285f, 1286
 - global climate change of. *See* Climate change
 - global ecology of, 1165f. *See also* Global ecology
 - human population, and carrying capacity of, 1209, 1210f, 1211
- importance of seedless vascular plants to, 633–634
- as level of biological organization, 4f
- photosynthesis as process that feeds, 188f. *See also* Photosynthesis
- terrestrial biomes of, 1171f–1176f, 1189
- Biosynthetic pathways, 144, 183
- Biotechnology, 433
- DNA technology. *See* DNA technology
 - evolution and, 441
 - genetic code and, 342f, 441
 - genetic engineering of plants, 837, 838f, 839–840
 - in genetic testing, 288, 289f
 - genome-sequencing, 9
 - phytoremediation, 809
 - practical applications of, 433, 434f–437f, 438–439
 - prokaryotes in, 589, 590f–591f
 - science, society, and, 23, 24f
- Biotic factors, 1170
- microclimate and, 1169–1170
 - in pollination, 824f–825f
 - in species distributions, 1178, 1183f–1184f
- Biotic stresses, plant, 862, 866, 867f–869f
- Bipedal animals, 750f, 1135
- Bipolar cells, 1118f, 1120, 1121f
- Bipolar disorder, 1103
- Birds
- adaptations of kidneys of, 992f
 - alimentary canals in, 905f
 - avian flu in, 1234, 1235f
 - axis formation in, 1060
 - brains of, 1091f
 - breathing by, 925, 944, 945f
 - cleavage in, 1048
 - DDT and, 1276f
 - derived characters of, 738f, 739
 - as descended from dinosaurs, 564f, 565
 - endangered or threatened, 1261, 1262f
 - evolution of, 679
 - evolution of cognition and brains of, 1098, 1099f
 - evolution of finches, 473f, 486f–487f
 - evolution of genes in, 456, 457f
 - flight adaptations of, 1135–1136
 - flower pollination by, 825f
 - gastrulation in, 1052f
 - genetic variation in migration patterns of, 1156, 1157f
 - greater prairie chicken, 495f, 496, 1267f
 - hearing and equilibrium in, 1116
 - limb formation in, 1062, 1063f, 1064
 - living, 739, 740f
 - migration behaviors of, 1140, 1141f
 - nitrogenous wastes of, 982f, 983f
 - organogenesis in, 1055f
 - origin of, 739f
 - phylogeny of, 719f
 - plastic waste and, 1277f
 - as pollinators, 522
 - populations of, 1190f
 - problem solving of, 1147
 - red-cockaded woodpecker decline, 1269f–1270f
 - salt excretion in marine, 982f
 - sex determination of, 298f
 - species-area curves for, 1232f
 - thermoregulation in, 886f
 - unity and diversity of, 14f
 - wings of, 739, 740f
- Birth control, human, 1037, 1038f, 1039
- Birth control pills, 1038f, 1039
- Birth defects, human, 902f, 1039–1040
- Births
- demographics of, 1193t, 1194f–1195f
 - in density-dependent population growth, 1203f–1205f
 - in exponential population growth, 1196, 1197f
 - in population dynamics, 1192
- Births, human
- birth defects in, 902f
 - effects of vitamin supplementation on neural tube defects in, 902f
 - life-expectancy at, 1208–1209
 - newborn screening and, 289–290
 - stages of labor in, 1036, 1037f
 - zero population growth and, 1208
- Bisphenol A, 1015
- Bitter tastes, 1123f–1124f
- Bivalves, 699, 701f–702f
- Black-bellied seedcracker finches, 498
- Black bread mold, 662f, 663
- Black-breasted hill turtle (*Geomyda spengleri*), 736f
- Black-capped chickadees (*Poecile atricapillus*), 517f
- Blackcap warblers, 1156, 1157f
- Black rush plants, 1221f
- Blacktip reef sharks (*Carcharhinus melanopterus*), 727f
- Bladderwort, 448t, 449
- Blades, 602, 603f, 761
- Blastocoel, 1047f
- Blastocysts, 430, 431f, 1034, 1035f, 1052, 1053f
- Blastomeres, 1047f
- Blastopores, 682f, 1050f, 1062f
- BLAST program, 444, 445f
- Blastula, 674f, 1044, 1047f
- Blebbing, 229f–230f
- Blending hypothesis on inheritance, 271
- Blindness, 311, 495, 584f, 1122
- Blind spot, eye, 1118f
- Blood, 878f, 923. *See also* Blood pressure; Blood vessels
- ABO blood groups for human, 280f, 292
 - animal thermoregulation and, 885, 886f
 - apoptosis of human white blood cells, 229f
 - blood groups of, 969–970
 - cell division of bone marrow cells and, 235f
 - cholesterol in, and atherosclerosis, 75
 - in closed circulatory systems, 707, 923, 923f. *See also* Cardiovascular systems; Closed circulatory systems
 - clotting of, 10, 300, 418f, 436, 703f, 704, 936f, 937
 - components of, 934f–936f, 937
 - diffusion from, to interstitial fluid across capillary walls, 932, 933f
 - enzymes and glucose levels in, 157
 - filtration of, by nephrons, 987, 988f, 989
 - flow velocity of, 930f
 - gas exchange systems and components of, 947f–949f
 - glucose level regulation in, 10f
 - glycoproteins and types of human, 131
 - hormones in, 999
 - immune system rejection of transfusions of, 969–970
 - melatonin concentrations in human, 883f
 - pH of human, 52f, 53
 - regulation of calcium levels in, 1011f
 - sickle-cell disease and. *See* Sickle-cell disease
 - small intestine and, 125
 - vampire bat digestion of, 991f, 992
- Blood-brain barrier, 1090
- Blood doping, 936
- Blood flow velocity, 930f
- Blood flukes, 696f, 1220
- Blood groups, 280f, 969–970
- Bloodhounds, 1138
- Bloodletting, 703f, 704
- Blood pressure
- cardiac cycle changes in, 930, 951
 - in closed circulatory systems, 925
 - gravity and, 931f–932f, 951
 - hormonal regulation of, 994f–996f
 - hypertension and, 939
 - regulation of, 930–931
- Blood vessels
- blood flow velocity in, 930f
 - blood pressure in, 930, 931f–932f, 951
 - capillary function, 932f–933f
 - lymphatic systems and, 933f
 - structure and function of, 929f, 930
 - Viagra and, 224
- Blooms
- algal, 1227f, 1242, 1243f
 - diatom, 602
 - dinoflagellate, 605f
 - nitrogen pollution and phytoplankton, 1275f
- Blowfly, 825f
- Blueberry maggot fly (*Rhagoletis mendax*), 508f
- Blue crab, 1237
- Blue dragons (*Glaucus atlanticus*), 686f
- Bluefin tuna, 1265f
- Blue-footed boobies, 508f
- Bluehead wrasse (*Thalassoma bifasciatum*), 1020
- Blue jays (*Cyanocitta cristata*), 1146f
- Blue-light photoreceptors, 855, 856f, 858–859

- Blue whales, 719
 Bobcat, 894f
 Body axes, 1060f
 Body cavities, **680**, 681f, 717
 Body hairs, insect, 1112f
 Body plans, **679**
 angiosperm, 648f
 animal, 679, 680f–682f
 arthropod, 706f, 707
 cell fate and. *See* Cell fate
 correlation of diversity of miRNAs with complexity of animal, 678
 fungal, 655f–656f
 hierarchical organization of animal, 876t, 877f–879f. *See also* Animal form and function
 homeotic genes and, 463f–464f
 human. *See* Human body
 lichen, 668f–669f
 macroevolution of, 544f–546f, 547
 maximizing body surface area in animal, 695f
 mollusc, 699f
 morphogenesis and. *See* Morphogenesis
 pattern formation of, 384, 385f–387f
 plant, as herbivore defense, 868f
 Body size, metabolic rate and animal, 891f
 Body temperature regulation. *See* Thermoregulation
 Bog mummy, 627f
 Bohr shift, **948f**
 Bolting, 851
 Bolus, 906f
 Bombardier beetle, 43
Bombina toads, 516, 517f, 520
Bombus affinis, 1170f
Bonasa umbellus, 1271
 Bonds, chemical. *See* Chemical bonds
 Bone marrow, 235f, 434f
 Bone morphogenetic protein 4 (BMP-4), 1062
 Bones, 725, **878f**
 of human skeleton, 1134f
 of mammalian ear, 741, 742f
 Bonobos, 460, 746f–747f
 Bony fishes, 979f, 992, 993f
 Book lungs, **708f**
 Boom-and-bust population cycles, 1205f, 1206
 Borisy, Gary, 241f
Borrelia burgdorferi, 584f
 Botox, 1080
 Bottleneck effect, **495f**, 496
 Bottlenose dolphins, 886f, 1094f
 Bottom-up control, 1226, **1227f**
 Botulism, 218f, 403, 584f, 588, 1080
 Boundaries
 ecosystem, 1270, 1271f, 1287
 Bound ribosomes, 103f, 104, 354f
 Boveri, Theodor, 295
 Bowden, Richard, 627f
 Bowman's capsule, **987f**
 Box jellies, 692f–693f
 Boysen-Jensen, Peter, 847f, 848
 Brachiopods, 688f, **698f**, 699, 713
Brachystius frenatus, 1203f
 Brainbow technology, 1085f
 Brain cancer, 250
 Brain cells, 126f
 Brain Research through Advancing Innovative Neurotechnologies (BRAIN), 1106
 Brains, **1069**. *See also* Nervous systems
 arousal and sleep functions of, 1094f
 biological clock regulation by, 1094–1095
 breathing control centers in human, 946f
 in central nervous systems, 1086f, 1087
 cerebral cortex and cognitive functions of, 1096, 1097f–1099f
 development of, 722f, 1092f, 1099–1100
 disorders of, 1103, 1104f
 drug addiction and reward system of, 1103f
 emotional functions of, 1095f, 1096
 evolution of chordate and vertebrate, 722f
 evolution of cognition in avian pallium and human, 1098, 1099f
 evolution of vertebrate, 1091f
 frontal lobe function of, 1098
 glia in mammalian, 1069f
 glioblastoma cancer of, 447
 human, 748, 1092f–1093f, 1095f–1104f
 hypothalamus of human, in thermoregulation, 888, 889f
 imaging of, 1085f, 1096f
 information processing by, 1096, 1097f–1098f
 language and speech functions of, 1098f
 lateralization of cortical function of, 1098
 mammalian, 741
 Neanderthal, 752
 nervous tissue of, 879f
 in neuroendocrine signaling, 1007f–1008f
 neurons in, 1068, 1085f, 1091. *See also* Neurons
 opiate receptors in mammalian, 1082
 of primates, 747–784
 regions of, 1091f–1093f
 in sensory systems, 1109
 size of, 756
 strokes in, 937
 visual information processing in, 1121f
 Zika virus and, 409
 Brainstem, **1092f**–1093f, 1094–1095
 Brain waves, 1094f
 Branching, body surface area and, 695f
 Branching, carbon skeleton, 60f
 Branching, plant, 770
 Branching evolution, 548–549
 Branch length, phylogenetic tree, 561, 562f
 Branch points, **555**, **556f**
 Brassinosteroids, 845, 846f, **854**–855
 Brazil nut tree, 1202f
BRCA1 and *BRCA2* genes, 392f–393f, 394
 Bread mold. *See* *Neurospora crassa*
 Breakdown pathways, 144
 Breast cancer, 220, 249f, 391, 392f–393f, 394, 433
 Breasts, 1026–1027
 Breathing, 756, 920, 925, **944**, 945f–946f
 Breathing control centers, 946f
 Breeding
 as artificial selection, 474, 475f
 plant, 823, 835–837
 Brenner, Sydney, 1058–1059
 Brewer's yeast. *See* *Saccharomyces cerevisiae*
 Briggs, Robert, 428
 Brightfield microscopy, 95f
 Brine shrimp, 464f, 545f, 546
 Bristlecone pine tree, 643f
 Bristletails, 712f
 Brittle stars, 714f, 715
 Broca, Pierre, 1098
 Broca's area, 1098f
 Bronchi, **942**, 943f
 Bronchioles, **943f**
 Brood bodies, 625f
 Brown algae, 598f, **602**, 603f, 604
 Brown bears, 145f
 Brown fat, 178, 887f
 Brown-headed cowbird (*Molothrus ater*), 1271, 1287
 Brown tree snake, 1264
 Brundtland, G. H., 1262
 Brush border, 909f
 Brushtail possum, 743f
 Bryophytes, **622**–623
 ecological and economic importance of, 627f, 628
 evolution of, 635
 gametangia of, 625, 626f
 gametophytes of, 624f–626f
 gametophyte-sporophyte relationships in, 637f, 638
 mosses, liverworts, and hornworts as, 623, 626f
 as nonvascular plants, 622, 622t
 phylogeny of, 623f
 sporophytes of, 625, 626f
 Bryozoans, 687f, 698f
 B soil horizon, 806f
Bt toxin, 837, 838f, 839
Bubulcus ibis, 1183, 1184f, 1221f
 Buck, Linda, 1124
 Budding, 100f, 255f, 659f, 1020
 Buff-end moth (*Phalera bucephala*), 476f
 Buffers, **52**–53
 Bugs, 712f
 Bulbourethral glands, 1025f, 1026
 Bulk feeders, **903f**
 Bulk flow, **791**
 as long-distance transport, 791f
 as translocation mechanism in angiosperms, 800, 801f
 of water and minerals from roots to shoots, 792, 793f–795f, 796
 Bulk transport, 126
 Bumblebees, 522, 1170f, 1279
 Bundle sheath, 771f
 Bundle-sheath cells, **203**, 204f
Burkholderia glathei, 586f
 Burkitt's lymphoma, 394
 Burmese pythons (*Python molurus bivittatus*), 887, 888f
 Bush babies, 746f
 Butterflies, 313, 551, 711f–712f, 824f, 839
 Buttress roots, 760f
 Buxbaum, Joseph, 462f
- C**
- C*₃ plants, **203**, 205
*C*₄ plants, **203**, 204f–206f
*C*₄ Rice Project, 438
Cabomba aquatica, 775f
 Cacao tree, 667f, 668
 Cachexia, 1016
 Cactus, 799f, 825f, 1172f, 1178, 1183f
 Caddisflies, 551
 Cadherin proteins, 676f
 Caecilians, 732f
Caenorhabditis elegans (soil nematode)
 apoptosis in, 230f
 fate mapping for, 1058f–1059f
 genome size and number of genes of, 448t, 449
 as model organism, 22, 705f
 nervous system of, 1086f, 1087
 Caffeine, 233
 Caimans, 925
 Calcitonin, 1004f, **1011f**
 Calcium, 29t
 Calcium homeostasis, 1011f
 Calcium ions
 diffusion of, across synapses, 1077, 1078f
 in formation of fertilization envelope, 1045f, 1046
 in regulation of muscle contraction, 1128, 1129f, 1131–1132
 in signal transduction pathways, 224, 225f, 844f, 845
 California Current, 1168f
 California mice, 1143, 1144t
 Callus, **835**–836
 Calmodulin, 1132
Calochortus tiburonensis, 30f
 Calories (cal), **46**, 890
 Calorimeters, 890
 Calvin, Melvin, 191
 Calvin cycle, **191f**, 192, 201, 202f, 206, 207f
 Cambrian explosion, 533f, **536f**, **677f**, 678, 685
 Camels, 980
 Camouflage, 20f–21f, 23, 468f, 476f, 501f, 1218f, 1219
 cAMP (cyclic AMP), **223f**–**224f**, 233, **369f**, 1002, 1003f, 1080
 CAM (crassulacean acid metabolism) plants, 205, **206f**, 798, 799f
 cAMP receptor protein (CRP), 369f
 Canada goose, 886f
 Canary Islands, 1213
 Cancer
 abnormal cell cycle control systems in, 248, 249f, 250
 abnormal protein kinases in, 222–223
 biotechnology in treatment of, 434
 carcinogen screening and, 360
 chromosomal translocations and, 309
 DNA microarray detection of, 426
 endocrine disruptors and, 1015
 faulty apoptosis in, 231
 faulty cell-surface receptors in, 217, 220
 faulty growth factors in, 226
 genetic markers for, 428
 genomics, cell signaling, and breast, 391, 392f–393f, 394
 genomics and proteomics in study and treatment of, 88f
 HIV and, 974
 immune system and, 974f
 inherited disposition and environmental factors in, 394
 interferences with normal cell-signaling pathways in development of, 389, 390f, 391
 lymph nodes and, 933

- mismatch repair and colon, 327
multistep model of development of, 391f, 394
ozone depletion, UV radiation, and, 1284
personal genome analysis and, 433
personalized medicine and, 433
PET scanners and, 31, 32f
skin, 328, 1284
species and genetic diversity and treatments for, 1263f
sponges and, 691
stem cells and, 431
systems biology approach to, 447, 448f
telomeres and prevention of, 329
treatment of, with cell cycle inhibitor, 250
tumor-suppressor genes and, 388
types of genes associated with, 388, 389f
viruses in, 394–395
- Cancer Genome Atlas*, 392f–393f, 394, 447
- Candida albicans*, 670
- Cane toads, 1217
- Canine parvovirus, 409
- Cannibalism, 413, 1237
- Canopy, **1172**
- Canyon tree frog, 1218f
- Capillaries, **924f**–**926f**, **929f**–**930f**, **932f**–**933f**
- Capillary beds, **924**, **932f**–**933f**
- Capra pyrenaica pyrenaica*, 1266
- Capsaicin, 1111
- Capsids, **400f**–**401f**
- Capsomeres, 400f, 402
- Capsule, **97f**, **575f**
- Capsule, sporangium, **625**
- Carbohydrates, **68**
- cell-cell recognition role of membrane, 130f–131f
 - digestion and absorption of, 908f–909f
 - as fuel for catabolism, 182f, 183
 - glycoproteins and, 400–401. *See also Glycoproteins*
 - as macromolecules, 66
 - monosaccharides and disaccharides, 68f–69f, 70
 - oxidation of, during cellular respiration, 166–167
 - in plant composition, 809
 - polysaccharides, 70f–72f
 - as product of photosynthesis, 206, 207f
- Carbon
- in amino acids, 75
 - as essential element, 29t, 64
 - half-life of, 33
 - isotopes of, 31–33
 - in organic compounds, 58, 59f, 60. *See also Organic compounds*
 - in peatlands, 628
 - in plant composition, 809
- Carbon-12, 530
- Carbon-14, 530
- Carbonate ions, **53f**, 54
- Carbon cycle, **1250f**, **1257f**
- Carbon dioxide (CO_2)
- atmospheric, 205, 1278f, 1279, 1282, 1283f
 - in carbon cycle, 1250f
 - in carbon fixation, 191f, 201, 202f–206f
 - covalent bonding of carbon atoms in, 59–60
 - diatom capture of, 602
 - diffusion of, across capillary walls, 932
 - in ecosystem interaction, 10f, 11
 - food quality and levels of, 812
 - fossil fuels, ocean acidification, and, 53f, 54
 - in gas exchange, 921, 939t, 940, 947f–949f
 - in global climate change, 204–205
 - global climate change and, 11, 48, 1170
 - inhibition of fruit ripening with, 854
 - insect effects on forest absorption of, 1245
 - in mammalian circulation, 926f
 - metabolic rate and, 890
 - net ecosystem production and, 1242, 1245
 - nonvascular plants and, in Ordovician period climate change, 629
 - in Permian mass extinction, 540
 - in photosynthesis, 41f
 - photosynthetic processing of, by marine protists, 615f
 - in plant cells, 209f
 - prokaryotic chemical recycling of, 586
 - in regulation of human breathing, 946f
 - rubisco as acceptor for, 201, 202f
 - seedless vascular plants and, 633
 - in *Sphagnum* peat moss, 628
- as stimulus for stomatal opening and closing, 797–798
- tropical rain forest deforestation and, 651f, 652
- Carbon fixation, **191f**, 192, 201, 202f–206f
- Carbonic acid, **51**, **53f**, **54**, 946
- Carbon monoxide, 1082
- Carbon sink, 1245
- Carbon skeletons, 56, 60f–61f
- Carbon source, 1245
- Carbonyl group, **63f**
- Carboxyl end. *See* C-terminus
- Carboxyl group, **63f**
- Carboxylic acid, **63f**
- Carcharhinus melanopterus*, 727f
- Carcinogens, 360, 388. *See also* Cancer
- Cardiac cycle, **927f**–**928f**, 930, 951
- Cardiac muscle, **879f**, **1131**
- Cardiac output, **927**
- Cardiomyopathy, familial, 357
- Cardiovascular diseases, 74, 311, 937f, 938–939, 951
- Cardiovascular systems, **924**
- adaptations of, 947f–949f
 - blood composition and function in, 934f–937f, 938–939
 - blood vessels of, 929f–933f, 951
 - closed circulatory systems. *See* Circulatory systems
 - coordination of gas exchange systems and. *See Gas exchange*
 - diseases of, 74, 937f, 938–939, 951
 - effects of adrenal hormones on, 1012
 - evolutionary variations in double circulation of, 925
 - hearts and blood vessels in single and double circulation of, 924f, 925
 - hearts in mammalian, 926f–928f
 - lymphatic systems and, 933f
 - single and double circulation in, 924f–926f
- Caribou (*Rangifer tarandus*), 490f, 1021, 1256f–1257f, 1281f
- Carnegiea gigantea*, 1178, 1183f
- Carnivora, phylogenetic tree of, 555f, 745f
- Carnivores, **901**
- alimentary canals of, 912f
 - dentition and diet in, 911f, 912
 - energetic hypothesis and biomass of, 1225f
- Carnivorous plants, 818, 819f, 820
- Carolina chickadees (*Poecile carolinensis*), 517f
- Carotenoids, 193, 194f, **195**, 570, 605f
- Carpellate flowers, 834
- Carpels, 270f, 271, **644f**, **823f**
- Carrier proteins, 132, 135f–137f
- Carriers, genetic disorder, **285f**, 286, 288
- Carrian flower, 825f
- Carrots, 428
- Carrying capacity (K), **1197**
- global, for human population, 1209, 1210f, 1211
 - in logistic population growth model, 1198f–1199f, 1198t, 1200
- Carson, Rachel, 1276f
- Cartilage, **878f**
- Cartilage skeleton, 723–726
- Cas9 protein, 360, 361f. *See also* CRISPR-Cas9 system
- in gene editing, 426, 427f, 434–435
 - prokaryotes and, 589, 590f
- Cascade
- hormonal, 1008, 1009f, 1010, 1014
- Casein, **76f**
- Case studies
- on decline of red-cockaded woodpecker, 1269f–1270f
 - on evolution of tolerance to toxic elements, 30f
 - on greater prairie chicken extinction vortex, 1267f
 - on grizzly bear populations, 1268f, 1269
 - on kidney function in vampire bats, 991f, 992
 - on nutrient cycling in Hubbard Brook Experimental Forest, 1252f
 - on predation and mouse coat coloration, 20f–21f
 - sustainable development in Costa Rica, 1284, 1285f
 - on variation in migratory patterns, 1156, 1157f
 - on variation in prey selection, 1155, 1156f
- Caspian strip, **792**, **793f**
- Caspases, 230, 233
- Cas protein, 404f
- Cassava, 651, 838f
- Castor beans, 829
- Catabolic pathways, **144**, 165, 166f–168f, 182f–184
- Catalysis, **154**, 155f–156f. *See also* Enzymatic catalysis
- Catalysts, **75**, **153**. *See also* Enzymatic catalysis
- Catalytic cycle, 156f
- Catalytic knob, ATP synthase, 175f
- Cataracts, 1284
- Catecholamines, 1012f
- Catenulida, 694
- Caterpillars, 488f, 871, 897, 903f, 1006f, 1007, 1246f
- Catharanthus roseus*, 1263f
- Cation exchange, **806**, 807f
- Cations, **37**, **38f**, 806, 807f
- Cats, 293, 300f, 364, 430f
- Catskill Mountains, 1263
- Cattails (*Typha angustifolia*), 1186
- Cattle, 914f
- Cattle egrets (*Bubulcus ibis*), 1183, 1184f, 1221f
- Caulerpa*, 610f
- Causation, behavioral, 1140
- Cavendish banana, 268
- CC (Carbon Copy, cloned cat), 430f
- CCR5 gene, 435
- CCR5 protein, 130f
- Cdk5 (cyclin-dependent kinases), **245**, 246f
- Cecum, **911f**
- Cedar Creek Ecosystem Science Reserve, 1223f
- Celera Genomics, 443f
- Cell adhesion molecules, 1056
- Cell body, 879f, **1068f**, 1079f
- Cell-cell recognition
- by cellular membranes, 130f, 131
 - in local cell signaling, 215f
- Cell cycle, **237**. *See also* Cell cycle control system; Cell division
- binary fission in bacterial, 242, 243f
 - cell division roles in, 234f–235f
 - cellular organization of chromosomes in, 235f, 236
 - cytokinesis in, 241, 242f–243f
 - distribution of chromosomes during eukaryotic, 236f, 237
 - evolution of, 252
 - evolution of mitosis of, 243, 244f
 - interpreting histograms on, 250
 - mitosis stages of, in animal cells, 238f–239f
 - mitotic phases and interphases of, 237f
 - mitotic spindle in mitotic phase of, 240f–241f
 - regulation of eukaryotic, by cell cycle control system, 244, 245f–249f, 250
 - treating cancer by inhibiting, 250
- Cell cycle control system, **245**. *See also* Cell cycle in cancer development, 248, 249f, 250, 388, 389f–393f, 394
- checkpoints in, 245f
- cyclins and cyclin-dependent kinases in, 245, 246f
- cytoplasmic signals in, 244, 245f
- internal and external signals at checkpoints of, as stop and go signs, 246, 247f–248f
- interpreting histograms on, 250
- Cell cycle-inhibiting pathway, 389, 390f
- Cell cycle-stimulating pathway, 389, 390f
- Cell differentiation. *See* Differentiation, cell
- Cell division, **235**
- bacterial, 242, 243f
 - cancer and interference with cell-signaling pathways of, 389, 390f, 391
 - in cell cycle, 234f–235f. *See also* Cell cycle
 - cytokinins in, 850
 - cytoplasmic determinants and induction in, 382f, 383
 - distribution of chromosomes during eukaryotic, 235f–236f, 237
 - as embryonic development process, 381f, 382.
 - See also* Embryonic development
 - evolution of, 243, 244f
 - of HeLa cancer cells, 252
 - key roles of, 235f
 - in meiosis, 259f–262f. *See also* Meiosis
 - in mitosis vs. in meiosis, 262, 263f, 264
 - newt lung cell, 7f
 - in plant growth, 776, 777f
 - prokaryotic, 577–578
- Cell expansion, 777f
- Cell fate, 1057–1059f, 1061–1064f
- Cell fractionation, **96f**, 97, 125
- Cell-free fetal DNA, 288

- Cell junctions
in local cell signaling, 215f
plasmodesmata in plants, 119f, 120
tight junctions, desmosomes, and gap junctions
in animals, 120f
- Cell-mediated immune response, 957f, 963, 966f–967f
- Cell migration
in organogenesis, 1054f, 1055
- Cell motility, 112, 113t, 114, 115f–117f, 1056f
- Cell plate, 241, 242f–243f
- Cells, 5f, 759
animal. *See Animal cells*
auxin in differentiation of, 850
auxin in elongation of, 848, 849f
blood, 934f–936f, 937
calculating volume and surface area of, 99
cell fractionation in study of, 96f, 97
cellular integration of, 121f
cellular membranes of. *See Cellular membranes*
cellular respiration and. *See Cellular respiration*
climate change effects on, 1280f
communication between. *See Cell signaling*
cytokinins in division and differentiation of, 850
differentiation of. *See Differentiation, cell*
division of, as fundamental to life, 235. *See also*
 Cell cycle; Cell division
eukaryotic vs. prokaryotic, 97f–98f, 99. *See also*
 Eukaryotic cells; Prokaryotic cells
as fundamental units of life, 5f–6f, 93f
locations of enzymes in, 161f
metabolism of. *See Metabolism*
microscopy in study of, 94f–95f, 96
molecular machinery in, 122f–123f
photosynthesis and. *See Photosynthesis*
plant. *See Plant cells*
programmed death of. *See Apoptosis*
programming of, by viral DNA, 315f–316f, 317
protein folding in, 83f
protocells as first, 528f
sequential gene regulation in differentiation of, 383, 384f
shape changes in animal morphogenesis, 1056f–1057f
in sickle-cell disease, 502f
size range of, 94f
of small intestine, 125
stem cells. *See Stem cells*
transcription specific to type of, 374–375, 377f
unity in, 13f
water regulation of, 142
- Cell sap, 108
- Cell signaling. *See also Signal transduction pathways*
by animal endocrine and nervous systems, 880f
in apoptosis, 229f–231f
cancer and interference with normal, 389, 390f, 391
in cell cycle control system, 244, 245f–248f.
 See also Cell cycle control system
cellular membrane selective permeability and, 130f
cilia in, 114
endocrine system, 1000f–1004f
evolution of, 213f, 214, 233
feedback regulation of, 1005–1006
fight-or-flight responses in, 212f
local and long-distance, 215f, 216
mechanical, 119
pathways of. *See Endocrine signaling*
 Neuroendocrine signaling
 reception stage of, 217f–221f
 response stage of, 226f–228f, 229
 in simple endocrine pathway, 1004, 1005f
 in simple neuroendocrine pathway, 1005f
 sympathetic, 801–802
 three stages of, 216f, 217
 transduction stage of, 221, 222f–225f
- Cell-surface proteins, 119f, 130f
- Cell-surface receptor tyrosine kinases (RTKs), 250
- Cell-surface transmembrane receptors, 217f–220f
- Cellular hormone response pathways, 1002f–1003f
- Cellular innate immune defenses, 954, 955f
- Cellular-level herbivore defenses, plant, 868f
- Cellular membranes. *See also* Plasma membranes
 active transport across, 136, 137f–138f, 139
 animal, 674
 bulk transport across, by exocytosis and
 endocytosis, 139, 140f, 141
- evolution of differences in lipid composition of, 129
 fluidity of, 128f, 129
 as fluid mosaics of lipids and proteins, 127f, 128
 interpreting scatter plots on glucose uptake
 across, 136
- membrane carbohydrates in cell-cell recognition
 by, 130f–131f
- membrane proteins of, 129f–130f, 132
- of mitochondria, 110, 111f
- movement across plant cell, 209f
- nuclear envelopes, 102, 103f
- organelles and internal, 98f, 99
- passive transport as diffusion across, 132, 133f–135f
- phospholipids in, 74f, 75
- in plant response to cold stress, 865
- selective permeability of, 127f, 131, 132f
- specialized prokaryotic, 577f
- synthesis and sidedness of, 131f
- Cellular respiration, 165
 ATP production by catabolic pathways and, 165
- ATP yield at each stage of, 177f, 178
- bar graphs of, 179
- biosynthesis in anabolic pathways and, 183
- in carbon cycle, 1250f
- as catabolic, 144, 165
- in energy flow and chemical cycling, 9f, 164f, 165
- enzymes for, in mitochondria, 161f
- evolutionary significance of glycolysis in, 182
- fermentation vs., 165, 179, 180f–181f, 182
- glycolysis in, 170f–171f
- metabolic rate and, 890f
- mitochondria in, 109–110, 111f
- monosaccharides in, 69
- origin of, 534, 535f
- overall reaction for, 149
- oxidative phosphorylation in, 174f–177f
- oxygen diffusion and, 133
- photosynthesis vs., 190. *See also* Photosynthesis
 in plant cells, 209f
- pyruvate oxidation and citric acid cycle in, 171f–173f
- redox reactions and, 165, 166f–168f
- regulation of, via feedback mechanisms, 183f, 184
- scale of, 122f
- stages of, 168, 169f
- using cell fractionation to study, 97
- versatility of catabolic pathways and, 182f, 183
- Cellular slime molds, 612, 613f
- Cellulose, 71
 microfibrils, 77f
 in plant cell walls, 70f–71f, 72, 118
 as product of photosynthesis, 206, 207f
- Cellulose synthase, 118
- Cell walls, 118
 cellulose in plant, 619
- fungal cell, 100f, 661
- osmosis, water balance, and, 134f–135f
- plant cell, 101f, 118f
 prokaryotic, 97f, 574, 575f
- Cenozoic era, 530f, 533f, 539f, 679
- Center for Plant Conservation, 1261
- Centipedes, 708, 709f
- Central axis, 680f
- Central canal, 1087f
- Central disk, sea star, 714f
- Central dogma, DNA, 339
- Central nervous system (CNS), 1069, 1086. *See also*
 Brains
 neuronal plasticity of, 1100f
 neurons of, 1069
- neurotransmitters and, 1080
- peripheral nervous system and, 1086, 1087f–1090f
 in sensory systems, 1108–1109
- structure and function of vertebrate, 1087f–1088f
- Central vacuoles, 101f, 108f
- Centrifuge, 96f, 97
- Centrioles, 114f
- Centromeres, 236f, 264
- Centromeric DNA, 452
- Centrosomes, 100f, 114f, 238f, 240f
- Centrostephanus rodgersii, 1281f
- Century plants, 1200, 1201f
- Cephalization, 1086–1087
- Cephalochordata (lancelets), 719f, 720, 721f–722f
- Cephalopods, 699, 701f, 702
- Ceratotherium simum cottoni, 1266
- Cercozoans, 608f, 609
- Cerebellum, 1091f, 1092f–1093f
- Cerebral cortex, 1093f, 1096, 1097f–1099f, 1100, 1114
- Cerebral ganglia, 704f–710f
- Cerebral hemispheres, 1093f
- Cerebrospinal fluid, 946f, 1087f
- Cerebrum, 1091f, 1092f–1093f, 1094
- Certainty of paternity, 1150, 1151f
- Cervical cancer, 974f
- Cervix, 1026, 1027f
- Cetaceans, 481f–482f, 745f
- Cetartiodactyla, 745f
- cGMP (cyclic GMP), 224, 844f, 845
- Chaetae, 703, 704f
- Chagas' disease, 600
- Chain worms, 694
- Chambered nautilus, 701f, 702
- Chameleons, 673f, 735f
- Chamerion angustifolium, 636f
- Chamois (*Rupicapra rupicapra*), 901f
- Change, global. *See Global change*
- Change, spontaneous, 148f
- Channel proteins, 132, 135f, 136
- Chaparral biomes, 1174f
- Character displacement, 1216, 1217f, 1237
- Characters, 270
 dominant vs. recessive traits and, 271f, 272f
- multifactorial, 282f
- shared ancestral and shared derived, 560, 561f
- taxonomy and, 554
- traits and, 270–271
- Character tables, 561f
- Charadrius melanotos, 1190f
- Chargaff, Edwin, 317f, 318
- Chargaff's rules, 317f, 318, 320
- Charged tRNA, 349f
- Charophytes, 610, 619f–620f
- Charpentier, Emmanuelle, 426
- Chase, Martha, 316f, 317
- Cheating behavior, 1159
- Checkpoints, cell cycle control system, 245f–247f
- Cheetahs, 212f, 1204f
- Chelicerae, 708
- Chelicерates, 707, 708f
- Chemical bonds, 36
 with carbon, 56, 58, 59f, 60
- covalent, 36f–37f
- hydrogen bonds, 38, 39f
- ionic, 37, 38f
- van der Waals interactions, 39
- Chemical cycling
 in ecosystems, 1238f–1240f, 1241
- Chemical cycling, energy flow and. *See*
 Biogeochemical cycles; Energy flow and
 chemical cycling
- Chemical defense, prey, 1218f
- Chemical digestion, 907f–908f, 909
- Chemical energy, 143–144, 145f, 889, 890f. *See also*
 Cellular respiration; Photosynthesis
- Chemical equilibrium, 41
 buffers and, 52–53
- in chemical reactions, 41
- free energy change and, 147, 148f
- metabolism and, 148, 149f–150f
- Chemical mutagens, 360
- Chemical reactions, 40
 activation energy barrier of, 153, 154f–155f
- chemical energy in, 144, 145f
- endergonic, 148, 149f
- enzymatic catalysis of. *See* Enzymatic catalysis
- exergonic, 148, 149f, 154f, 165
- free energy change and, 147, 148f
- making and breaking of chemical bonds by, 40f–41f
- metabolism and. *See* Metabolism
- in photosynthesis, 190f, 191. *See also* Light
 reactions
- Chemical signals, 1068. *See also* Animal hormones;
 Hormones; Plant hormones
- Chemical structure, DNA, 319f
- Chemical synapses, 1077, 1078f. *See also* Synapses
- Chemical work, 150–151, 152f
- Chemiosmosis, 169, 175, 176f–177f, 191f, 199f–200f, 201
- Chemistry
 atoms in, 30f–36f
- biological molecules in. *See* Biological molecules

- calculating standard radioactive isotope decay curves in, 33
- chemical bonding between atoms in, 36f–41f
- chemical bonding with carbon in, 58, 59f, 60
- connection to biology. *See* Biology
- matter as elements and compounds in, 29f–30f.
- See also* Compounds; Molecules
- organic, as study of carbon compounds, 57f, 58.
- See also* Organic compounds
- of water. *See* Water
- Chemoautotrophs, 581t
- Chemoheterotrophs, 581t
- Chemoreceptors, 1110, 1111f, 1123f–1125f
- Chemosynthetic organisms, 1240
- Chemotaxis, 576
- Chemotherapy, 249, 393f
- Chemotrophs, 581t
- Chesapeake Bay estuary food web, 1225f, 1237
- Chestnut blight, 669, 867, 1226, 1234
- Chewing, 920
- Chiasmata, 260f, 262f–263f, 264
- Chickadees, 517f
- Chicken pox, 962
- Chicks
- embryo image, 1043f
 - gastrulation in, 1052f
 - limb formation in, 1062, 1063f, 1064
 - organogenesis in, 1055f
- Chicxulub crater, 541f
- Chief cells, 907f
- Chikungunya virus, 409f, 412
- Childbirth, human, 1036, 1037f. *See also* Births, human
- Chimaeras, 719f, 726, 727f
- Chimpanzees (*Pan troglodytes*)
- comparison of human genome with genome of, 87, 89, 454f–455f, 460f, 461
 - heterochrony and differential growth rates in skulls of, 544f
 - humans vs., 748
 - J. Goodall's research on, 17f
 - as primates, 746f–747f
 - problem solving of, 1147
 - skulls of humans and, 558
 - social learning in, 1147f
 - tool use by, 750
- China, 1208
- Chips, human gene microarray, 447, 448f
- Chiroptera, 745f
- Chi-square (χ^2) test in Scientific Skills Exercise, 304
- Chisholm, Penny, 552
- Chitin, 72f, 656, 661, 707, 1133
- Chitons, 699f, 1086f
- Chlamydias, 584f, 1039
- Chlamydomonas, 101f, 610, 611f. *See also* Green algae
- Chlamydomonas nivalis, 211
- Chlorarachniophytes, 596f, 609
- Chloride cells, 992, 993f
- Chloride ions, 1069f, 1070t, 1071f
- Chloride transport channels, 286
- Chlorinated hydrocarbons, 1275, 1276f
- Chlorine, 29t, 1283–1284
- Chlorofluorocarbons (CFCs), 1283f, 1284
- Chlorophyll, 5f, 189f, 190
- chemiosmosis, 199, 200f, 201
 - cyclic electron flow in, 198f, 199
 - light excitation of, 195f
 - linear electron flow in, 197f–198f
 - in photosystems, 195, 196f, 197
 - structure of, 194f
- Chlorophyll *a*, 193, 194f, 195–198
- Chlorophyll *b*, 193, 194f, 196
- Chlorophyll *d*, 194
- Chlorophyll *f*, 194–195
- Chlorophytes, 610f
- Chloroplasts, 109, 189
- chemiosmosis in, 177
 - chemiosmosis in mitochondria vs. in, 199f–200f, 201
 - evolutionary origins of, 109, 110f
 - folding of, 695f
 - light reactions in. *See* Light reactions
 - as organelles, 5f, 6
 - photosynthesis by, 109–110, 111f, 187
 - in plant cells, 101f, 209f
 - as sites of photosynthesis, 189f, 190, 206, 207f
 - transgenic crops and DNA in, 840
- Chlorosis, 810, 812
- Choanocytes, 690f
- Choanoflagellates, 614, 675f–676f
- Cholecystokinin (CCK), 915f
- Cholera, 218f, 224, 584f, 588
- Cholesterol, 75f
- in cellular membranes, 127f–128f
 - DNA methylation and, 372f
 - in egg yolks, 91
 - G protein-coupled receptors and, 217f
 - receptor-mediated endocytosis and, 139, 141
 - types of, in blood, 937–938
- Chondracanthus harveyanus*, 1222
- Chondrichthians, 719f, 726, 727f
- Chondrocytes, 878f
- Chondroitin sulfate, 878f
- Chordates, 719
- endoskeletons of, 1133, 1134f
 - evolution of, 722f
 - hagfishes and lampreys, 723f, 724
 - invertebrate, 689f, 715, 719f–722f
 - lancelets, 720, 721f–722f
 - phylogeny and derived characters of, 719f–720f
 - phylogeny of, 683f
 - tunicates, 721f, 722
 - vertebrates as, 689f, 715, 719f, 722, 723f–725f
- Chorion, 735f, 1053f
- Chorionic villus sampling (CVS), 289f, 1039
- Choroid, 1118f
- Christmas tree worm, 703f
- Chromatin, 102, 235, 331
- animal cell, 100f
 - in cell division, 235f–236f, 237
 - in eukaryotic cell nucleus, 102, 103f
 - in eukaryotic chromosomes, 330f–332f
 - plant cell, 101f
 - regulation of structure of eukaryotic, 371f–372f, 373
 - remodeling of, by siRNAs, 380–381
- Chromatin loops, 377, 378f
- ChromEMT, 330f
- Chromoplasts, 111
- Chromosomal basis of inheritance
- as basis for Mendelian inheritance, 294f, 295
 - chromosomal alterations and genetic disorders in, 306, 307f–309f
 - evolution of gene concept from, 361
 - exceptions to Mendelian inheritance in, 310f, 311
 - genomic imprinting in, 310f, 311
 - inheritance of organelle genes in, 311f
 - linked genes and linkage in, 301f–306f
 - sex-linked genes in, 298f–300f
 - T. H. Morgan's experimental discovery of, 295f–296f
- Chromosomal breakage points, 454–455
- Chromosome conformation capture (3C) techniques, 377
- Chromosomes, 102, 235. *See also* DNA; Genes
- alleles on, 272, 273f. *See also* Alleles
 - alterations of, 306, 307f–309f, 454f–455f
 - bacterial, 242, 243f
 - in cancer cells, 249–250
 - in cell division, 234f–235f, 244f
 - in chromosomal basis of Mendelian inheritance, 294f, 295. *See also* Chromosomal basis of inheritance
 - correlating behavior of alleles with pairs of, 295, 296f–297f
 - crossing over and recombinant, 265, 266f
 - distribution of, during eukaryotic cell division, 235f–236f, 237
 - DNA, genes, and, 7f–8f
 - DNA and chromatin packing in, 330f–332f
 - in eukaryotic cell nucleus, 102, 103f
 - gene expression and interaction of, in interphase nucleus, 377, 378f
 - genetic variation due to mutations in, 488–489
 - in genome evolution, 454f–455f
 - homologous, 256f–257f
 - human, 102, 235, 236f, 237, 256f–257f, 258
 - independent assortment of, 265f
 - as information, 268, 313
 - inheritance of genes and, 255
 - in interphase, 252
 - karyotypes of, 256f
 - locating genes along, 295, 296f–297f
 - mapping distance between genes on, 305f–306f
 - in meiosis, 254, 259f–263f, 264
 - molecular tags and karyotypes of human, 332f
- movement of, on kinetochore microtubules, 240, 241f
- in prokaryotic and eukaryotic cells, 97f, 98, 577f
- prokaryotic conjugation and gene transfer between, 579, 580f, 581
- Chromosome theory of inheritance, 295
- Chronic inflammation, 956–957
- Chronic myelogenous leukemia (CML), 309f, 435
- Chronic traumatic encephalopathy (CTE), 1104
- Chroococcidiopsis thermalis*, 194f, 195
- Chrysanthemums, 860
- Chthamalus stellatus*, 1216f
- Chum salmon (*Oncorhynchus keta*), 89
- Chylomicrons, 910f
- Chyme, 907, 915f
- Chytrids, 660f, 661f, 669, 670f, 733
- Cichlid fish, 515f, 519f, 520
- Cigarette smoke, cardiovascular and lung disease and, 394, 951
- Cilia, 114
- architecture of eukaryotic, and unity, 13f
 - bronchial, 943
 - cell fate and, 1064f
 - ciliate, 607f
 - flagella vs., 115f
 - as microtubules, 114, 115f–116f
- Ciliates, 606, 607f, 617
- Cilium-based signaling, 114
- Cinnabar (*cn*) gene, 305f–306f
- Circadian rhythms, 798, 858, 882. *See also* Biological clocks
- in animal behavior, 1141
 - in animal homeostasis, 882, 883f
 - brain regulation of, 1094–1095
 - hibernation and, 893f
 - melatonin and, 1015
 - in plant responses to light, 857, 858f–860f
 - in stomatal opening and closing, 798
- Circannual rhythms, 1141
- Circulatory systems
- cardiovascular systems. *See* Cardiovascular systems
 - gas exchange and, 921f–924f, 925, 947f. *See also* Gas exchange
 - gas exchange systems and. *See* Gas exchange
 - gastrovascular cavities as, 922f, 923
 - internal exchange surfaces and, 875f
 - invertebrate, 699f, 702, 704f, 707
 - open and closed, 923f
 - organization of vertebrate, 924f, 925. *See also* Cardiovascular systems
 - thermoregulatory adaptations of animal, 885, 886f
- cis* face, Golgi apparatus, 106f, 107
- cis* isomers, 61f
- Cisternae, 104, 106f, 107
- Cisternal maturation model, 106
- Cisternal space, 104
- cis-trans* isomers, 61f
- Citric acid cycle, 168, 169f, 172f–173f, 177f
- Citrulline, 338f
- Clades, 559, 560f, 561, 622–623
- Cladistics, 559, 560f, 572. *See also* Systematics; Taxonomy
- Clams, 688f, 699, 701f
- Clark's nutcracker (*Nucifraga columbiana*), 1146
- Classes, taxonomy, 554, 555f
- Classical conditioning, 1146
- Clausen, Jens, 1189
- Claw-waving behavior of male fiddler crab, 1141f
- Cleaner wrasse, 1214f
- Cleanup, environmental, 418f, 437
- Cleavage, 241, 674, 1046
- in animal embryonic development, 674f, 1044, 1046, 1047f–1048f, 1049
 - in cell cycle, 241, 242f–243f
 - in human embryonic development, 1035f
 - in protostome and deuterostome development, 681, 682f
- Cleavage furrows, 239f, 241, 242f, 1048f
- Click beetle (*Pyrophorus nyctophanus*), 143f
- Climate, 1167. *See also* Climate change
- continental drift and changes in, 539
 - effect of large bodies of water on, 47f
 - global patterns of, 1166f, 1167
 - greenhouse gases and, 1278f–1283f
 - latitudinal gradients and, affecting community diversity, 1232f

- Climate (continued)
 microclimate and, 1169–1170
 nonvascular plants in Ordovician period changes of, 629
 Permian mass extinction and changes in, 540
 regional and local effects on, 1167f–1169f
 seedless vascular plants and ancient, 633
 species distributions and, 1164, 1170f
 terrestrial biomes and, 1171f
 using dendrochronology to study, 773f
 vegetation effects on, 1169f
- Climate change, **11, 1170f, 1278**
 biodiversity hot spot preservation and, 1272
 biological effects of, 1279, 1280f–1281f, 1282
 coral reefs and, 693
 crop productivity and, 863
 ecological footprints, fossil fuels, and, 1210f, 1211
 as ecosystem interaction, 11
 effects of, on photosynthetic marine protists, 615f
 extinction rates and, 541f, 542
 food quality and, 812
 fossil fuel burning and, 11
 greenhouse gases and, 1278f–1283f
 habitat loss from, 1263
 hybrid zones and, 517f
 lizards and, 11f
 melting of Arctic sea ice and, 48f
 models of, 1282, 1283f
 nonvascular plants in Ordovician period, 629
 ocean acidification and, 53f, 54–55
 overharvesting of peat moss and, 628
 in Permian mass extinction, 540
 plant adaptations to, 204–205
 positive feedbacks of, 1189
 primary production response to, 1244f, 1245
 ringed seals and, 44f
 seedless vascular plants and, 633–634
 snowshoe hares and, 501f
 solutions for, 1282–1283
 tropical rain forest deforestation and, 651f, 652
 tropical rain forest photosynthesis and, 211
 using dendrochronology to study, 773f
 viral transmission and, 412
- Climax communities, 1228
- Climographs, **1171f**
- Clitoris, **1026, 1027f**
- Cloaca, **727, 1024**
- Clock, cell cycle, 245, 246f
- Clock genes, 858
- Clonal selection, **962f, 963, 976**
- Clone (term). *See* Organismal cloning
- Cloned genes. *See also* DNA cloning; Gene cloning
 of crystallin, 441
 expressing eukaryotic, 422–423
 in gene therapy, 434f
 uses for, 418f
- Clones, **255, 1066**. *See also* Organismal cloning
 asexual reproduction of, 255f
 of extinct species, 1266
 fragmentation and, 833f
 from plant cuttings, 835–836, 849
 test-tube or *in vitro*, 836f
- Cloning vectors, **418**. *See also* Recombinant DNA
- Closed circulatory systems, 702, 704f, **923f**. *See also* Cardiovascular systems
- Clostridium botulinum*, 584f, 588
- Clostridium difficile*, 912
- Clotting, blood, 10, 300, 418f, 436, 703f, 704, 936f, 937
- Cloudina*, 677f
- Club fungi, 665f–667f
- Club mosses, 631, 632f, 633
- Clumped dispersion, 1192f
- Clutch size, 1200, 1201f–1202f
- Cnemaspis psycadelica*, 1260f
- Cnidarians, 687f, 691f–693f, 1086f
- Cnidocytes, **691f–692f**
- Coal, 633–634. *See also* Fossil fuels
- Coal gas, 852
- Coastal Indonesia restoration project, 1254f
- Coat coloration case studies, 20f–21f, 23
- Cocaine, 1103f
- Coccidioidomycosis, 670
- Coccosteus cuspidatus*, 533f
- Cochlea, **1113f–1115f**
- Cocklebur, 859
- Cocktails, drug, 409, 489
- Coconut, 828, 832f
- Cod (Gadus morhua)*, 728, 979f
- Coding strand, **340f**
- Codominance, **279**
- Codon recognition, 352, 353f
- Codons, **340**
 evolution of, 364
 in genetic code, 340f–342f
 in translation, 347f–350f, 352, 353f
- Coefficient of relatedness (*r*), **1158f–1159f**
- Coefficients, correlation, 678, 751
- Coelacanths, 719f, 729f
- Coelom, **680, 681f, 698, 704f, 717**
- Coelomates, 681
- Coenocytic fungi, **656f**
- coenzyme Q (CoQ), 175, 186
- Coenzymes, **158**
- Coevolution, **825f**
- Cofactors, **158**
- Coffee, 651
- Cognition, 1096, 1098, 1099f, **1146, 1147f**
- Cognitive maps, **1146**
- Cohesins, 236, 240, 262f
- Cohesion, **45, 46f, 795–796**
- Cohesion-tension hypothesis, **794f–795f, 796**
- Cohorts, **1193**
- Coho salmon (*Oncorhynchus kisutch*), 89, 1200
- Coitus, human, 1034
- Coitus interruptus, 1038f
- Cold
 plant response to stress of, 865
 thermoreceptors and, 1111f
- Cold viruses, 401, 404–405
- Coleoptera (beetles), 712f
- Coleoptiles, **829f–830f, 847f, 848**
- Coleorhiza, **829f**
- Colistin, 588
- Collagen, 76f, 81f, **118, 119f, 674**
- Collagenous fibers, 878f
- Collar cells, 675f
- Collared flycatchers (*Ficedula albicollis*), 519
- Collecting duct, **987f–988f, 989**
- Collenchyma cells, **764f, 770**
- Colon, **911f**
- Colon cancer, 327
- colony collapse disorder, 661
- Coloration
 case studies on mouse, 20f–21f, 23
 of chromosomes, 332f
 as prey defensive adaptation, 1218f, 1219
 skin, 1016, 1018
- Color blindness, 299f, 1122f
- Colorectal cancer, 391f, 394
- Color vision, 1117–1118, 1121, 1122f
- Colossal squid, 702
- Columbine flowers, 825f
- Columnar epithelium, 877f
- Combinatorial control elements, 375–376, 377f
- Comb jellies, 687f
- Comet collision, mass extinction by, 541f
- Commensalism, **587, 662, 1221f**
- Commercial value
 of fungi, 670, 671f
 of mosses, 627f
- Common arrowhead flower, 835f
- Common juniper, 643f
- Communicating junctions, 120f
- Communication, animal, 880f, **1141f–1143f**
- Communication, cellular. *See* Cell signaling
- Communities, **4f, 1165f**
 biogeographic factors affecting, 1231, 1232f–1234f
 climate change effects on, 1281f
 disturbances of, 1214, 1228, 1229f–1231f
 diversity in, 1261f–1262f
 interspecific interactions in, 1214f–1221f, 1237
 as level of biological organization, 4f
 pathogen alteration of structure of, 1234, 1235f
 scientific, 19f, 24
 species diversity and stability of, 1222f–1223f.
See also Species diversity
 structure of, 1214f, 1215, 1234, 1235f
 study of, by community ecology, 1165f. *See also* Community ecology
- trophic structure of, 1223, 1224f–1227f. *See also* Trophic structure
- Community diversity, 1261f–1262f
- Community ecology, **1165f**. *See also* Ecology
 biogeographic factors in, 1231, 1232f–1234f
 community boundaries in. *See* Communities
 disturbances in, 1214, 1228, 1229f–1231f
 influences on community structure and, 1214f, 1215
 interspecific interactions in, 1214f–1221f, 1237
 pathogens in, 1234, 1235f
 species diversity and trophic structure in, 1222f–1227f. *See also* Species diversity; Trophic structure
- Community-level herbivore defenses, plant, 869f
- Community structure, 1214f, **1215**
 pathogen alteration of, 1234, 1235f
- Compact body cavity, 681f
- Companion cells, **765f**
- Compartmentalized processing, **898**
- Competition, **1215, 1256f–1257f**
 density-dependent population regulation by, 1204f
 interspecific, 1215, 1216f–1217f, 1237
 sexual, 499f–500f, 1153f
 in species distributions of plants, 1186
- Competitive exclusion, **1215**
- Competitive inhibitors, **158, 159f**
- Complementary base pairing, DNA and RNA, 86f
- Complementary DNA (cDNA), **424, 425f–426f**
- Complement systems, **957, 966f**
- Complete digestive tracts, 905f
- Complete dominance, **279**
- Complete flowers, **824**
- Complete growth medium, 336f–338f
- Complete metamorphosis, **711f, 712f**
- Complex eyes, 547, 548f
- Compound eyes, 712f, 894f, **1117f, 1118**
- Compound leaves, 761f
- Compounds, **29**. *See also* Molecules
 biological. *See* Biological molecules
 emergent properties of, 29f
 ionic, 38f
 organic. *See* Organic compounds
 properties of, 28
 pure elements vs., 37
- Compromises, evolutionary, 501f
- Computational tools, 9, 444, 445f–448f, 776. *See also* Bioinformatics
- Concentration gradients, **133f, 136, 137f–138f, 139**
- Concentrations, chemical reactions and, 41
- Conception, human, **1034, 1035f**
- Condensation reaction, 67
- Condensins, 331f
- Condoms, 1038f
- Conduction, animal heat exchange and, **885f**
- Conduction, of action potential, 1075f, 1076
- Cones (photoreceptor), **1119f–1121f, 1122–1123, 1138**
- Cones, gymnosperm, 640, 643f
- Conch snails (*Conus geographus*), 1067f–1068
- Confocal microscopy, 95f, 96
- Conformer animals, **881f**
- Congenital disorders, 256f
- Conidia, **664f**
- Conifers, 623, **640f, 641, 643f**
- Conjugation, **579, 580f, 581, 606, 607f**
- Connective tissue, animal, 76f, **878f**
- Connell, Joseph, 1216f
- Conodonts, **724f, 725**
- Consanguineous mating, human, 285–286
- Conservation Areas, Costa Rican, 1273f
- Conservation biology, **1261**. *See also* Ecology
 biodiversity and, 1260f–1266f
 conservation of mollusc species, 702f
 genomics and proteomics in, 88f
 global change and, 1265, 1266f, 1274, 1275f–1283f, 1284f
 landscape and regional conservation in, 1270, 1271f–1274f
 population conservation in, 1266, 1267f–1270f
 species-area curves of species richness in, 1232f
 sustainable development in, 1284, 1285f, 1286
- Conservation of energy, 145f, 146, 1239
- Conservation of mass, 1239–1240
- Conservative model, DNA replication, 321f–322f
- Conserved Domain Database (CDD), 445f
- Constant (C) region, light and heavy chain, 958f–961f
- Constipation, 911
- Consumers, **9, 188, 673f**

- in carbon cycle, 1250f
primary, 1240f, 1246, 1247f, 1248
secondary, 1240f, 1246, 1247f, 1248
tertiary, 1240f, 1246, 1247f, 1248
- Consumption, regulation of animal, 917f, 918
- Continental drift, 482–483, 525, 538f–539f, 540
- Contour tillage, 809f
- Contraception, 1037, 1038f, 1039, 1208
- Contraceptives, as environmental toxins, 1276
- Contractile proteins, 76f
- Contractile vacuoles, 108, 135f
- Contraction, muscle, 1126, 1127f, 1128. *See also Muscle*
- Contrast, 94
- Control
- animal, 880f
- Control center, homeostatic, 882f
- Control elements, 373f–377f
- Control groups, 20, 21f
- Controlled experiments, 20–21
- designing, in Scientific Skills Exercise, 1014
- Conus geographus*, 1067f–1068
- Convection, animal heat exchange and, 885f
- Convergent evolution, 481
- analogies and, 558f
 - of cacti and euphorbs, 1172f
 - of fast swimmers, 874f
 - of homologies, 481f
 - of marsupials, 744f
 - in phylogenies, 553f–554f
- Convergent extension, 1056, 1057f
- Conversion, data, 264
- Cooksonia* sporangium, 622f
- Cooling, evaporative, 47, 48f, 886
- Cooper, Vaughn, 578f
- Cooperativity, 160
- allosteric activation, 160f
 - prokaryotic metabolic, 582f
 - science and, 22–23, 24f
- Coordinately controlled genes, 366, 375–376
- Coordination
- animal, 880f
- Coordination, cell-signaling response, 227, 228f
- Copepods, 710f
- Coprophagy, 914
- Copy-number variants (CNVs), 461–462
- CoQ (coenzyme Q), 175, 186
- Coral atolls, 1182f
- Coral polyps, 1019f
- Coral reefs, 53f, 54, 614, 1182f, 1234, 1264, 1277f, 1282
- Corals, 692f–693f
- Corepressors, 367f
- Cork cambium, 766f, 774
- Cork cells, 774, 783
- Cormorant, flightless (*Phalacrocorax harrisi*), 506f, 507, 511
- Corn (*Zea mays*), 205, 448t, 651. *See also Maize*
- Cornea, 1118f
- Corn smut, 669f
- Corpus callosum, 1093f, 1098
- Corpus luteum, 1029f, 1032f, 1033
- Correlation coefficients in Scientific Skills Exercise, 678, 751
- Correlations, positive and negative, in Scientific Skills Exercise, 834
- Correns, Carl, 311f
- Corridors, movement, 1271f, 1272
- Cortex, 116, 763, 770f
- Cortical microfilaments, 116
- Cortical nephrons, 986f, 991
- Cortical reactions, 1045f, 1046
- Cortical rotation, 1060f
- Cortisol, 1001f
- Corynebacterium diphtheriae*, 97f
- Costa Rica, 1273f, 1284, 1285f
- Cost-benefit behavior analysis, 1149
- Cotransport, 138f, 139
- Cotton, 49, 804
- Cottongrass, 1256f
- Cotyledons, 647, 649f, 828f–830f
- Counseling, genetic, 287–288
- Countercurrent exchange, 886f, 941f
- Countercurrent multiplier systems, 990–991
- Courtship rituals. *See also Mating behavior*
- behavioral isolation and, 508f
 - external fertilization and, 1023
- forms of animal communication in, 1141f–1142f
- genetic basis of, 1155f
- reproductive cycles and, 1021f
- sexual selection and, 499f–500f, 1151, 1152f–1153f, 1154
- Covalent bonds, 36
- of disaccharides, 69f
 - formation of, 36f
 - in organic compounds, 58, 59f, 60, 64
 - in protein tertiary structure, 81f
 - types of, 36f–37f
- Cowbirds, 1271, 1287
- Crabs, 709f
- “Crank” drug, 62
- Crassulacean acid metabolism (CAM) plants, 205, 206f, 798, 799f
- Crawling, 1133f, 1135
- Crayfish, 709, 940f, 1112
- Creatine phosphate, 1128
- Crenarchaeota clade, 586–587
- Cretaceous mass extinction, 540, 541f
- Creutzfeldt-Jakob disease, 412
- Crictetus cricetus*, 893f
- Crick, Francis
- central dogma of, 339
 - discovery of DNA molecular structure by, 4, 23–24, 314f, 317, 318f–320f
 - model of DNA replication by, 320, 321f
- Crickets (*Anabrus simplex*), 449, 712f, 1112f
- Cri du chat, 309
- Crinoidea, 715f
- CRISPR-Cas9 system, 360, 361f, 380, 404f, 589
- in gene editing, 426, 427f, 434–435
 - in gene identification, 446
 - plant mutations and, 776
 - prokaryotes in development of, 589, 590f
- Cristae, 110
- Critical habitat, 1269f–1270f
- Critical load, 1275
- Crocodiles, 564f, 719f, 737f, 738, 925, 1091f
- Crop (esophageal pouch), 905f, 913
- Crop plants. *See also Agriculture; Plants*
- artificial selection and breeding of, 835–837
 - biotechnology and genetic engineering of, 837, 838f, 839–840
 - climate change and, 863
 - effects of atmospheric carbon dioxide on, 205
 - as polyploids, 514–515
 - seed plants as, 651
 - transgenic and genetically modified, 438–439
- Crop rotation, 817
- Cross-fostering studies, 1143, 1144t
- Crossing over, 260f, 302
- chromosomal alterations during, 307, 308f
 - evolution and, 313
 - gene duplication due to unequal, 455f
 - genetic variation from, 265, 266f
 - in meiosis, 260f, 262f
 - recombination of linked genes in, 302, 303f
- Cross-pollination, 646
- angiosperm, 646f, 647
 - G. Mendel’s techniques of, 270f–271f
 - of plants, 837
- Cross-talk, cell-signaling, 228f
- Crotalus atrox*, 1084
- Crows, 1150
- CRP (CAMP receptor protein), 369f
- Crustaceans, 464f, 545f, 546, 689f, 708, 709f–710f
- Crustose lichens, 668f, 672
- Cryo-electron microscopy (cryo-EM), 95f, 96
- Cryptic coloration, 1218f, 1219
- Cryptochromes, 856
- Cryptomyctes, 660f–661f
- Cryptophyte, 597f
- Crypts, 799f
- Crystallin, 377f, 441
- Crystallin proteins, 8f
- Crystals, ice, 48f
- C soil horizon, 806f
- Ctenophora, 687f
- Ctenophores, 683f, 684
- C-terminus, 78f, 352
- Cuatro ojos fish, 365f
- Cuboidal epithelium, 877f
- Cubozaans, 692f–693f
- Cuckoo bee, 1218f, 1219
- Cud, 914f
- Culex pipiens*, 496
- Culture, 1148, 1159f, 1160
- Cupula, 1116f
- Curl cat, 293
- Curvularia*, 672
- Cuscuta*, 819f
- Cushing’s syndrome, 1018
- Cuticle, ecdysozoan, 705, 707
- Cuticle, exoskeleton, 1133
- Cuticle, leaf, 763
- Cuticle, plant, 621
- Cuttings, plant, 428, 835–836, 849
- Cutworms, 705
- Cuvier, Georges, 469f, 470–471
- Cyanobacteria
- blooms of, 1227f
 - bryophyte symbiosis with, 626f, 627
 - chemical recycling by, 586f
 - evolution of glycolysis in, 182
 - fungi and, as lichens, 663, 668f–669f
 - metabolic cooperation in, 582f
 - mutualism with, 813f
 - origin of photosynthesis in, 533, 534f
 - photosynthesis by, 188f, 194f, 195, 199, 584f
 - protist endosymbiosis and photosynthetic, 596f–597f, 608f, 609
- Cyanocitta cristata*, 1146f
- Cycads, 642f
- Cyclic AMP (cyclic adenosine monophosphate, cAMP), 223f–224f, 233, 369f, 1002, 1003f, 1080
- Cyclic electron flow, 198f, 199
- Cyclic GMP (cGMP), 224, 844f, 845
- Cyclin, 245, 246f
- Cyclin-dependent kinases (Cdks), 245, 246f
- Cycliophora, 688f
- Cyclosporine, 670
- Cyclostomes, 723
- Cynodonts, 531f, 532
- Cysteine, 63f, 77f
- Cystic fibrosis, 83, 280, 286, 433
- Cystic kidney disease, 1064
- Cytochromes, 175, 199, 230, 566
- Cytogenetic maps, 306
- Cytokines, 955–956, 1001
- Cytokinesis, 236
- in meiosis, 260f–261f
 - mitosis and, 234, 239f, 241, 242f–243f
 - nuclear envelope during, 252
- Cytokinins, 846t, 850f
- Cytology, 96
- Cytoplasm, 98
- cell cycle control signals in, 244, 245f
 - cell-signaling responses in, 226, 227f
 - cytokinesis and division of, 236, 239f, 241, 242f–243f
 - of prokaryotic and eukaryotic cells, 98–99
- Cytoplasmic determinants, 382f, 383
- Cytoplasmic genes, 311
- Cytoplasmic responses, cell-signaling, 226, 227f
- Cytoplasmic streaming, 117f, 608
- Cytosine, 84, 85f, 86, 317f, 318, 341f
- Cytoskeletons, 112
- actin microfilaments of, 113t, 115, 116f–117f
 - animal cell, 100f
 - ATP in mechanical work of, 152f
 - intermediate filaments of, 113t, 117
 - membrane proteins and attachment to, 130f
 - microtubules of, 113t, 114f–116f
 - in morphogenesis, 1056f–1057f
 - plant cell, 101f
 - scale of, 123f
 - structure and function of, 113t
 - support and motility roles of, 112f–113f
- Cytosol, 97
- Cytosolic calcium ions, 844f, 845
- Cytotoxic chemotherapy, 393f
- Cytotoxic T cells, 962, 966f, 967

D

- DAG (diacylglycerol), 225f
- Dalton (atomic mass unit), 31, 50
- Dalton, John, 31
- Danaus plexippus*, 839, 1146f
- Dance language, honeybee, 1142f
- Dandelions, 824f, 832f, 1192f, 1202f
- Dangi, Jeffery, 814f
- Danio rerio* (zebrafish) model organism, 22

- Daphnia pulex*, 448*t*, 1021, 1199*f*, 1200
 Darkness
 flowering in long-night plants and, 859*f*, 860
 plant etiolation response to, 843*f*
 Dark responses, rod cell, 1121*f*
 D'Arrigo, Rosanne, 773*f*
 Darwin, Charles. *See also* Evolution
 on barnacles, 710
 Beagle voyage and field research of, 471, 472*f*–473*f*
 on coevolution of flower-pollinator mutualism, 825
 on earthworms, 704
 evidence supporting theory of, 476, 477*f*–482*f*, 483
 on grandeur of evolutionary process, 484
 historical context of life and ideas of, 469*f*–471*f*
 on island species, 483
 on lung evolution from swim bladders, 728
 on mystery of flowering plants, 477, 647, 825*f*
 on mystery of speciation, 506*f*, 507
 on natural selection, 266, 267*f*, 487
 On the Origin of Species by Means of Natural Selection by, 469, 473, 483–484, 487
 speciation theory of, 473, 474*f*–476*f*
 on species diversity of tropics, 1232
 study by of phototropism in grass coleoptiles, 847*f*
 theory of descent with modification by, 14*f*–16*f*, 469–470, 473*f*–476*f*, 483–484
 timeline of work of, 469*f*
 Darwin, Francis, 847*f*
Dasyatis americana, 727*f*
 Data, 17, 19*f*, 21–22. *See also* Scientific Skills Exercises
 Databases
 in estimating reproductive rates, 1194, 1195*f*
 genome-sequence, 444, 445*f*
 Dating, radiometric, 32–33, 529, 530*f*
 dATP, 324
 Daughter cells, 234, 235*f*–236*f*, 237, 266*f*
 Day-neutral plants, 859*f*
db gene, 918
 DDT pesticide, 158, 485, 518, 1276*f*
 Dead-leaf moth (*Oxytenis modestia*), 476*f*
 Dead Sea, 585
 Dead zone, 1242, 1275*f*
 Deamination, amino acid, 182
 Deaths
 demographics of, 1193*t*, 1194*f*–1195*f*
 in density-dependent population growth, 1203*f*–1205*f*
 in exponential population growth, 1196, 1197*f*
 in human population dynamics, 1208–1209
 in population dynamics, 1192, 1256*f*
 Death signals, apoptosis, 230, 231*f*. *See also* Apoptosis
 Decapods, 709*f*, 710
 Decay curves, radioactive isotope, 33
 December solstice, 1167*f*
 Deciduous forest, nutrient cycling in, 1252*f*
 Decomposers, 188, 586, 1240*f*
 in energy flow and chemical recycling, 9*f*, 1240*f*, 1241
 fungi as, 654–655, 658*f*, 661*f*, 663, 665, 667
 lichens as, 669
 prokaryotic, 586
 Decomposition, 1240*f*, 1241, 1248*f*–1251*f*, 1259
 Deconvolution microscopy, 95*f*, 96
 Deductive reasoning, 18, 617
 Deep-sea hydrothermal vents, 527*f*, 1182*f*
 Deer, 871, 1149, 1271
 Deer mice, 498*f*, 892
 DEET insect repellent, 1123
 De-etiolation (greening), 843*f*–844*f*, 845
 Defensive adaptations, 28*f*, 43, 1217, 1218*f*–1219*f*, 1220, 1237
 Defensive proteins, 76*f*
 Deficiencies, plant, 810, 811*f*, 818
 Deforestation
 climate effects of, 1169*f*
 experimental, and nutrient cycling, 1252*f*
 as human community disturbance, 1231
 loss of species from, 1260*f*, 1263
 rising atmospheric carbon dioxide levels from, 1278
 of tropical rain forests, 651*f*, 652, 1263
 Degradation, protein, 379
 Dehydration
 animal, 980
 plant, 203, 204*f*–206*f*, 536
 Dehydration reactions, 67*f*
 Dehydrogenases, 167*f*, 168
 Defac, Lynn, 24*f*
 Delayed reproduction, 1208
 Deletions (mutations), 358*f*, 359
 Deletions, chromosome, 307, 308*f*, 309
 Dementia, 1103, 1104*f*
 Demographics, population, 1193*t*, 1194*f*–1195*f*
 Demographic transition, 1208
 Demography, 1193. *See also* Demographics, population
 Denaturation, 82*f*, 83
 Dendrites, 879*f*, 1068*f*, 1078, 1110*f*
 Dendritit cells, 955
Dendrobates pumilio, 524
 Dendrochronology, 773*f*
Dendroctonus ponderosae, 1244*f*, 1245, 1280*f*
 Dengue fever, 412
 Denitrifying bacteria, 1251*f*
 Density, population, 1191*f*–1192*f*, 1193, 1202, 1203*f*, 1256*f*
 Density-dependent inhibition, 247, 248*f*
 Density-dependent population change, 1202, 1203*f*–1206*f*, 1207, 1213
 Density-independent population change, 1203
 Dentition, 530, 531*f*, 532, 911*f*, 912
 Deoxyribonucleic acid. *See* DNA
 Deoxyribose, 85*f*, 317*f*, 324
 Dependent assortment hypothesis, 275, 276*f*
 Dependent variables, 21, 513
 Dephosphorylation, protein, 223
 Depolarization, 1072*f*–1074*f*
 in fertilization, 1044*f*, 1045
 Depolymerization, protein, 240
 Depression, 1081, 1102–1103
 Derelle, Romain, 612*f*
 Derived characters, shared, 560, 561*f*
 Derived traits, plant, 620*f*–621*f*
 Dermal tissue system, plant, 758, 762, 763*f*
 DES (diethylstilbestrol), 1015
 Descending limb, loop of Henle, 988*f*, 989
 Descent with modification theory, 14*f*–16*f*, 469–470, 473*f*–476*f*, 483–484. *See also* Evolution
 Desert animals, 980–981
 Desert iguana (*Dipsosaurus dorsalis*), 888
 Desert mice, 981
 Deserts, 798, 799*f*, 1168, 1169*f*, 1173*f*
 Desert spring, 1239*f*
 Desiccation, 979
Desmognathus ochrophaeus, 513
 Desmosomes, 120*f*
 Desynchronization, 858–859
 Determinate cleavage, 681, 682*f*
 Determinate growth, 766*f*–767*f*
 Determination, 383, 384*f*, 1057
 Detoxification, 104–105, 112, 809
 Detritus, 1177, 1240*f*, 1241
 Deuteromycetes, 659
 Deuterostome development, 681, 682*f*
 Deuterostomes, 683*f*, 689*f*, 713, 714*f*–715*f*, 719*f*. *See also* Chordates; Echinoderms
 Development, 775
 of brain, 722*f*, 1092*f*, 1099–1100
 as cell division function, 235*f*
 embryonic. *See* Embryonic development
 in human life cycle, 257*f*, 258. *See also* Human embryonic development
 macroevolution of, 545*f*–546*f*, 547
 plant and animal, 894*f*. *See also* Animal development; Plant development
 postzygotic barriers and, 509*f*, 510
 as property of life, 3*f*
 sustainable. *See* Sustainable development
 Developmental biology, 1057
 Developmental genes. *See* Homeotic genes; *Hox* genes
 Developmental plasticity, 775*f*
 Developmental potential, cell fate and, 1060, 1061*f*
 Diabetes
 aquaporin mutations as causes of diabetes insipidus, 995*f*
 autoimmunity and, 971
 disruption of glucose homeostasis in, 916–917
 genetic engineering of insulin to treat, 436
 genetic markers for, 427
 mitochondrial mutations in, 311
 neonatal, insulin mutations and, 359
 stem cells for, 431
 Diabetes insipidus, 995*f*
 Diabetes mellitus, 916–917
Diacodexis, 482*f*
 Diacylglycerol (DAG), 225*f*
 Diagnosis
 antibodies as tools in, 969*f*
 biotechnology in, 433, 434*f*, 435
 Diamond-back rattlesnake (*Crotalus atrox*), 1084
 Diaphragm in breathing, 945*f*
 Diaphragm, birth control, 1038*f*
 Diapsids, 736
 Diarrhea, 139, 224, 588, 598*f*, 911
 Diastole, 927*f*
 Diastolic pressure, 930, 931*f*
 Diatomaceous earth, 602
 Diatoms, 244*f*, 599*f*, 602*f*, 617, 1170
 Diazepam, 1081
 Dicer-2, 954*f*
 Dicots, 649
Dictyostelium discoideum, 613*f*
 Dideoxy DNA sequencing, 416
 Dideoxyribonucleotide (dideoxy) chain termination DNA sequencing, 443
Didinium, 617
 Diencephalon, 1093*f*
 Diets. *See also* Food
 adaptations of vertebrate digestive systems for, 911*f*–914*f*
 assessing nutritional needs in, 902*f*
 catabolism and human, 182*f*, 183
 deficiencies in, 901*f*, 902
 essential nutrients for, 899*f*, 900*f*–901*t*, 901*f*
 genetic variation in prey selection and, 1155, 1156*f*
 nonheritable variation and, 488*f*
 phenylketonuria and, 492
 typical and opportunistic, 901
 Differential centrifugation, 96*f*, 97
 Differential gene expression, 370. *See also* Gene regulation
 cytoplasmic determinants and induction in, 382*f*, 383
 in eukaryotic gene regulation, 370*f*, 371
 in gene regulation, 365*f*
 in pattern formation of body plans, 384, 385*f*–387*f*
 in processes of embryonic development, 381*f*, 382. *See also* Embryonic development
 sequential regulation of, during cellular differentiation, 383, 384*f*
 Differential-interference microscopy, 95*f*
 Differential reproductive success, 266, 267*f*
 Differential speciation success, 548–549
 Differentiation, 1057
 Differentiation, cell, 381
 cytokinins in, 850
 as embryonic development process, 381*f*, 382. *See also* Embryonic development
 plant development and, 763, 775–776, 778*f*
 sequential gene regulation in, 383, 384*f*
 stem cells and, 430*f*, 431. *See also* Stem cells
 Diffusion, 132, 922
 body surface area and, 695*f*
 effects on water balance of osmosis as, 133*f*–135*f*
 extracellular, 768
 free energy change and, 148*f*
 interpreting scatter plots on glucose uptake as, 136
 as passive transport, 132, 133*f*
 in plant cells, 209*f*
 proteins and facilitated, 135*f*, 136
 of water across plant plasma membranes, 788, 789*f*–791*f*
 of water and minerals into root cells, 792
 Digestion, 904
 in animal food processing, 904*f*–905*f*
 compartmentalized processing in, 898
 digestive compartments in, 902, 903*f*–905*f*
 digestive systems and, 875*f*
 extracellular, 904*f*–905*f*
 feeding mechanisms and, 902, 903*f*
 fungal, 655, 668
 hydrolysis in, 67
 intracellular, 904
 lysosomes in intracellular, 107*f*, 108
 regulation of animal, 915*f*
 sea star, 713, 714*f*

- in small intestine, 908f, 909
in stomach, 907f–908f
vertebrate adaptations for, 911f–914f
- Digestive enzymes, 76f
- Digestive secretions, 898, 907f–908f, 909–910, 915f
- Digestive systems
adaptations of, 911f–914f
alimentary canals, 905f, 912f
bacteria in, 911–912, 913f–914f
feedback regulation of, 915f
internal exchange surfaces and, 875f
of invertebrates, 71f
large intestine in, 910, 911f
oral cavity, pharynx, and esophagus in, 905, 906f–908f
small intestine in, 908f–910f
stomach in, 907f–908f
- Digger wasps, 1145f
- Dihybrid crosses, 275, 276f
- Dihybrids, 274–275, 276f
- Dihydroxyacetone, 68f
- Dijkstra, Cor, 1201f
- Dikaryotic mycelia, 658
- Dimers, tubulin, 114
- Dimorphism, sexual, 499f, 752, 1149–1150, 1151f
- Dinitrophenol (DNP), 186
- Dinoflagellates, 244f, 594f, 604, 605f
- Dinosaurs, 736
blood pressure of, 931
disappearance of, 679
as early reptiles, 736
flying, 1135
in fossil record, 529f, 564f, 565
mass extinction of, 541f, 542
in Mesozoic era, 533
- Diomedea exulans*, 977f
- Dionaea muscipula*, 802, 819f, 862
- Diphtheria, 403
- Diploblastic animals, 680
- Diploid cells, 257
genetic variation preserved in recessive alleles of, 500
haploid cells vs., 257
mitosis vs. meiosis in, 262, 263f, 264
in sexual life cycles, 258f, 259
- Diplomonads, 600f
- Dipnoi (lungfishes), 719f, 729
- Dipodomys merriami*, 741f, 998
- Dipsosaurus dorsalis*, 888
- Diptera, 712f
- Direct contact, cell signaling by, 215f
- Direct inhibition hypothesis, 850
- Directionality, DNA replication, 324, 325f–326f
- Directional selection, 497, 498f
- Disaccharides, 68, 69f, 70
- Diseases, animal
density-dependent population regulation by, 1204f
movement corridors and spread of, 1271f, 1272
viral, 400f, 407f, 409f–412f
- Diseases, plant
community structure and pathogens in, 1234
density-dependent population regulation by, 1204f
disease-resistant genes and, 866, 867f
viral, 399f–400f, 412f
- Diseases and disorders, human
adenoviruses and, 400f
alkaptonuria, 336
allergies, 970f, 971
Alzheimer's disease, 413, 1103, 1104f
amebic dysentery, 613
amyotrophic lateral sclerosis (ALS), 1129
antibiotic resistance and, 478f
asthma, 62, 217
atherosclerosis, 74, 75, 139, 141, 937f, 938–939
autism spectrum disorder, 1100
autoimmune, 971f
bacterial, 403, 574, 575f–576f, 584f, 587, 588f
biotechnology in diagnosis and treatment of, 433, 434f–436f
cachexia, 1016
cancer. *See Cancer*
cardiovascular diseases, 74, 311, 937f, 938–939, 951
chikungunya virus, 409f
cholera, 224, 584f, 588f
- color blindness, 299f, 1122f
community ecology, pathogens, and, 1234, 1235f
cri du chat and chronic myelogenous leukemia, 309f
- CRISPR-Cas9 system for, 360, 361f
- cystic fibrosis, 286, 293
- cystic kidney disease, 1064
- density-dependent population regulation by, 1204f
detecting fetal, during pregnancy, 1039–1040
- diabetes. *See Diabetes*
diabetes insipidus, 995f
- diarrhea, 139
- dominantly inherited, 287f
- Down syndrome, 307, 308f, 309f
- drug addiction, 1103f
- Duchenne muscular dystrophy, 299f
- due to chromosomal alterations, 306, 307f–309f
- Ebola virus, 409f
- emerging viral diseases and, 409f–412f
- endocrine disruptors and, 1015
- endometriosis, 1033
- epilepsy, 1098
- erectile dysfunction, 1081–1082
- familial cardiomyopathy, 357
- faulty apoptosis in nervous system and, 231
- faulty cell-surface receptors and, 218f, 220
- fetal screening for, 288, 289f
- flatworm parasites and, 696f–697f
- flesh-eating disease, 478f
- fungus, 670
- gastric ulcers and acid reflux, 908
- genetic. *See Genetic disorders*
genomics and proteomics in, 88f
- gonorrhea, 576, 584f
- gout, 983
- growth-related, 1009, 1010f
- heart murmurs, 928
- hemophilia, 300
- HIV/AIDS. *See AIDS; HIV*
- Hodgkin's disease, 971
- Huntington's disease, 287
- hypercholesterolemia, 139
- hypertension, 939
- immune system disruptions and, 970f–974f, 973t
- immunization against, 968f, 976
- immunodeficiency, 971, 972f, 973
- influenza, 400f, 410
- insects as carriers of, 713
- iodine deficiency and goiter, 29
- Kartagener's syndrome, 1064
- karyotypes and, 256f
- Klinefelter syndrome, 309
- lactose intolerance, 70
- Leber's congenital amaurosis, 1122
- lymphatic system and, 933
- major depressive disorder and bipolar disorder, 1102–1103
- malaria. *See Malaria*
- mitochondrial, 311
- mosaicism, 300f
- multifactorial, 287
- mutations and, 357f–358f, 359
- myasthenia gravis, 1129
- myotonia and epilepsy, 1076
- nematode parasites and trichinosis, 705f, 706
- of nervous system, 1102f–1104f
- neurodegenerative, 413
- neurotransmitters and, 1080–1082
- from ozone depletion, 1284
- parasitic. *See Parasites*
- Parkinson's disease, 413, 1081, 1104
- phenylketonuria, 492–493
- from plastic waste, 1277
- pleiotropy and inherited, 280
- pneumonia, 315f, 579
- polydactyly, 280
- protein misfolding and, 83
- protists and, 598f–599f
- recessively inherited, 285f–286f, 287
- respiratory distress syndrome, 943, 944f
- retinitis pigmentosa, 495
- schizophrenia, 1102f
- sexually transmitted diseases. *See Sexually transmitted diseases*
- sickle-cell disease. *See Sickle-cell disease*
- sleeping sickness, 600, 601f
- spina bifida, 1055
- Tay-Sachs disease and lysosomal storage, 108, 280, 285, 288, 289f
- testing genetic markers for, 427f
- thyroid, 1009
- Turner syndrome, 309
- Wiskott-Aldrich syndrome, 229
- xeroderma pigmentosum, 328
- X-linked disorders, 299f, 300
- Zika virus, 409f
- Disease-suppressive soil, 590
- Disorder, entropy and, 146
- Disparity, vertebrate, 719
- Dispersal, 1183
fruit and seed, 832f
movement corridors and, 1271f, 1272
- seed, 645f
- species, 1183, 1184f
- Dispersion, population, 1191f–1192f, 1193
- Dispersive model, DNA replication, 321f–322f
- Disruptive selection, 498f
- Dissociation, water, S1
- Distal control elements, 374
- Distal tubule, 987f–988f, 989
- Distance vision, 1122f
- Distribution patterns, analyzing, 283
- Distributions, species. *See Species distributions*
- Disturbances, 1172, 1214, 1228, 1229f–1231f
- Disulfide bridges, 81f
- Divergence
allopatric speciation and, 506, 511f–512f, 513
of angiosperms, 647f, 648
of closely related species, 460–461, 462f
of fungi, 659f, 660
in phylogenetic trees, 555, 556f, 557
of unicellulars from other eukaryotes, 612f
- Diversity. *See also Biodiversity*
B cell and T cell, 960, 961f
- biological. *See Biodiversity*
- cellular structures and, 125
- evolution and, 11, 468f, 469, 473
- in science, 24
- within a species, 507f
- Diving bell spider (*Argyroneta aquatica*), 951
- Diving mammals, respiratory adaptations of, 949f
- Division, cell. *See Cell division*
- Dixon, Henry, 794
- Dizygotic twins, 1036
- Dizziness, 1116
- DNA (deoxyribonucleic acid), 6, 84. *See also Chromosomes; Genes; Genetics; Nucleic acids*
amplification of, using polymerase chain reaction, 420, 421f, 422
- analyzing DNA deletion experiments, 376
- in bacterial binary fission, 242, 243f
- of B and T cells, 976
- bending of, 374, 375f, 451
- in cancer cells, 249–250
- cell-free fetal, 288
- changes of, in meiosis of yeast cells, 264
- Chargaff's rules on structure of, 317f, 318
- complementary DNA. *See Complementary DNA components of, 84, 85f*
- CRISPR-Cas9 system and, 360, 361f
- discovery of structure of, 4, 18–19, 23–24, 314f, 317, 318f–320f
- diseases of mitochondrial, 311f
- distribution of, during eukaryotic cell division, 235f–236f, 237
- in ecological forensics, 1265f
- elevation and UV damage to, affecting species distributions, 1186f
- eukaryotic, 6, 97f, 98, 102, 103f
- evidence for, as genetic material, 315f–317f, 318
- evolutionary significance of mutations of, 328
- evolution of genomes from changes in, 454f–457f, 458–459
- in expression and transmission of genetic information, 6, 7f–8f
- gene density and noncoding, 449–450
- genetic code for, 340f–342f
- genetic variation due to mutations in, 488–489
- genomics, bioinformatics, and proteomics in study of, 9, 86, 87f
- homeoboxes in, 463f–464f

- DNA (deoxyribonucleic acid) (continued)
- human gene microarray chips containing, 447, 448f
 - in hybrids, 524
 - inheritance of, in chromosomes and genes, 255
 - as measure of evolution, 87, 89, 397
 - methylation of, 371, 372f, 373, 391, 430
 - molecular homologies and, 479–480, 558, 559f
 - ozone depletion and damage to, 1284
 - p53* gene and repair of, 390–391
 - packing of proteins and, into chromosomes, 330f–332f
 - phylogenies based on, 554f
 - in plant cells, 208f
 - programming of cells by viral, 315f–316f, 317
 - prokaryotic, 6f, 97f, 98, 577f, 579f–580f, 581
 - proofreading and repairing of, 327, 328f
 - recombinant. *See* Recombinant DNA
 - repetitive noncoding, 450f–451f, 452
 - replication of. *See* DNA replication
 - roles of, in gene expression, 84f
 - sequencing of. *See* DNA sequencing
 - simple sequence and short-tandem repeat, 452
 - species identity in mitochondrial, 557f
 - structure of, 86f
 - structure of, and inheritance, 334, 364
 - technology of. *See* DNA technology
 - testing of, in forensic science, 436, 437f
 - in transcription, 337, 339f
 - viral, 400f–407f, 406t
- DNA amplification, 420, 421f, 422
- DNA “barcode,” 1222
- DNA-binding domain, 374f
- DNA-binding proteins, 91
- DNA chips, 426
- DNA cloning, **418**
- amplification of DNA using polymerase chain reaction in, 420, 421f, 422
 - copying DNA with gene cloning and, 418f, 419
 - expressing cloned eukaryotic genes in, 422–423
 - in gene therapy, 434f
 - using restriction enzymes to make recombinant DNA plasmids for, 419f–420f
- DNA Data Bank of Japan, 444
- DNA deletion experiments in Scientific Skills Exercise, 376
- DNA ligases, **325f**–326f, 327t, 328f, 419f, 420
- DNA methylation, **371**, 372f, 373, 391, 430
- DNA microarray assays, 289, **426f**. *See also* Microarray chips, human genome
- DNA pol I and pol III, 325, 326f, 327t
- DNA polymerases, **324f**
- DNA profiles, 1223f
- DNA replication, **320**
- base pairing to template strands in semiconservative model of, 320, 321f–322f
 - errors in, and genome evolution, 455f–457f
 - evolutionary significance of mutations during, 328
 - genetic information and, 314
 - inheritance and, 7f–8f
 - in molecular basis of inheritance, 314–315.
 - See also* Molecular basis of inheritance
 - proofreading and repairing of DNA during, 327, 328f
 - steps of, 322f–327f
 - of telomeres, 328, 329f
- DNA replication complex, 326f–327f, 334
- DNA sequences
- analyzing phylogenetic trees based on, to understand viral evolution, 411
 - animal phylogeny and, 682, 683f, 684
 - constructing phylogenetic trees using, 562, 563f, 564
 - evaluating molecular homologies in, 558f–559f
 - exon and intron, 345f–347f
 - genes as, 361–362
 - interpreting sequence logos for, 351
 - on medical records, 448
 - noncoding, 449–450
 - promoter and terminator, 342, 343f
 - types of, in human genome, 450f
- DNA sequencing, **87**, **416**
- of complementary DNA, 426f
 - in genetic testing for cancer predisposition, 394
 - genome sequencing and, 443f, 444
 - genomics, bioinformatics, proteomics, and, 86, 87f
- human genome sequencing by, 415f, 416
- standard vs. next-generation techniques for, 416f–417f
 - systems biology, medicine, and, 447, 448f
 - three-domain taxonomy system and, 12f, 13
- DNA strands, 7f–8f, 317, 318f–320f, 340f, 419f, 420.
- See also* DNA replication
- DNA technology, **416**
- amplifying DNA with polymerase chain reaction in, 420, 421f, 422
 - in analyzing gene expression and function, 423, 424f–428f
 - bioinformatics and, 444, 445f–448f
 - in biotechnology applications, 416, 433, 434f–437f, 438–439. *See also* Biotechnology
 - in breast cancer treatment, 250
 - creating recombinant DNA plasmids using restriction enzymes and gel electrophoresis in, 419f–420f
 - DNA cloning and gene cloning in, 418f, 419
 - DNA sequencing in, 415f–417f
 - in ecological forensics, 1265f
 - in eukaryotic gene regulation, 371
 - evolution and, 441
 - in expressing cloned eukaryotic genes, 422–423
 - genetic code and gene transplantation in, 341, 342f
 - organismal cloning in, 428, 429f–432f
 - science, society, and, 23, 24f
 - DNA testing, forensic, 436, 437f
 - DNA viruses, 400f–407f, 406t
 - DNP (dinitrophenol), 186
 - Dobzhansky, Theodosius, 11
 - Dodder (*Cuscuta*), 819f
 - Dog rose, 650f
 - Dolly (cloned lamb), 429f
 - Dolphins, 481f–482f, 886f, 1094f, 1191f, 1192, 1262f
 - Domains, protein, **347f**, 444, 445f, 446, 676f
 - Domains, taxonomy, 12f, 13, 460f, **554**, 555f, 568, 569f, 585t. *See also* Archaea, domain; Bacteria, domain; Eukarya, domain
 - Domestication, plant, 651
 - Dominance, degrees of, 279f, 280
 - Dominant alleles, **272**, 273f–276f, 279f, 280, 287f, 293. *See also* Alleles
 - Dominantly inherited disorders, human, 287f
 - Dominant traits, 271f, 272t
 - Donkeys, 335f, 337
 - L-Dopa, 65
 - Dopamine, 56, 1081t, 1102, 1103f, 1104
 - Doppler, Christian, 270
 - Dormancy, endospore, 575f
 - Dormancy, seed, 639, **828**–829, 833–834, 852
 - Dormouse, 893f
 - Dorsal lip, **1051f**, 1062f
 - Dorsal sides, 680f
 - Dorsal-ventral axis, 1060f
 - Double bonds, **36**, 37f, 60f
 - Double circulation, 924f–926f, **925**
 - Double fertilization, 646f, **647**, **826**, 827f
 - Double helix, DNA, 7f, **86f**, 314f, **318f**–320f, 330f
 - Double-stranded DNA (dsDNA) viruses, 406t, 408
 - Double-stranded RNA (dsRNA) viruses, 406t
 - Doudna, Jennifer, 42f, 361, 426
 - Douglas fir, 643f
 - Doushantuoiphyton*, 535f
 - Dowling, Herndon, 888f
 - Down syndrome, 256f, 289, 307, **308f**, 309, 432
 - Dragonflies, 887f
 - Draw It Questions, 15f, 16, 26, 39f, 41f, 42–43, 45f, 54–55, 61f, 62, 64–65, 69f, 74f, 78f, 86, 91, 102, 103f, 116f, 125, 131f, 141–142, 154f, 159, 163, 186, 202, 210, 224f, 233, 236f, 240f, 252, 259f, 263f, 268, 276, 290, 292, 303f, 313, 323f, 326f–327f, 334, 342, 345f, 355, 362, 397, 414, 419f, 423, 441, 446, 485, 491f, 524, 530f, 558f, 560f–561f, 572, 598f, 617, 635, 644f, 653, 709f, 719f, 730, 756, 769f, 780f, 782, 821, 841, 871, 904f, 920, 951, 963, 976, 1018, 1042, 1066, 1073f–1075f, 1084, 1106, 1138, 1161, 1195, 1203f, 1237, 1253, 1259, 1287
 - Drip irrigation, 808
 - Dromaius novaehollandiae*, 739, 740f
 - Drosophila melanogaster* (fruit fly). *See also* Fruit flies
 - alternative RNA splicing in, 378f
 - analyzing single-gene expression in, 423, 424f–425f
- changes in developmental genes of, 545f, 546
- circadian rhythm molecular mechanisms in, 883
- courtship behaviors of, 1141f
- diploid and haploid numbers of, 257
- female bias in sperm usage of, 1024f
- foraging genes of, 1148, 1149f
- gene density of fungi vs., 665f
- genetic basis of behavior in, 1155
- genetic variation of, 487, 488f
- genome size and number of genes of, 448t, 449
- homeotic genes in, 463f–464f
- linkage maps of, 305f–306f
- linked genes and, 301f–303f
- as model organism, 22, 295f, 1044
- natural selection and adaptive evolution of, 494
- one gene–one enzyme hypothesis on, 336
- pattern formation of body plan of, 384, 385f–387f
- phylogenetic trees of, 562f
- reproductive anatomy of, 1024f
- Drosophila* species (fruit flies), 512f, 522–523, 567
- Drought, 1228, 1244f
- abscisic acid in plant tolerance to, 852
 - American Dust Bowl and, 807f
 - climate change and, 11
 - plant responses to, 863–864
- Drugs. *See also* Medicine; Pharmaceutical products
- addiction to, 1103f
 - antibiotic. *See* Antibiotic drugs
 - antiviral, 409
 - biotechnology in production of, 435, 436f
 - cocktails of, in AIDS treatment, 489
 - enantiomers in, 62f
 - as environmental toxins, 1276, 1277f
 - fungi and, 670–671
 - molecular shape and, 40f, 78
 - plant-derived, 651t, 652
 - resistance to, 478f, 592
 - species and genetic diversity and, 1262, 1263f
 - from sponges, 691
 - tolerance of, 104–105
- Dryas*, 1230f–1231f
- Dry fruits, 645f
- Dubautia* species, 543f
- Duchenne muscular dystrophy, **299**, 433
- Duckweed (*Spirodela oligorrhiza*), 101f
- Ducts, male reproductive, 1025f
- Dulse, 609f
- Dune fescue grass, 1203
- Dung beetle, 1259
- Dunstan, William, 1243f
- Duodenum, **909**
- Duplications, chromosome, **307**, 308f, 454f–456f
- Duplications, gene, 489, 565f, 566
- Dusky salamanders (*Desmognathus ochrophaeus*), 513
- Dust Bowl, American, 807f
- Dust mites, 708f
- Dutch Hunger Winter, 372f
- Dwarfism, 287f, 436, 1010
- Dynamics, population, 1191f, 1192, 1205f–1206f, 1207, 1256f. *See also* Population growth
- Dyneins, **115**, 116f
- Dysentery, 613
- E**
- Eagles, 1262f
- Ear bones, mammalian, 530, 531f, 532, 741, 742f
- Eardrum, 1112, 1113f
- Ears. *See also* Hearing
- bones of mammalian, 530, 531f, 532, 741, 742f
 - human, 1113f
 - insect, 1112f
- Earth. *See also* Biosphere; Global ecology
- development of photosynthesis and atmospheric oxygen on, 533, 534f
 - importance of seed plants to ecosystems of, 636f
 - mass extinctions of life on, 540f–542f
 - origins of life on, 57f, 58, 526f–528f
 - plate tectonics of, 538f–539f, 540
- Earthworms, 688f, 704f, 705, 807, 905f, 923f, 985f
- East Australian Current, 1168f
- Eastern tent caterpillars (*Malacosoma americanum*), 897
- Ebola virus, 409f
- Ecdysis, 683–684, **705**, 707, 894f
- Ecdysozoans, 683f, **684**
- arthropods, 706f–712f, 713. *See also* Arthropods
 - nematodes, 705f, 706
 - phylogeny of, 688f–689f

- Ecdysteroid, 1006f, 1007
 Echinidnas, 742, 743f
 Echinoderms, 689f, **713**, 714f–715f, 719f, 1044f–1047f, 1086f, 1133
 Echinoidea, 715f
 ECM. *See* Extracellular matrix
 Ecological footprint, **1209**, 1210f, 1211
 Ecological forensics, 1265f
 Ecological niches, **1215**, 1216f
 Ecological pyramids, 1246, 1247f, 1248
 Ecological species concept, **510**
 Ecological succession, **1229**, 1230f–1231f
 Ecology, **1165**. *See also* Community ecology; Conservation biology; Ecosystem ecology; Global ecology; Landscape ecology; Organismal ecology; Population ecology evolution and, 1187f factors of, in evolutionary rates, 538 of fungi, 667f–670f genomics and proteomics in, 88f as interactions between organisms and environment, 1165 of mosses, 627f, 628 population growth and, 1213 prokaryotes in, 586f–591f scope and fields of, 1165f of seedless vascular plants, 633–634 urban, 1273, 1274f
 Ecosystem diversity, 1261f–1262f
 Ecosystem ecology, **1165f**. *See also* Ecology; Ecosystems
 Ecosystem engineers, **1226f**
 Ecosystems, **4f**, **1165f**, **1239**, 1256f–1257f biogeochemical cycles in, 1248f–1252f climate change effects on, 1279, 1281f decomposition in, 1240f, 1241, 1248f, 1249 diversity of, 1261f–1262f edges between, 1270, 1271f, 1287 effects of mass extinctions on, 542f energy budgets of, 1241, 1242f energy flow and chemical cycling in, 9f, 164–165, 1238f–1240f, 1241, 1256f–1257f evolution of, 1259 fungi in, 667f–670f importance of mosses to, 627f, 628 importance of seedless vascular plants to, 633–634 importance of seed plants to, 636f interactions in, 10f–11f as level of biological organization, 4f metagenomics and genome sequencing of species in, 444 primary production in, 1241, 1242f–1244f, 1243t, 1245 prokaryotes in, 586f, 587 protists in, 614f–615f restoration of degraded, 1253f–1255f secondary production in, 1246f–1247f, 1248
 Ecosystem services, **1263**
 Ecotones, **1172**
 Ectoderm, **680**, **1049**, 1050f–1051f
 Ectomycorrhizae, **817**, 818f
 Ectomycorrhizal fungi, **656**
 Ectoparasites, **1220**
 Ectopic cells and tissue, **1033**
 Ectopic pregnancies, 1039
 Ectoprocts, 688f, **698f**, 713
 Ectothermic organisms, **736**, **884f**, 885f–887f, 888, 890–892
 Edema, 933
 Edges, ecosystem, 1270, 1271f, 1287
 Ediacaran biota, 535f, 536, **676f**–677f
 Edidin, Michael, 128f
 Effective population size, **1268**
 Effector cells, **961**, 962f
 Effectors, **866**
 Effector-triggered immunity, 866
 Efferent arteriole, 987f
 Efferent neurons, 1088f
 Efficiency, cell-signaling, 228f, 229
 Egg-polarity genes, 386
 Eggs, **1020**
 amniotic, 718, 734, 735f
 amphibian, 732, 733f
 of birds and dinosaurs, 564f, 565
 Burmese python thermogenesis for incubating, 887, 888f
 in embryonic development, 381f, 382
 in fertilization, 1022f–1024f, 1044f, 1045–1046 human, 236–237, 1027, 1035f human oogenesis and, 1029f monotremes, 742 nitrogenous wastes and, 983 ovules and production of, in seed plants, 638f
 Egg yolk, 91
 Egrets, 1183, 1184f
 Ejaculation, **1025**, 1034
 Ejaculatory duct, 1025f
 Elastic fibers, 878f
 Elastin, 76f
 Electrically charged side chains, 76, 77f
 Electrical signals
 neuron, 880f, 1067–1068. *See also* Neurons phloem and symplastic, 802
 Electrical synapses, 1077. *See also* Synapses
 Electrocardiogram (ECG or EKG), **928f**
 Electrochemical gradients, 137, **138f**
 Electroencephalogram (EEG), 1094f
 Electrogenic pump, **138f**
 Electrolytes, blood plasma, 934f
 Electromagnetic receptors, **1110**, 1111f
 Electromagnetic spectrum, **192f**
 Electron distribution diagrams, 34f–35f, 37f
 Electronegativity, **37**, 45
 Electron microscope (EM), **94f**–95f
 Electrons, **30**
 chemical properties and, 34f, 35
 cyclic flow of, in light reactions of photosynthesis, 198f, 199
 distribution of, 34f–35f
 in electron transport chains, 167f–168f
 energy levels of, 32f, 33–34
 linear flow of, in light reactions of photosynthesis, 197f–198f
 orbitals of, 35f, 36, 39f, 40
 in organic compounds, 58, 59f, 60
 in redox reactions, 165, 166f
 as subatomic particles, 30f, 31
 Electron shells, 32f, **34**, 35f, 36
 Electron transfer, 37, 38f
 Electron transport chains, **168**
 in anaerobic respiration and fermentation, 179–180
 in cellular respiration, 167f–168f
 in chemiosmosis, 175, 176f, 177
 in oxidative phosphorylation, 174f, 175
 Electrophysiologists, 1072f
 Electroporation, **422**
 Elements, **29**, 809
 atomic number and atomic mass, 31
 electron distribution in, 34f–35f
 electron orbitals in, 35f, 36
 energy levels of, 32f, 33–34
 isotopes of, 31
 of life, 29t
 organisms ratio of, 43
 subatomic particles in, 30f, 31
 tolerance to toxic, 30f
 Elephantiasis, 933
 Elephants, 10f, 88f, 474f, 1197f, 1265f
 Elephant seals (*Mirounga angustirostris*), 999f, 1267
 Elephant shark (*Callorhinus milii*), 442f
 Elevation
 climate and, 1169f
 genetics and, 1189
 ultraviolet (UV) light damage at, 1186f
 Elicitors, 866
 Elimination, **904**, 905f, 911
 Elk, 1151f
 Elkhorn coral, 1234
Elkinsia, 641f
Elodea, 55
 Elongation, antiparallel DNA strand, 324, 325f–326f, 327t
 Elongation factors, 352, 353f
 Elongation stage
 transcription, 343f–344f
 translation, 352, 353f
 Embryo development, plant, 828f–829f
 Embryonic development. *See also* Differential gene expression
 analyzing single-gene expression in, 423, 424f–425f
 animal, 674f, 675. *See also* Animal development
 cell division, cell differentiation, and morphogenesis in, 381f, 382
 cell fate specification in, 1057, 1058f–1064f cleavage in, 1044, 1046, 1047f–1048f, 1049 cytoplasmic determinants and induction in, 382f, 383
 fertilization in, 1044f–1046f
 gene conservation in, 466 genomic imprinting and, 310f, 311 human. *See* Human embryonic development morphogenesis in, 1049 pattern formation of body plans in, 384, 385f–387f processes of, 1043f sequential gene regulation in, 383, 384f
 Embryonic lethals, **386**
 Embryonic stem (ES) cells, 431f
 Embryophytes, 619f–**620f**, 621
 Embryos. *See also* Embryonic development anatomical homologies of vertebrate, 479f, 480 plant, 620f maternal immune tolerance of, 1037 monocot vs. eudicot, 649f survival of, 1023f
 Embryo sacs, **646f**, **826**, 827f
 Emergent properties, **5**
 of apoptosis, 233 chemical waste and, 43 of compounds, 29f of flowers, 841 of gastrula, 1066 hierarchical organization of animal body plans and, 876 integration of Mendelian inheritance with, 282–283 levels of biological organization and, 4f–6 life as, 125 of protein function, 78 of sickle-cell disease, 505 of water. *See* Water weak chemical bonds and, 38
 Emerging diseases, 409f–412f, 1234
 Emigration, **1192**, 1196, 1197f, 1206f, 1207, 1256f
 Emotions, 1095f, 1096, 1106
 Emperor penguins (*Aptenodytes forsteri*), 873f
 Emu (*Dromaius novaehollandiae*), 739, 740f
 Enantiomers, **61f**–62f, 65
 Encephalitis, 401, 409
 ENCODE (Encyclopedia of DNA Elements), 446, 450
 Endangered species, 1199f, **1261**, 1262f, 1272f, 1288
 Endergonic reactions, 148, **149f**
 Endocarp, 832f
 Endocrine disruptors, 1015, 1276
 Endocrine glands, **1003**. *See also* specific glands of human endocrine system, 1004f in neuroendocrine signaling, 1007f–1008f regulatory functions of, 1011f–1015f, 1016
 Endocrine signaling, 1000f. *See also* Endocrine systems
 cascade pathways in, 1008, 1009f, 1010, 1014 in cell signaling, 215, 216f cellular response pathways for, 1002f–1003f feedback regulation of, 1005–1006 simple pathway of, 1004, 1005f
 Endocrine systems, **880**, **1000**. *See also* Animal hormones
 coordination of nervous systems and. *See* Neuroendocrine signaling disruption of, 1015, 1276 evolution of hormone function in, 1015f, 1016 feedback regulation of, 1005–1006 glands and hormones of human, 1003, 1004f hormone cascade pathways of, 1008, 1009f, 1010, 1014 hormones and cell signaling in, 880f nervous system coordination with, 1000f, 1001, 1006f–1008f in regulation of blood pressure, 931 in regulation of digestive systems, 915f regulatory functions of endocrine glands in, 1011f–1015f, 1016 signaling molecules, target receptors, and response pathways in, 1000f–1004f, 1018 simple endocrine pathway of, 1004, 1005f simple neuroendocrine pathway of, 1005f
 Endocytosis, 126, **139**, 140f, 141, 208f–209f

- Endoderm, **680, 1049**, 1050f–1051f
 Endodermis, **768, 792**, 793f
 Endomembrane system, **104**
 bound ribosomes and, 354f
 endoplasmic reticulum of, 104, 105f
 Golgi apparatus, 105, 106f, 107
 lysosomes, 107f, 108
 signal mechanism for targeting polypeptides to, 354f
 vacuoles, 108f
Endometriosis, 1033
Endometrium, 1026, 1027f
Endomyorrhizae, 656, 660, 663, **817**, 818f
Endoparasites, 1220
Endophytes, 667f, 668, 814
Endoplasmic reticulum (ER), 104, 109f
 animal cell, 100f
 as biosynthetic factory, 104, 105f
 cellular membrane synthesis and, 131f
 ribosomes and, 103f, 104
 in RNA virus replicative cycle, 405f
 targeting polypeptides to, 354f, 355
Endorphins, 40f, 78, 1081t
Endoskeletons, 1132f–1134f, 1133
Endosperm, 647, 826, 826, 827f–829f
Endospores, 575f
Endosymbiont theory, 109, 110f, 189, 534, 535f
Endosymbiosis, 109, 110f, 534, 535f, **594–595**, 596f–597f, 608f, 609, 617
Endothelin, 931
Endothelium, blood vessel, 929f
Endothermic organisms, 736, 884f, 885f–889f, 890–892
Endotoxins, 588
Energetic hypothesis on food chain length, 1225f
Energy, 32, 144
 allocation and use of, 889, 890f
 animal. *See* Bioenergetics
 in arctic tundra ecosystem, 1256f–1257f
 ATP energy coupling and, 150, 151f–153f
 biofuel technology to reduce dependence on fossil fuels for, 838
 chemical, 144, 889, 890f
 chemiosmosis as energy-coupling mechanism, 175, 176f, 177
 conservation of, 1239
 in ecosystems, 1238f–1240f, 1241
 electrons and levels of, 32f, 33–34
 in energy flow and chemical cycling, 164f, 165
 enzymatic catalysis and. *See* Enzymatic catalysis
 forms of, 144, 145f
 free-energy change and. *See* Free-energy change
 global human use of, 1210f, 1211
 heat as, 46
 hydrothermal vents, prokaryotes, and, 592
 kinetic, 46, 144, 145f, 163
 laws of transformation of, 145f–146f, 147
 light. *See* Light energy
 locomotion and, 1135–1136
 metabolism and. *See* Metabolism
 in photosynthesis, 41f
 potential, 32, 144, 145f, 163
 primary production of, 1241, 1242f–1244f, 1243t, 1245
 processing of, as theme of biology, 2, 3f
 regulation of storage of, in animal nutrition, 915, 916f, 917
 secondary production of, 1246f–1247f, 1248
 storage of, in fats, 74
 thermal, 46, 132, 144
 transfer and transformation of, as theme of biology, 9f, 143
 transformation of, 109, 110f–111f, 209f
 trophic levels and, 1240f, 1241, 1246, 1247f, 1248
Energy and matter
 bioenergetics, 163
 decomposition and, 1259
 eukaryotic cells and, 93f
 hibernation, 897
 photosynthesis and, 211
 reproductive success and, 1042
 as theme of biology, 2, 3
 transfer and transformation of, 9f
Energy budgets
 animal, 892
 ecosystem, 1241, 1242f
Energy conservation, animal, 892, 893f
Energy coupling, 150, 151f–153f
Energy flow
 in ecosystems, 1238f–1240f, 1241, 1256f–1257f
 between trophic levels, 1246f–1247f, 1248
Energy flow and chemical cycling, 9f, 164f, 165.
 See also Biogeochemical cycles; Primary production; Secondary production
Energy pyramids, 1246, 1247f, 1248
Engelmann, Theodor W., 193, 194f
English ivy, 784f
Enhancers, 374f–375f, 397
Entamoebas, 613
Enteric division, peripheral nervous system, 915, 1088f–1089f
Enthalpy, 147
Entomopathogenic fungus, 672
Entomophthora muscae, 662f
Entropy, 143, 146–147, 1239
Entry stage, phage lytic cycle, 402f
Enveloped viruses, 401, 405f
Environment
 adaptation to, 2f
 adaptive evolution as fitness to, through natural selection, 494, 498, 499f. *See also* Adaptive evolution
 animal and plant responses to, 894f
 behavior and stimuli from, 1140f–1141f
 biotechnology in cleanup of, 418f, 437
 bottleneck effect from changes in, 495f, 496
 cancer and factors of, 394–395
 C. Darwin on natural selection and adaptations to, 14f–16f. *See also* Adaptations; Evolution; Natural selection
 cell cycle control system and factors of, 247, 248f
 cellular membranes and factors of, 128f, 129
 Earth's early, and origin of life, 526f–528f
 ecology as interactions between organisms and. *See* Ecology
 enzymatic catalysis and factors of, 157, 158f, 159
 evolution and, 485
 exchanges with, in animals, 874, 875f, 876
 as factor in red maple leaf structure, 762
 gene regulation in response to, 377
 heat exchange with, in animals, 873f, 885f–889f
 hormones and, 1018
 human impacts on. *See* Human environmental impacts
 hybrid zones and, 517f
 impact of, on phenotypes, 282f
 induction in differential gene expression as response to, 382f, 383
 influence of evolution and, on nitrogenous wastes, 983
 interaction with, as theme of biology, 10f–11f
 metagenomics and genome sequencing of groups of species in, 444
 nervous system disorders and, 1102f
 organism interactions with, 1165, 1178, 1183f–1186f
 as organisms and their surroundings, 469
 plant responses to abiotic stresses from, 797–798, 862–863, 864f, 865
 population ecology as study of populations in, 1190f, 1191. *See also* Population ecology
 population growth in unlimited, 1196, 1197f
 prokaryotic adaptations to extreme conditions in, 573f, 574
 protein structure and factors of, 82f, 83
 reproductive cycles and cues from, 1021
 response to, as property of life, 3f
 strength of ionic bonds and factors in, 38
 vertebrate kidney adaptations to diverse, 991f–993f
Environmental issues. *See also* Climate change; Ecology; Pollution
 decline in amphibian populations, 733
 density-dependent population regulation by toxic waste, 1204f
 prokaryotes, biotechnology, and, 589, 590f–591f
 threats to biodiversity, 1260f, 1261, 1263, 1264f–1266f
 threats to seed plant diversity, 651f, 652
Environmental toxins, 1275, 1276f–1277f
Enzymatic catalysis. *See also* Enzymes
 activation energy barrier and, 153, 154f
 allosteric regulation of, 160f–161f
 of cellular respiration, 183f, 184
cofactors and, 158
 effects of temperature and pH on, 157, 158f
 in enzyme active sites, 156f
 enzyme inhibitors and, 158, 159f
 evolution of enzymes and, 159f
 graphing, for blood glucose levels, 157
 lowering of activation energy by enzymes in, 154, 155f
 in plant cells, 208f
 regulation of, 366f–369f, 370
 by ribozymes, 346
 substrate specificity of enzymes in, 155f, 156
Enzymatic hydrolysis, 904, 908f
neurotransmission and, 1079, 1080f
 in vacuoles, 108
Enzymatic proteins, 76f
Enzymes, 67, 153. *See also* Enzymatic catalysis
 active sites of, 155f–156f
 activity measurement of, 163
 as catalysts, 153
 in cell-signaling nuclear responses, 226, 227f
 in chemical digestion, 907f–908f, 909
 evolution of, 159f
 facilitation of synthesis and breakdown of polymers by, 67f
 fungal, 654–655
 in gastric juice, 907f–908f
 gene relationship with, in protein synthesis, 336f–338f
 inducible and repressible, 367f–368f, 369
 locations of, in cells, 161f
 lowering plasma LDL levels by inactivating liver, 938
 lysosomes and, 107f, 108
 as proteins, 75, 76f, 130f
 restriction. *See* Restriction enzymes
 ribozymes as, 346
 in saliva, 906
 smooth ER and rough ER, 104–105
 substrate specificity of, 155f, 156
 from *Thermus aquaticus*, 441
Enzyme-substrate complexes, 155f, 156
Eosinophils, 934f–935f, 955
Epéndymal cells, 1090f
Ephedra, 642f
Éphrussi, Boris, 336
Epiblast, 1052f–1053f
Épicotyl, 829f–830f
Epidemics, 409f, 410, 867
Epidemiology, 902
Epidermis, 5f, 763f
Epididymis, 1025f
Epigenetic inheritance, 372f, 373
Epigenetic modifications, cancer gene, 388, 389f
Epigenetics, 430
Epiglottis, 906f
Epilepsy, 1076, 1098
Epinephrine (adrenaline), 1002, 1003f
 adrenal glands and, 1004f, 1012f–1013f
 in fight-or-flight responses, 212f, 928
 multiple effects of, 1004f, 1013f
 second messenger of, 223f–224f
 signal transduction pathway of, 216, 226, 227f, 233
 as water-soluble hormone, 1001f
Epiphytes, 632f, 818, 819f, 820
Epistasis, 281f
Epithalamus, 1093f
Epithelial milk-secreting cell, 392f
Epithelial tissue, 877f
 as barrier defense, 954
 cell junctions in, 120f
 in small intestine, 909f
 transport, 981, 982f, 988f, 989
Epitopes, 958, 959f, 969, 976
Épstein-Barr virus, 394
Equilibrium
 chemical. *See* Chemical equilibrium
 mechanoreceptors for sensing, 1112f–1116f
 population, 1203f
Equilibrium potential (Eion), 1071f
Equine encephalitis virus, 401
Equisetum, 632f, 633
Equus, 548, 549f
ER. *See* Endoplasmic reticulum
Erectile dysfunction, 1026, 1081–1082
Ergots, 669f

- ER lumen, 104
 Erosion, soil, 809f
 Errantians, 703f
 Errors, DNA replication, 327, 328f
 Erythrocytes (red blood cells), 82f, 500–501, 502f–503f, 878f, 934f–**935f**
Erythropoietin (EPO), 936
Erythropsidinium, 594f
Escherichia coli (E. coli) bacteria, 595
 binary fission in, 242, 243f
 DNA cloning and gene cloning of, 418f, 419, 589
 DNA packing in chromosomes of, 330–331
 DNA replication and repair in, 322f–327f
 genetic recombination and conjugation in, 579, 580f, 581
 genome size and number of genes of, 448t, 449
 as model organism, 22
 pathogenic strains of, 588
 rapid adaptive evolution of, 578f, 579
 regulation of gene expression in, 366f–369f, 370
 viral infection of, 401, 402f–403f
 viral phages in DNA research on, 316f, 317
 E site (exit site), 350f, 352f–353f
 Esophagus, **906f**, 908f
 Essential amino acids, **899f**
 Essential elements, 29t, 64, 809, **810f**, 811t
 Essential fatty acids, **899f**
 Essential nutrients, animal, **899f**, 900t–901t, 901f
 Estivation, 893
 Estradiol, 62f, 1003f, **1014**, 1015f, **1030**, 1032f, 1037f
 Estrogen receptor alpha (ER α), 392f–393f
 Estrogens, 62f, 376, 397, 1003f–1004f, **1014**, 1015f, 1030, 1032f, 1038, 1276
 Estrous cycles, **1033**–1034
 Estuaries, **1180f**, 1186
 Ethane, 59f
 Ethanol, 63f, 180f, 590, 1204f
 Ethene (ethylene), 59f
 Ethical issues
 on biotechnology, 438–439, 839–840
 on diagnosing fetal genetic diseases, 1039–1040
 on DNA technology, 24
 on gene therapy, 435
 on seed plant extinctions, 652
 on silencing gene expression in humans, 427
 Ethylene, 216, 846f, **852**, 853f–854f, 864f
 Etiolation, **843f**
 Euchromatin, 330f, **332**
 Eudicots, **649f**–650f, 761, 769f–770f, 828f–830f
 Eugenics, 435
 Euglenids, **601f**
 Euglenozoans, **600f**–601f
Euhadra species, 522
 Eukarya, domain, **12f**, 568, 569f, 585t, 594
 Eukaryotes. *See also* Animals; Fungi; Plants
 cells of. *See* Eukaryotic cells
 chemiosmosis in, 175, 176f, 177
 cilia in, 13f
 electron transport chains in, 168–169
 endosymbiosis in evolution of, 594–595, 596f–597f
 Eukarya, domain, **12f**, 568, 569f, 585t, 594
 genome sizes and number of genes for, 448t, 449
 origins of multicellular, 533f, 535f–536f
 origins of single-celled, 533f–535f
 photosynthesis of unicellular, 188f
 phylogenetic tree of, 612f
 protists as single-celled, 594. *See also* Protists
 taxonomy of, 568, 569f
 unikonts as first to diverge, 612f
 Eukaryotic cells, **6**, **97**. *See also* Cells
 animal and plant, 100f–101f. *See also* Animal cells;
 Plant cells
 cellular integration of, 121f
 chromatin packing in chromosomes of, 330f–332f
 combinatorial transcription control for types of, 374–375, 377f
 cytoskeletons of, 112f–117f
 distribution of chromosomes in cell division of, 235f–236f, 237
 DNA replication in, 322, 323f
 in embryonic development, 381f, 382
 endomembrane system of, 104, 105f–109f
 evolution of cell division of, 243, 244f
 expressing cloned eukaryotic genes in, 422–423
 extracellular components and connections between, 118f–120f
 genetic instructions in nucleus of, 102, 103f
 internal membranes and organelles of, 93f, 98f, 99, 100f–101f
 mitochondria, chloroplasts, and peroxisomes of, 109, 110f–112f
 organization of typical genes in, 373f
 origins of, 534, 535f
 plasma membranes of, 98f, 99
 prokaryotic cells vs., 6f, 97f–98f, 99. *See also* Prokaryotic cells
 regulation of gene expression in. *See* Eukaryotic gene regulation
 replication of DNA telomeres of, 328, 329f
 ribosomes as protein factories of, 102, 103f, 104
 RNA processing in, 345f–347f
 transcription and translation in, 339f, 342, 343f–344f, 356f. *See also* Translation volume and surface area of, 98f, 99
 Eukaryotic gene regulation. *See also* Gene regulation
 analyzing DNA deletion experiments on, 376
 differential gene expression in, 365f, 370f, 371. *See also* Differential gene expression
 post-transcriptional regulation in, 377, 378f, 379
 regulation of chromatin structure in, 371f–372f, 373
 regulation of transcription initiation in, 373f–378f, 379
 Eukaryotic genomes
 evolution of, from DNA changes, 454f–457f, 458–459
 genes and multigene families in, 452, 453f
 horizontal gene transfer in, 569, 570f
 noncoding repetitive DNA sequences in, 450f–451f, 452
 sizes and number of genes for, 448t, 449
 Eumetazoans, **683f**, 686, 691
 Euphorbs, 1172f
 European flycatchers, 519
 European hamster (*Cricetus cricetus*), 893f
 European honeybees, 1142f
 European kestrels, 1201f
 European larch, 643f
 European Molecular Biology Laboratory, 444
 European robin, 14f
 European starling, 1264
 Euryarchaeota clade, 586
 Euryhaline animals, 978
 Eurypterids, **708**
 Eustachian tube, **1113f**
 Eutherians (placental mammals), 481f, 543f, 744f–747f. *See also* Primates
 Eutrophication, 1227f, **1242**, 1275f
 Eutrophic lakes, **1179f**
 Evaporation, 46f, 47, **885f**, 886
 in water cycle, 1250f, 1259
 Evaporative cooling, **47**, 48f
 Evapotranspiration, **1232f**
 in water cycle, 1250f
 Even-toed ungulates, 481f–482f
 Evergreen trees, 643f
 Evidence
 fossils as, for evolution, 13f
 scientific data as, 17f, 19f
 theories and, 21–22
 Evo-devo. *See* Evolutionary developmental biology
 Evolution, **11**, **469**. *See also* Adaptations; Natural selection
 abiotic synthesis of organic molecules as origin of life on Earth, 57f, 58
 of action potentials, 1084
 altered DNA nucleotides as mutations in, 328
 of alternative carbon fixation mechanisms in plants, 203
 of amniotes, 735f
 of anatomical and molecular features, 485
 of angiosperms, 647f–649f
 of animals, 675f–677f, 678–679
 of animal size and shape, 874f
 of antifreeze proteins, 865
 of arthropods, 706f, 707
 of ATP synthase, 186
 of axon width and myelination, 1076f–1077f
 of behaviors by associative learning, 1146
 bilateral phylogenetic tree, 717
 biochemical pathways, 163
 of biological diversity. *See* Biodiversity
 of biological order, 147
 of bryophytes, 635
 of cell cycle, 252
 of cell signaling, 213f, 214, 233
 cellular structures in, 125
 of cellular water regulation, 142
 of chewing while breathing, 920
 of chordates, 722f
 cladistic analysis and, 572
 classification of diversity of life and, 12f–13f
 of codons, 364
 coevolution of flowers and pollinators in, 825f
 of cognition in vertebrates, 1098, 1099f
 comparing genome sequences to study, 459, 460f–464f
 convergent. *See* Convergent evolution
 crossing over and, 313
 cross-species gene expression in, 423
 Darwinian theory of, as descent with modification by natural selection, 14f–16f, 469–470, 473f–476f, 483–484
 of differences in cellular membrane lipid composition, 129
 divergence of human globin genes during, 458
 DNA and proteins as measures of, 87, 89, 397
 DNA-based technologies and, 441
 of double circulation, 925
 of drug resistance, 435, 592
 early vertebrate, 724f–725f
 ecological change and, 1187f
 of ecological niches, 1215, 1216f
 ecosystem, 1259
 elemental makeup of organisms and, 43
 endosymbiosis in eukaryotic, 594–595, 596f–597f, 608f, 609
 environment and, 485
 of enzymes, 159f
 evidence supporting Darwinian theory of, 476, 477f–482f, 483
 evolutionary developmental biology “evo-devo” in study of, 387
 exaptation, 783
 of extraembryonic membranes in amniote development, 1053f, 1054
 extremophiles and, 55
 field research by C. Darwin on, 471, 472f–473f
 of fishes, 730
 of flowers, 825f
 of foraging behaviors, **1148**, 1149f
 of fungi, 659f, 660
 of fungus-alga symbiosis, 672
 of gas exchange, 947f–949f
 of gecko appearance, 26
 gene conservation in, 466
 of genes and genomes, 454f–457f, 458–459, 565f, 566
 genes shared between organisms, 26
 of genetic code, 341, 342f
 genetic variation and, of behavior, 1155f–1157f
 of genetic variation in populations, 266, 267f
 genomics and proteomics in study of, 88f
 of glycolysis, 182
 of gnathostomes and jaws, 725f, 726
 of gymnosperms, 641f
 of hermaphroditism, 1042
 of high-density populations, 1213
 historical context of Darwinian theory of, 469f–471f
 hominin and human, 748f–754f
 of hormone function, 1015f, 1016
 of human genome, 524, 566
 imperfections of organisms and, 505
 influence of environment and, on nitrogenous wastes, 983
 of insect size, 951
 of intelligence, 1106
 of intracellular receptors, 1018
 of introns, 346, 347f
 of kidneys, 991, 998
 of plants, 617, 618, 619f, 621, 622t
 late-acting dominant lethal alleles, 293
 of life history traits, 1200, 1201f–1202f
 of life on planets with water, 50f
 light-sensitive germination, 871
 of lignin, 783
 of locomotion, 1163

- Evolution (continued)
- making and testing predictions of Darwinian, 483
 - of mammals, 741, 742^f
 - mass extinctions and, 653, 1287
 - of mitochondria and chloroplasts, 109, 110^f
 - of mitosis, 243, 244^f
 - molecular clocks and rates of, 566, 567^f–568^f
 - mutation rate and, 334
 - of mycorrhizae in plants, 817
 - natural selection and genetic variation from recombination of alleles in, 305
 - of nitrogen recycling in bacteria, 821
 - of pathogen detection by plants, 866
 - of pathogens that evade immune systems, 957, 971–972, 973^f, 973t, 974, 976
 - pattern and process aspects of, 470, 483
 - photorespiration and, 211
 - phylogenetic bracketing and, 572
 - phylogenies as history of, 554^f–556^f. *See also Phylogenies*
 - of plant secondary growth, 774
 - of plant self-compatibility, 841
 - of prokaryotic flagella, 576^f, 577
 - as property of life, 3^f
 - protein divergence and, 91
 - radiometric dating and, 32–33
 - rapid prokaryotic, 573, 578^f, 579
 - of reproductive method switch, 268
 - of reptiles, 736
 - of resource acquisition adaptations in vascular plants, 784^f–786^f, 787
 - reversals of, 756
 - of RNA interference, 380
 - of seeds in seed plant, 639
 - of segmentation, 1066
 - of sex reversal, 1020
 - sexual reproduction as enigma of, 1021, 1022^f
 - of short-term and long-term memory, 1100, 1101^f
 - sickle-cell disease and, 286^f, 287
 - silicon-based life and, 65
 - small population size and extinction vortex in, 1266, 1267^f
 - of smooth muscles, 1132
 - speciation as conceptual bridge between macroevolution and microevolution, 507, 523. *See also Macroevolution; Microevolution; Speciation*
 - species distributions and, 1183, 1189
 - of tetrapods, 730
 - as theme of biology, 2, 3, 11, 12^f–16^f
 - theoretical aspects of Darwinian, 483–484
 - of tolerance to toxic elements, 30^f
 - of transport cells in kelp, 804
 - tree of life and, 15^f–16^f
 - unity and diversity in, 13^f, 26
 - using protein data to test hypotheses on horizontal gene transfer in, 570
 - of vascular plants, 628^f–631^f
 - of vertebrate brain structure, 1091^f
 - of viruses, 406, 408, 411, 414
 - of visual perception, 1117^f–1119^f
 - Evolutionary developmental biology (evo-devo), 387, 463, 467, 544
 - Evolutionary lineage, 555, 556^f
 - Evolutionary trees, 474^f, 480^f. *See also Phylogenetic trees*
 - Exaptations, 548, 577, 783
 - Excavates, 597, 598^f, 600
 - Exchange surfaces, animal, 874, 875^f, 876
 - Excitatory postsynaptic potential (EPSP), 1078–1079
 - Excitement phase, sexual, 1034
 - Excretion, 978, 982, 984^f. *See also Excretory systems; Osmoregulation*
 - Excretory systems, 983
 - hormonal regulation of, 994^f–996^f
 - internal exchange surfaces and, 875^f
 - kidneys in mammalian and human, 985, 986^f–993^f
 - Malpighian tubules in, 985^f
 - metanephridia in, 985^f
 - nitrogenous wastes and, 977–978, 982^f–983^f
 - osmoregulation and, 977^f–982^f
 - processes of, 984^f
 - processing of blood filtrate by nephrons in, 987, 988^f, 989
 - protonephridia in, 984^f, 985
 - Executive functions, brain, 1098
 - Exercise, immune systems and, 971
 - Exercises, Scientific Skills. *See Scientific Skills Exercises*
 - Exergonic reactions, 148, 149^f, 154^f, 165
 - Exhalation, 944, 945^f
 - Exit tunnel, ribosome, 350^f
 - Exocrine glands, 1004
 - Exocytosis, 126, 139^f, 208^f–209^f
 - Exome, 434
 - Exons, 345^f–347^f, 346, 449, 456, 457^f, 488^f
 - Exon shuffling, 347^f, 457^f
 - Exoskeletons, 693, 1133
 - animal, 683
 - anthozoan, 693
 - arthropod, 707^f
 - chitin as structural polysaccharide in, 72^f
 - ectoproct, 698^f
 - in locomotion, 1132^f, 1133
 - Exotic species, 1264^f
 - Exotoxins, 588
 - Expansins, 848, 849^f
 - Experimental groups, 20, 21^f
 - Experiments, 17–21. *See also Case studies; Inquiry Figures; Research Method Figures; Scientific Skills Exercises*
 - Exploitation, 1217, 1218^f–1219^f, 1220
 - Exploration, 17^f
 - Explosive seed dispersal, 645^f
 - Exponential population growth, 1196, 1197^f, 1207^f, 1208
 - Expressed sequence tags (ESTs), 445–446
 - Expression vectors, 422
 - Extavour, Cassandra, 467
 - Extension, muscle, 1132^f
 - Extensively drug-resistant tuberculosis (XDR-TB), 589
 - External factors, cell cycle control system, 246, 247^f–248^f
 - External fertilization, 1022^f, 1023, 1151
 - Extinctions
 - of amphibians, 733
 - climate change and, 11
 - current rate of, 1261, 1262^f
 - of dinosaurs, 736
 - ecological factors affecting rates of, 538
 - in fossil record, 481, 529^f
 - global and local, 1262
 - global temperature and, 541^f, 542
 - human impacts on, 1261, 1262^f
 - introduced species and, 1264^f, 1287
 - island equilibrium model and, 1232, 1233^f
 - mass, 540^f–542^f, 1287
 - of molluscs, 702^f
 - resurrection of species after, 1266
 - of seed plant species, 651^f, 652
 - small population risks for, 1266, 1267^f–1268^f, 1269
 - speciation and, 520–523
 - Extinction vortex, 1266, 1267^f
 - Extracellular diffusion, 768
 - Extracellular digestion, 904^f–905^f
 - Extracellular matrix (ECM), 118, 119^f, 130^f, 1056
 - Extraembryonic membranes, 734, 735^f, 1052, 1053^f, 1054
 - Extranuclear genes, 311
 - Extreme halophiles, 585–586
 - Extreme thermophiles, 585^f, 586
 - Extremophiles, 55, 585^f, 586
 - Eyes. *See also Visual systems*
 - euglenid eyespot as, 601^f
 - evolution of, 547^f–548^f
 - evolution of light detecting organs and, 1117^f–1119^f
 - insect compound, 712^f, 894^f
 - vertebrate, 1118^f–1122^f, 1123
 - Eyespots, 601^f, 1117^f
- F**
- F₁ (first filial) generations, 271^f, 524
 - F₂ (second filial) generations, 271^f
 - Faceted eyes, arthropod, 1117^f, 1118
 - Facilitated diffusion, 135^f, 136, 209^f
 - Facultative anaerobes, 181, 582
 - FAD (flavin adenine dinucleotide), 172^f–173^f, 178
 - FADH₂, 172^f–173^f, 175, 178
 - Fagus grandifolia*, 1170^f
 - Fairy ring, mushroom, 666, 667^f
- Falling phase, action potential, 1074^f, 1075
- Familial cardiomyopathy, 357
- Families, taxonomy, 554, 555^f
- Family planning, 1208
- Family resemblance, genetics and, 254^f
- Family studies, 1102^f
- Family trees, 284^f, 285
- Far-red light, plant response to, 857^f
- Fas molecule, 233
- Fast block to polyspermy, 1045
- Fast-twitch fibers, 1131
- Fate maps, 1058^f–1059^f
- Fathead minnows (*Pimephales promelas*), 1276
- Fatigue, muscle, 1131
- Fats, 72
- absorption of, in small intestine, 910^f
 - animal heat exchange and, 885, 887^f
 - blood cholesterol and, 938
 - digestion and absorption of, 908^f–910^f
 - in egg yolks, 91
 - as fuel for catabolism, 182^f, 183
 - in glyoxysomes, 112
 - hydrocarbons in, 60, 61^f
 - as lipids, 72, 73^f, 74
 - oxidation of, during cellular respiration, 166–167
 - trans fats, 61
- Fat-soluble vitamins, 900^t
- Fatty acids, 72
- beta oxidation of, for catabolism, 182^f, 183
 - essential, 899^f
 - fats and, 72, 73^f, 74
- Fd, 198^f, 199
- Feathers, 738^f, 739
- Feather stars, 715^f
- Fecal microbial transplantation, 912
- Feces, 697, 832^f, 911, 1246^f
- Feedback, scientific, 19^f
- Feedback inhibition, 161^f, 183^f, 184, 366^f
- Feedback mechanisms, 397
- Feedback regulation, 10. *See also Regulation*
- of animal digestion, energy storage, and appetite, 914, 915^f–917^f, 918
 - of animal homeostasis, 881^f–883^f
 - Cambrian explosion and, 685
 - in density-dependent population growth, 1203
 - of endocrine systems, 1005–1006
 - of molecular interactions, 10^f
- Feeding mechanisms, 655, 902, 903^f
- Feet, bird adaptation to perching, 740^f
- Feline panleukopenia virus, 409
- Female condoms, 1038
- Female gametophytes, angiosperm, 826, 827^f
- Females
- autoimmune diseases in human, 971
 - fruit fly bias in sperm usage by, 1024^f
 - hormonal regulation of reproductive systems of human, 1032^f, 1033–1034
 - hormones of, 999^f, 1004^f, 1007^f, 1008, 1014, 1015^f
 - inactivation of X-linked genes in mammalian, 300^f
 - mate choice by, 499^f–500^f, 1151, 1152^f–1153^f, 1154
 - maternal immune tolerance of embryo and fetus during pregnancy, 1037
 - oogenesis in human, 1027, 1029^f
 - parental care by, 1151
 - parthenogenesis by, 697–698
 - reproductive anatomy of human, 1026, 1027^f
 - reproductive rates and, 1194, 1195^f, 1204^f, 1208,
 - 1213
 - sex chromosomes of, 298^f, 299
- Fermentation, 165
- anaerobic and aerobic respiration vs., 179–180
 - cellular respiration vs., 165, 181^f, 182
 - types of, 180^f, 181
- Fern galls, 678
- Ferns, 630^f–632^f, 633, 635, 637^f
- Ferredoxin (Fd), 198^f, 199
- Fertilization, reproductive, 258, 826, 1022, 1044. *See also Reproductive isolation*
- angiosperm double, 646^f, 647, 826, 827^f. *See also Pollination*
- in animal embryonic development, 1044^f–1046^f
- external versus internal, 1022^f, 1023
- gamete production and delivery in, 1023^f, 1024
- genetic variation from random, 266, 305
- in human life cycle, 254, 257^f, 258, 1035^f

- mechanisms preventing angiosperm self-fertilization, 834, 835f
meiosis and, 237
G. Mendel's techniques of plant, 270f–271f
offspring survival following, 1023f
parental care and internal vs. external, 1151
parthenogenic self-fertilization, 1020, 1021f
prezygotic barriers and, 508f–509f, 510
in varieties of sexual life cycles, 258f, 259
in vitro, 1039f
Fertilization, soil, 807–808, 983, 1244, 1275f
Fertilization envelope, 1045f, 1046f
Fertilizers, in nitrogen cycle, 1251f
Fescue grass, 1203
Fetal alcohol syndrome, 1036
Fetal testing, 288, 289f
Fetus, **1036**
 detecting disorders of, during pregnancy, 1039–1040
 gestation and birth of, 1035f–1037f
 maternal immune tolerance of, 1037
 Zika virus and, 409
Fever, 888, 889f, 956–957
F factor, **580f**, 581
Fiber cells, 764f
Fibers, muscle, 1130, 1131t
Fibrillanosema crangonycis, 661f
Fibrin, 936f
Fibrinogen, 936f
Fibroblast growth factor (FGF), 1062
Fibroblasts, 113t, 247, **878f**
Fibronectin, **119f**
Fibrous connective tissue, 878f
Fibrous proteins, 78
Fibrous root systems, 760
Ficedula species, 519
Fiddler crabs, 1141f
Fierer, Noah, 1223f
Fight-or-flight responses, 212f, 928, 1003, 1012f–1013f, 1089
Filamentous fungi, 659
Filaments, 879f
Filaments, flagellum, 576f, 577
Filaments, flower, **644f**
Filter feeders, **690f**, **903f**
Filtrates, **984f**, 987, 988f, 989
Filtration, **984f**
Fimbriae, 97f, **575**, 576f
Finches, 15, 16f, 21, 473f, 486f–487f, 498, 519, 1217f
Fingerprints, DNA, 436
Finland, 1227f
Fire, 1172, 1228, 1229f, 1244f
Firefly gene, 341, 342f
Fireweed, 636f
First law of thermodynamics, 143, **145f**, 146, 1239
Fishapod discovery, 730f, 731
Fishes
 adaptations of kidneys of, 992, 993f
 allopatric speciation in, 511f, 512
 in biomanipulation, 1227f
 changes in gene regulation of, 546f, 547
 differential gene expression in, 365f
 discovery of "fishapod" *Tiktaalik*, 730f, 731
 endangered or threatened, 1262
 flashlight, 397, 587f
 frequency-dependent selection in, 500, 501f
 gills for gas exchange in, 941f
 hearing and equilibrium in, 1116f
 hybrid zones of, 515f, 519f, 520
 lux genes in, 397
 osmoregulation in, 979f
 parental care in, 1151f
 parthenogenesis in, 1020
 plastic waste and, 1277
 protists as pathogens of, 614
 ray-finned, and lobe-finned, 728f–729f, 730
 sex determination of, 298f
 sex reversal in, 1020
 single circulation in, 924f
 thermoregulation in, 881f
Fish fraud, 89
Fission, **1020**
Fitness, relative, **497**
FitzRoy, Robert, 472
Fixed action patterns, **1140f**
Fixed alleles, 490, 496
Flaccid cells, **135**, **790**, 791f, 797f
Flagella, **114**
 in animal cell, 100f
 bacterial, movement of, 993f
 cilia vs., 115f
 dinoflagellate, 605f
 euglenozoan, 600f
 flagellated sperm, 619
 as microtubules, 114, 115f–116f
 in prokaryotic cell, 97f, 576f, 577
 in protistan cell, 101f
 stramenopile, 602f
Flagellated sperm, 619
Flagellin, 866
Flame bulbs, 694, 984
Flamingo (*Phoenicopterus ruber*), 14f, 740f
Flashlight fish, 397, 587f
Flattening, body surface area and, 695f
Flatworms
 characteristics of, 687f, 694, 695f–697f
 gastrovascular cavities of, 922f, 923
 hydrostatic skeletons of, 1133f
 nervous systems of, 1086f
 protonephridia of, 984f, 985
Flavin adenine dinucleotide (FAD), 172f–173f, 178
Flavin mononucleotide (FMN), 175
Flavoproteins, 175
Flemming, Walther, 237
Flesh-eating disease, 478f
Fleshy fruits, 645f
Flexion, muscle, 1132f
Flies, 712f, 825f
Flight, 710, 711f–712f, 736, 738f, 739, 1135–1136
Flightless birds, 506f, 507, 511, 739, 740f
Floating bladderwort (*Utricularia gibba*), 448t, 449
Floating fern, 813f
Floating of ice, 48f
Flooding, 1228
 plant responses to, 804, 864f
Floral meristems, 830
Florida, restoration projects in, 1254f
Florida Keys mangrove islands, 1233f
Florida Keys National Marine Sanctuary, 1273f
Florida red-bellied turtles (*Pseudemys nelsoni*), 884f
Florigen, **860f**
Flowering, 830
FLOWERING LOCUS T (FT) gene, 860f
Flowers, **644**, **823**
 adaptations of, that prevent self-fertilization, 834, 835f
 coevolution of pollinators and, 825f
 as emergent property, 841
 genetic control of formation and flowering of, 779f–780f
 hormonal control of flowering of, 860f
 monocot vs. eudicot, and pollination of, 649f
 photoperiodism and flowering of, 859f–860f
 pollination of, 822f–825f
 preventing transgene escape with genetically engineered, 839–840
 structure and function of, 644f, 645, 823f–824f
 trends in evolution of, 825f, 826
Flu. *See Influenza viruses*
Fluctuation, population, 1205f
Fluid feeders, **903f**
Fluid mosaic model, **127f**
Flukes, 687f, 696f
Fluorescence, 195f, 250
Fluorescence microscopy, 95f, 96
Fluoxetine, 1103
Flycatchers, European, 519
Fly death fungus, 662f
Flying fox bats (*Pteropus mariannus*), 1262f
Flying squirrels, 481f, 517
FMN (flavin mononucleotide), 175
Focusing, visual, 1122f, 1123
Folding, body surface area and, 695f
Folding, protein, 83
Folic acid, 372f
Foliose lichens, 668f, 672
Follicles, **1026**, 1027f
Follicle-stimulating hormone (FSH), 1004f, 1008f, **1030**, 1031f–1032f, 1033
Follicular phase, 1032f, 1033
Food. *See also Animal nutrition; Trophic structure*
 animal processing of, 902, 903f–905f
 in bioenergetics and metabolic rates, 889, 890f
 brown algae as human, 603
calories of, 46
climate change and quality of, 812
digestion of. *See Digestion; Digestive systems*
as fuel for catabolism, 182f, 183
as fuel for cellular respiration, 164f, 165
fungi as human, 670
genetically modified organisms (GMOs) as, 438–439, 837, 838f, 839–840
as limiting factor for human population size, 1211
plants as, for animals, 617, 619
population cycles and shortages of, 1205f, 1206
ray-finned fishes as human, 728
red algae as human, 609f, 610
seed plants as human, 651
Food chains, **1224f**–**1225f**, 1257f
 biological magnification in, 1275, 1276f
 energy loss along, 1246, 1247f, 1248
Food poisoning, 403, 588, 1080
Food vacuoles, 107f, **108**, 607f, 904
Food webs, 614, 615f, **1224f**–**1225f**, 1237
Foolish seedling disease, 851
Foot, mollusc, **699f**
Foot, sporophyte, **625**
forager gene, 1148, 1149f
Foraging behaviors, **1148**, 1149f, 1150, 1161
Foraminiferans (forams), 599f, **608f**
Forebrain, **1091f**–**1092f**
Forelimbs, mammalian, 479f
Forensic ecology, 1265f
Forensic science, 24f, 436, 437f
Foreskin, penile, 1026
Forest fires, 1228, 1229f, 1244f
Forests. *See also Deforestation*
 climate change effects on, 1245, 1282
 climate effects of, 1169f
 decomposition in, 1248
 northern coniferous, 1175f
 temperate broadleaf, 1176f
 tropical, 1173f
Formic acid, 28f
Fossil fuels
 biofuel technology to reduce dependence on, 838
 in carbon cycle, 1250f
 ecological footprints and, 1210f, 1211
 global climate change and, 204–205, 1278,
 1280f–1281f, 1282, 1283f
 humans and burning of, 11
 hydrocarbons as, 60
 nutrient cycling and, 1249f
 ocean acidification and, 53f, 54
 photosynthesis as source of, 188
 seedless vascular plants and, 633–634
Fossil record. *See also Fossils*
 angiosperms in, 647f, 648
 animals in, 675f–677f, 678–679
 arthropods in, 706f, 707, 710
 colonization of land in, 536, 537f
 ecological factors affecting evolutionary rates
 in, 538
 evidence in, for dinosaurs as ancestors of birds,
 564f, 565
 evidence in, for evolutionary change, 13f
 evolutionary trends in, 548, 549f
 forams in, 608f
 fungi in, 659f, 660
 geologic record and, 532f–533f
 gymnosperms in, 641f
 as history of life, 525, 529f
 molecular clocks and, 567
 origin of mammals in, 530, 531f, 532
 origin of multicellular organisms in, 533f,
 535f–536f
 origin of single-celled organisms in, 532f–533f
 plant origin and diversification in, 621, 622f
 seedless vascular plants in, 628f
 whales in, 525f, 526
Fossils, **470**. *See also Fossil record*
 amniote, 735f
 biogeography and, 482–483
 bird, 739f
 dating of, 529, 530f
 early *Homo*, 750–751, 752f
 of early vertebrates, 724f–725f
 as evidence for Darwinian evolution, 481f–482f
 evolutionary theories and, 470f
 of gnathostomes, 726f
 hominin, 748f–749f, 750

- Fossils (continued)
- Homo sapiens*, 753f, 754
 - horseshoe crabs as living, 708f
 - radiometric dating of, 32–33
 - reptile and dinosaur, 736
 - speciation patterns of, 520f, 521
 - tetrapod, 730f–731f
 - whisk ferns as living, 633
- Foundation species, 1214, 1226
- Founder effect, 494–495
- Fovea, 1122f, 1123
- Fox, 1238f, 1244, 1256f
- FOXP2* gene, 461, 462f
- F plasmids, 580f, 581
- Fragmentation, habitat, 1263, 1264f, 1270, 1271f
- Fragmentation, reproductive, 833, 1020
- Frameshift mutations, 358f, 359
- Franklin, Rosalind, 317, 318f, 320
- Fraternal twins, 1036
- Free energy, 147
- Free-energy change, 149f–150f, 152f
- Free energy of activation (activation energy), 153, 154f
- Free ribosomes, 103f, 104, 354f
- Freezing, 865
- Fregata magnificens*, 1139f
- Frequency-dependent selection, 500, 501f
- Freshwater animals, 979f, 992
- Freshwater biomes, 1177f–1178f
- habitat loss in, 1264
- Freshwater lakes, primary production in, 1242–1243
- Freshwater marshes, 1186
- Friction, locomotion and, 1135
- Fringe wetlands, 1179f
- Fringing reefs, 1182f
- Fritillaries, 1206f, 1207
- Frogs
- as amphibians, 719f, 732f–733f
 - axis formation in, 1060f
 - breathing in, 925
 - cell developmental potential in, 1060, 1061f
 - cell fate and pattern formation by inductive signals in, 1062f
 - cleavage in, 1048f, 1049
 - coloration of, 1218f
 - discovery of new species of, 1164f, 1185
 - embryonic development of, 381f
 - external fertilization of, 1022f
 - fungus parasites of, 669, 670f
 - gastrulation in, 1051f, 1052
 - mate choice among tree, 500f
 - metamorphosis of, 1015f
 - neurulation in, 1054f, 1055
 - nuclear transplantation in, 428, 429f
 - polyploidy in, 514
 - reproductive isolation in, 524
- Fronds, 632f
- Frontal lobe, 1085, 1097f, 1098
- Frontal lobotomy, 1098
- Frost-tolerant plants, 865
- Fructose, 68f–69f, 153, 155
- Fructose 6-phosphate, 186
- fru* gene, 1155
- Fruit flies
- courtship behavior of, 1155
 - hybrid sterility of, 522–523
 - model organism. *See Drosophila melanogaster*
 - molecular clock of, 567
 - reproductive isolation of allopatric populations of, 512f
- Fruiting bodies, 213f, 612f–613f, 663f–664f, 665t
- Fruitlets, 830, 831f
- Fruits, 645, 830
- angiosperm seeds as, 644, 645f
 - auxin in growth of, 849
 - dispersal of, 832f
 - in ecosystem interaction, 10f, 11
 - ethylene in ripening of, 854
 - gibberellins in growth of, 851f
 - structure and function of, 830f–831f
- Fruticose lichens, 668f, 672
- Frye, Larry, 128f
- Fuels
- bacteria in production of ethanol, 590
 - fossil. *See Fossil fuels*
 - genetic engineering of, using fungi, 671f
 - peat and coal, 627f, 633–634
 - seed plants as, 651
- Fumonisin, 839
- Function, structure and, 6
- Functional groups, 62f–63f
- Functional magnetic resonance imaging (fMRI), 1096f
- Fundamental niches, 1215, 1216f
- Fungi
- amphibian population declines due to, 733
 - ascomycetes, 663f–664f, 665f, 671f
 - basiidiomycetes, 665f–667f
 - body structure of, 655f–656f
 - cells of, 100f
 - chitin in, 72
 - chytrids, 661f
 - cryptomycetes, 661f
 - as decomposers, 188, 1240f
 - in domain Eukarya, 12f
 - expressing cloned eukaryotic genes in, 422–423
 - fungi plant toxin, 839
 - immune system recognition of, 952f
 - kingdom and domain mutualisms with, 813f
 - land colonization by, 536, 537f
 - maximizing surface area by, 695f
 - microsporidians, 661f
 - mucoromycetes, 663f
 - mycorrhizal, 621, 656f, 657, 787, 817, 818f
 - nutrient limitations and, 1244
 - nutritional and ecological roles of, 12f, 13, 655, 667f–670f
 - as opisthokonts, 613
 - origin and evolution of, 659f, 660
 - phylogeny and diversity of, 660f–667f
 - practical uses of, for humans, 670, 671f
 - relationship of, to unikont protists, 611–612
 - sexual and asexual life cycles of, 258f, 259, 657, 658f–659f
 - sympiotic associations of, 672
 - terrestrial adaptations of, 660
 - zoopagomycetes, 662f, 663
- Fungi kingdom, 12f, 568
- Furcifer pardalis*, 735f
- Fusarium*, 839
- Fusion, hybrid zone, 519f, 520
- Fynbos*, 1174f
- G**
- G_0 phase, 246, 247f
- G_1 checkpoint, 245f–247f
- G_1 phase, 237f
- G_2 checkpoint, 245f–247f
- G_2 phase, 237f–238f
- G_3P , 201, 202f, 206, 207f
- Gadus morhua*, 728, 979f
- Gage, Phineas, 1098f
- Gaia hypothesis, 1259
- Galactose, 68f, 368f
- Galápagos Islands, 15, 16f, 21, 472f–473f, 506f, 519
- Galdieria sulphuraria*, 569f
- Gallbladders, 909
- Gälweiler, Leo, 848f
- Gambusia hubbsi*, 511f, 512
- Gametangia, 625, 626f
- Gametes, 236, 255
- formation of, 269
 - human gametogenesis and, 1027, 1028f–1029f
 - production and delivery of, in animal reproduction, 1023f, 1024
 - production of, by meiosis, 237
 - in sexual life cycles, 255, 257
- Game theory, 1154f, 1159
- Gametic isolation, 509f
- Gametogenesis, human, 1027, 1028f–1029f
- Gametophytes, 620f, 823
- in alternation of generations, 258f
 - angiosperm, 826, 827f
 - brown algae, 603f, 604
 - of plants, 620f–621f, 624f–626f
 - sporophyte relationships with, in plants, 637f, 638
- Gamma-aminobutyric acid (GABA), 1081t, 1084
- Ganglia, 1069, 1086f
- Ganglia, planarian, 696f. *See also Cerebral ganglia*
- Ganglion cells, 1118f, 1120, 1121f
- Gap junctions, 120f, 215f
- Garden peas, G. Mendel's experiments with, 269f–276f
- Gargique, 1174f
- Garlic, 836f
- Garlic mustard (*Alliaria petiolata*), 818
- Garrod, Archibald, 336
- Garter snakes, 1155, 1156f
- Gas chromatography, 852
- Gases
- greenhouse, 11, 48, 53f, 1170
 - as neurotransmitters, 1081t, 1082
- Gas exchange, 939
- adaptations for, 947f–949f
 - amphibian, 732
 - arthropod, 707–708, 710f
 - breathing in, 925, 944, 945f–946f
 - chordate, 720
 - circulatory systems and, 921f–924f, 925, 947f.
- See also Circulatory systems*
- coordination of cardiovascular systems and. *See Cardiovascular systems*
- fish, 728
- gills for, in aquatic animals, 921f, 940f–941f
 - of insects, 951
 - ion movements and gradients and, 993f
 - in lungs, 924f, 925, 942, 943f–946f.
 - mammalian respiratory systems, 942, 943f–946f.
- See also Respiratory systems*
- partial pressure gradients in, 939
- plant and animal, 895f
- respiratory media in, 939t, 940
- respiratory surfaces in, 940
- shark, 726
- tracheal systems for, in insects, 941, 942f
- Gasterosteus aculeatus*, 481, 546f, 547, 1140f
- Gastric glands, 907f
- Gastric juices, 907f, 908, 915f
- Gastric ulcers, 912, 913f
- Gastrin, 915f
- Gastrodermis, 691f
- Gastropods, 542, 699, 700f–701f, 702
- Gastrotrichs, 688f
- Gastrovascular cavities, 691f, 922f, 923
- Gastrovascular cavity, 696f, 904f
- Gastrula, 674f, 1044, 1049, 1050f–1053f, 1066
- Gastrulation, 674f, 680, 1044, 1049, 1050f–1053f
- Gated channels, 135
- Gated ion channels, 1072f–1077f
- Gause, G. E., 1215
- Geckos, 26, 39, 1260f
- Geese, 886f, 1256f–1257f
- Gel electrophoresis, 420f
- GenBank, 444, 445f
- Gender, 298
- Genealogy, molecular, 87, 89
- Gene amplification, cancer gene, 388, 389f
- Gene annotation, 445–446
- Gene cloning, 418f, 419, 421, 422f
- Gene drive, 427
- Gene editing, 360, 361f
- Gene expression, 8, 84, 336. *See also Genes; Genetics*
- auxin and, 848
 - basic principles of transcription and translation in, 337, 339f
 - of brain development genes in lancelets and vertebrates, 722f
 - changes in, in macroevolution, 545f–546f, 547
 - of cloned eukaryotic genes, 422–423
 - control of plant cell differentiation and, 778f
 - differential. *See Differential gene expression*
 - DNA, RNA, and genes in, 8f
 - DNA technology in analysis of, 423, 424f–428f
 - DNA technology in silencing, 427
 - evidence for, in study of metabolic defects, 336f–338f
 - evolutionary significance of cross-species, 423
 - experiment on, for red maple leaf structure, 762
 - flowering and, 860f
 - as flow of genetic information, 335–336
 - gene concept and, 361–362
 - genetic code in, 340f–342f
 - interacting groups of, 425f–426f
 - interpreting sequence logos to identify ribosome binding sites in, 351
 - mutations in, 357f–358f, 359
 - nematode parasite control of host, 706
 - nucleic acids in, 84f
 - polypeptide synthesis via RNA-directed translation in, 347f–356f

- regulation of. *See* Gene regulation
- RNA modification after transcription by eukaryotic cells in, 345f–347f
- RNA synthesis via DNA-directed transcription in, 342, 343f–344f
- stages of, that can be regulated, 370f
- study of, by systems biology, 446, 447f–448f
- summary of eukaryotic transcription and translation in, 356f
- as transcription, 371. *See also* Transcription
- Gene families, 565f, 566
- Gene flow, **496**
- biological species concept and, 506–507, 508f–509f, 510f
 - as cause of microevolution, 496, 497f
 - Hardy-Weinberg equilibrium and, 492t
 - in macroevolution, 551
 - between Neanderthals and humans, 752f–753f
 - speciation and, 522
- Gene pools, **490f**
- General transcription factors, 373–374
- Generative cells, 646f, 826
- Gene regulation
- analyzing DNA deletion experiments on, 376
 - in bacterial transcription, 366f–369f, 370
 - cancer due to faulty cell cycle control in, 388, 389f–393f, 394–395. *See also* Cancer
 - changes in, in macroevolution, 546f, 547
 - differential gene expression and, 365f. *See also* Differential gene expression
 - in eukaryotic cells. *See* Eukaryotic gene regulation
 - faulty, in cloned animals, 430
 - noncoding RNAs in, 379, 380f, 381
 - of plant cell differentiation, 778f
 - in plant signal transduction pathways, 845
 - steroid hormones and, 1003f
 - in treehopper, 466
- Genes, **7, 84, 255**. *See also* Chromosomes; DNA; Genetics; Genomes
- activator binding to, 397
 - alleles as alternative versions of, 272. *See also* Alleles
 - animal developmental. *See* Hox genes
 - apoptosis, 230f
 - appetite regulation, 918
 - associated with cancer, 388, 389f
 - B cell and T cell diversity and rearrangement of, 960, 961f
 - calibrating molecular clocks of, 566, 567f
 - for color vision, 1122f
 - conservation of, 466
 - coordinately controlled, 366, 375–376
 - density of, in genomes, 449
 - divergence of human globin, during evolution, 458
 - DNA technology in determining functions of, 426, 427f, 428
 - duplication of, due to unequal crossing over, 455f
 - editing of, 426, 427f, 434–435
 - effects of developmental, 544f–545f
 - enzyme relationship with, in protein synthesis, 336f–338f
 - evolution of, 455–457f, 461, 462f, 565f, 566
 - extending Mendelian inheritance for, 278, 279f–282f. *See also* Mendelian inheritance
 - flower formation, 779f–780f
 - foraging, 1148, 1149f
 - gene expression and, 7f–8f, 361–362. *See also* Gene expression
 - genetic diversity and, 1263
 - genetic variation due to alterations of number or position of, 489
 - genomic imprinting and, 310f, 311
 - genomics, bioinformatics, and proteomics in study of, 9, 86, 87f
 - as hereditary units, 255
 - homeotic and *Hox*, 385f, 463f–464f, 545f, 546
 - homologous, 479–480
 - horizontal gene transfer of, 568, 569f–570f
 - Hox* genes, 1064
 - identifying linked or unlinked, 304
 - identifying protein-coding, 445f, 446
 - inheritance of organelle, 311f
 - jumping. *See* Transposable elements
 - linked, 301f–303f. *See also* Linked genes
 - locating, along chromosomes, 295, 296f–297f
 - in macroevolution of development, 545f–546f, 547
- mapping distance between, on chromosomes, 305f–306f
- maternal effect, egg-polarity, and *bicoid*, 386f–387f
- G. Mendel's hereditary factors as, 269–270
- meristem identity and organ identity, 779f–780f
- molecular homologies and, 558, 559f
- multigene families and, in eukaryotic genomes, 452, 453f
- notation system for, 295
- nucleic acids and, 84. *See also* DNA; Nucleic acids; RNA
- number of, in genomes, 448t, 449
 - olfactory, 1124
 - organization of typical eukaryotic, 373f
 - pseudogenes, 450
 - rearrangement of parts of, 456, 457f
 - regulation of. *See* Gene regulation
 - regulatory, 367f
 - sex-linked, 298f–300f
 - speciation and, 522f, 523
 - split, 345f–347f
 - study of, by systems biology, 446, 447f–448f
 - transcription factors for, 221
 - transcription of, during cell-signal response stage, 226f
 - transgenes, 436f
 - transplanting, into different species, 341, 342f
 - variability of, in genetic variation, 488
- Gene therapy, 426, **434f**, 1122f
- Genetically modified organisms (GMOs), **438**
- for fossil fuel dependency reduction, 838
 - gene cloning and, 419
 - for hunger and malnutrition reduction, 837, 838f
 - issues about, 438–439, 839–840
- Genetically modified (GM) organisms. *See also* Transgenic animals; Transgenic plants
- fungi as, 671
 - issues about, 839–841
 - plant biotechnology and genetic engineering of, 837, 838f
- Genetic code
- biotechnology and, 441
 - codons and triplet code of nucleotides as, 340f, 341
 - cracking of, 341f
 - of DNA, 7f–8f
 - evolution of, 341, 342f
 - as molecular homology, 479–480
 - in mutations, 357f–358f, 359
 - neutral variation and redundancy of, 488–489
 - as sequence of nitrogenous bases, 85
 - universality of, 16
- Genetic counseling, 287–288, 293
- Genetic disorders
- alkaptonuria, 336
 - biotechnology in diagnosis and treatment of, 433, 434f, 435
 - from chromosomal alterations, 306, 307f–309f
 - counseling for, 287–288, 293
 - diagnosing fetal, 1039–1040
 - dominantly inherited, 287f
 - ethics of testing for, 24
 - multifactorial, 287
 - mutations and, 357f–358f, 359
 - recessively inherited, 285f–286f, 287
 - sickle-cell disease. *See* Sickle-cell disease
 - testing for, 288, 289f, 290
- Genetic diversity. *See also* Genetic variation
- in biodiversity, 1261f
 - as factor in extinction vortex, 1266, 1267f
 - in human welfare, 1262, 1263f
 - prokaryotic, 578f–580f, 581, 583f
 - in small populations, 1266, 1267f–1268f, 1269
- Genetic drift, 492, **494f**–495f, 496, 551
- Genetic engineering, **416**
- of antifreeze proteins, 865
 - CRISPR-Cas9 system, 360, 361f
 - DNA technology tools for, 416, 418f–422f, 423
 - of ethylene signal transduction pathways, 854
 - fungi in, 671
 - of genetically modified organisms, 438–439.
 - See also* Genetically modified organisms
 - opposition to, 839–841
 - of “pharm” animals, 436f
 - plant biotechnologists, 837
- of plants. *See* Transgenic plants
- plant tissue culture and, 836
- prokaryotes in, 589, 590f–591f
- Genetic Information Nondiscrimination Act, 288
- Genetic maps, **305f**–**306f**
- Genetic markers, 427f, 434, 436, 437f, 441
- Genetic mutants in Scientific Skills Exercises, 918, 1095
- Genetic profiles, 434, **436**, 1194, 1195f
- Genetic prospecting, 583
- Genetic recombination, **302**
- identifying linked genes for, 304
 - of linked genes in crossing over, 302, 303f
 - natural selection and genetic variation from, 305
 - in prokaryotes, 579f–580f, 581
 - transposable elements and, 459
 - of unlinked genes in independent assortment of chromosomes, 302f
- Genetics, **255**. *See also* Genetic variation; Inheritance; Mendelian inheritance
- of blood cholesterol levels, 938
 - designing experiments using genetic mutants, 1095
 - in ecological forensics, 1265f
 - in estimating reproductive rates, 1194, 1195f
 - flow of genetic information in plant cells, 208f
 - of foraging behaviors, 1148, 1149f
 - genetic basis of animal behavior, 1155f
 - genomics and proteomics in, 86, 87f
 - inheritance of chromosomes and genes in, 255
 - interpreting data from experiments with genetic mutants, 918
 - of nervous system disorders, 1102f
 - Punnett square as tool in, 273f, 274
 - of sickle-cell disease, 502f
 - solving complex problems of, with rules of probability, 277–278
 - of speciation, 522f, 523
 - as study of heredity and hereditary variation, 255
 - vocabulary of, 274f
- Genetic sequences in Scientific Skills Exercise, 595
- Genetic testing
- biotechnology in, 433–434
 - for breast cancer predisposition, 394
 - fetal, 288, 289f, 1039–1040
 - identifying carriers, 288
 - newborn, 289–290
 - personal genome analysis, 433
- Genetic variation, **255, 487**
- chromosome activity and, 268
 - from crossing over and recombinant chromosomes, 265, 266f
 - evolutionary significance of, within populations, 266, 267f
 - extinction vortex and loss of, 1266, 1267f
 - in genetic diversity, 1261f. *See also* Genetic diversity
 - genetics as study of, 255. *See also* Genetics
 - from independent assortment of chromosomes, 265f
 - microevolution of populations and sources of, 487f–488f, 489
 - in migratory patterns, 1156, 1157f
 - molecular clocks and rates of, 566, 567f
 - natural selection and, from recombinant chromosomes, 305
 - phylogenetic tree branch lengths and, 561, 562f
 - preservation of, 500
 - in prey selection, 1155, 1156f
 - from random fertilization, 266
 - in sexual reproduction, 255
 - in small populations, 1266, 1267f–1268f, 1269
- Gene trees, **557f**
- Genomes, **8, 235**. *See also* Genes
- analyzing phylogenetic trees based on, to understand viral evolution, 411
 - animal phylogeny and, 682, 683f, 684
 - bioinformatics in analysis of, 444, 445f–448f
 - in cell division, 235
 - comparing, 459, 460f–464f, 676f
 - complete, 665, 722, 776
 - differential gene expression for identical, 370f, 371. *See also* Differential gene expression
 - evolutionary history in, 565f, 566
 - evolution of, from DNA duplication, rearrangement, and mutation, 454f–457f, 458–459

- Genomes (continued)
- gene density of, 665f
 - genetic testing of fetal, 1039–1040
 - genome-wide association studies of, 427f, 433
 - genomics, proteomics, and bioinformatics in study of, 9, 86, 87f, 443
 - horizontal gene transfer between, 568, 569f–570f
 - Human Genome Project and development of DNA-sequencing techniques for, 443f, 444
 - interpreting data from, and generating hypotheses, 657
 - nervous systems and, 1106
 - noncoding DNA and multigene families in eukaryotic, 450f–453f
 - p53* gene as guardian angel of, 390–391
 - personal analysis of, 433
 - prokaryotic, 577f
 - reference, 443
 - species with complete sequences of, 448t
 - variations in size, number of genes, gene density, and noncoding DNA of, 448t, 449
 - viral, 400, 401f–407f, 406t
 - widespread conservation of developmental genes in animal, 463f–464f
- Genome sequencing, 443f, 444, 447, 448f, 657
- genomics, bioinformatics, proteomics, and, 9
- Genome-wide association studies, **427**, 433
- Genomic data in Scientific Skills Exercise, 657
- Genomic imprinting, **310**f, 311, 372
- Genomics, **9**, **86**, **87**, **443**–444, 583
- cell signaling, cancer, and, 391, 392f–393f, 394
 - contributions of, 88f
 - cracking the genetic code, 341f
 - DNA sequence analysis, 8f, 9
 - genetic material in, 7f–8f
 - polyadenylation signal sequence, 345f
 - simple sequence DNA, 452
 - taxonomy and, 12f, 13
 - transcription termination, 344
 - transposable elements, 450f–451f, 452
- Genotypes, **274**
- DNA transformation and, 315
 - gene expression as link between phenotypes and, 335–336
 - genetic variation and, 487, 488f
 - heterozygote advantage and, 500
 - phenotypes vs., 274f, 282f, 283
 - proteins and, 335
 - relative fitness of, 497
- Gento penguin, 14f
- Genus (genera), **12**, **554**, **555**
- Geochemical cycles, 1249f–1252f
- Geoemyda spengleri*, 736f
- Geographical barriers, allopatric speciation and, 511f–512f, 513
- Geographic species distributions. *See* Species distributions
- Geologic record, 530f, 532f–533f
- Geospiza fortis*, 486f–487f, 1217f
- Geospiza fuliginosa*, 1217f
- Germ cells
- fate maps and, 1058f–1059f
 - human, 258, 1029f
 - telomerase and telomeres in, 329
- Germination
- gibberellins in, 851f
 - light-sensitive, 871
 - phytochromes in, 856, 857f
 - seedling development after, 829, 830f
 - strigolactones in, 855
- Germ layers, 680, **1049**, 1050f–1051f
- Gestation, **1034**, 1035f–1037f
- Ghost crabs, 709f
- Ghrelin, 917f
- Giant panda (*Ailuropoda melanoleuca*), 448t
- Giant sequoia tree, 774f
- Giant squid, 702
- Giardia intestinalis*, 598f, 600
- Gibberellins, 846t, 850, **851f**
- Gibbons, 89, 746f–747f
- Gibbs, J. Willard, 147
- Gibbs free energy, 147. *See also* Free-energy change
- Gigantism, 1009, 1010f
- Gills, 921f, 940f–941f
- annelid, 703
 - arthropod, 707
 - of axolotls, 921f
- crustacean, 709
- of fishes, 728f
 - mollusc, 699f
 - osmoregulation by, 979f
- Gill slits, 720f
- Ginkgos, 642f
- Giraffes, 931
- GLABRA-2* gene, 778f
- Glaciation
- ecological succession after, 1230f–1231f
 - seedless vascular plants and, 633
- Glacier Bay, Alaska, 1230f–1231f
- Glands, endocrine system. *See* Endocrine glands
- Glans, 1025f, **1026**
- Glanville fritillaries (*Melitaea cinxia*), 1206f, 1207
- Glass lizard, 553f–554f
- Glass sponge, 146f
- Glaucomys volans*, 517
- Glaucus atlanticus*, 686f
- Glia (glial cells), **879**f, **1069**f, 1076f–1077f, **1090**f
- Glioblastoma, 250, 447
- Global biogeochemical cycles, 1249
- Global carrying capacity, human population, 1209, 1210f, 1211
- Global change. *See also* Climate change
- atmospheric ozone depletion in, 1283f, 1284
 - environmental toxins in, 1275, 1276f–1277f
 - greenhouse gases and climate change in, 1278f–1283f
 - human impacts on, 1265, 1266f, 1274, 1275f–1283f, 1284
 - nutrient enrichment in, 1274, 1275f
 - as threat to biodiversity, 1265, 1266f
- Global climate change. *See* Climate change
- Global climate patterns, 1166f, 1167
- Global cooling, 633
- Global ecology, **1165**f. *See also* Ecology
- aquatic biomes in, 1177f–1182f
 - of biosphere. *See* Biosphere
 - effects of mass extinctions on, 542f
 - evolution and, 1187f
 - global climate in, 1166f, 1167
 - global human population size issues in, 1209, 1210f, 1211
 - human environmental impacts in. *See* Human environmental impacts
 - importance of mycorrhizae to, 818
 - ocean acidification in, 53f, 54
 - species distributions in, 1164, 1170f, 1178, 1183f–1186f
 - terrestrial biomes in, 1171f–1176f, 1189
- Global energy budget, 1241
- Global extinctions, 1262
- Global human population, 1207f–1209f
- Global net primary production, 1241, 1242f
- Global temperatures, extinction rates and, 541f, 542
- Global warming. *See* Climate change
- as ecosystem interaction, 11
 - fossil fuel burning and, 11
- Globigerina*, 599f
- Globin genes, human, 453f, 455, 456f, 458
- Globular proteins, 78
- Glomeromycetes, 663
- Glomerulus, **987**f
- Glottis, 906f
- Glucagon, **916**f, 917, 1004f
- Glucocorticoids, 1004f, 1012f, **1013**, 1018
- Glucose
- blood regulation of, 10f
 - enzymatic catalysis and, 153, 155, 157
 - as fuel for cellular respiration, 165–167
 - glucocorticoids and metabolism of, 1012f, 1013
 - homeostasis of, 915, 916f, 917
 - insulin regulation of, 1004f
 - as monosaccharide, 68f–69f
 - oxidation of, to pyruvate by glycolysis, 170f–171f
 - in photosynthesis, 41f, 190f, 206, 207f
 - in positive gene regulation, 369f, 370
 - in signal transduction pathways, 216
 - transport of, 132, 136
 - in treating diarrhea, 139
- Glucose 6-phosphatase, 157
- Glutamate, 233, 1081t, 1101f, 1120, 1121f
- Glutamic acid, 77f, 152f, 341f
- Glutamine, 77f, 152f
- Glyceraldehyde, 68f
- Glyceraldehyde 3-phosphate (G3P), **201**, 202f, 206, 207f
- Glycerol phosphate, 63f
- Glycine, 63f, 77f, 1081t
- Glycocalyx, 97f
- Glycogen, **71**
- in cell signaling, 216f, 226, 227f
 - in glucose metabolism, 915, 916f
 - in muscle contraction, 1128
 - as storage polysaccharide, 70f, 71
- Glycogen phosphorylase, 216–217
- Glycolipids, **131**
- Glycolysis, **168**
- ATP yield in, 177f
 - evolutionary significance of, 182
 - fermentation and, 180f
 - oxidation of glucose to pyruvate by, 170f–171f
 - as stage of cellular respiration, 168, 169f
- Glycolytic fibers, 1130–1131
- Glycoproteins, **105**, **131**
- in animal morphogenesis, 1056
 - in cellular membranes, 127f, 130f, 131
 - in extracellular matrix, 118, 119f
 - genetic engineering of, using fungi, 671
 - rough ER and, 105
 - viruses and, 400f, 405f, 407f
- Glycosidic linkages, **69**
- Glyoxosomes, 112
- Glyphosate, 838
- Gnathostomes, **725**
- derived characters of, 725f, 726
 - fossil, 726f
 - ray-finned fishes and lobe-fins as osteichthyans, 728f–729f, 730
 - sharks and rays as chondrichthyans, 726, 727f
 - tetrapods as, 730
- Gnetophytes, 642f, 647
- Gnetum*, 642f
- Goats, 436f
- Goatsbeard plants (*Tragopogon miscellus*), 514, 515f
- Goiter, 29, 1009
- Golden Rice, 838
- Goldenrod (*Solidago canadensis*), 812
- Golden spiny mouse, 1216f
- Golgi apparatus, 100f, **105**, 106f, 107, 109f, 131f, 208f, 405f
- Gonadotropin-releasing hormone (GnRH), 1014, 1030, 1031f–1032f, 1033
- Gonads, 237, 258, 1004f, 1014, 1015f, **1023**
- Gonorrhea, 576, 584f, 1039
- Gonsalves, Dennis, 757
- Gonyosoma oxycephala*, 1053f
- Goodall, Jane, 17f
- Gorillas, 87, 89, 746f–747f
- Gormley, Andrew, 1191f
- Gout, 983
- GPCRs (G protein-coupled receptors), 217f–219f, **218**, 220, 224f, 1124
- GPP. *See* Gross primary production
- G protein-coupled receptors (GPCRs), 217f–219f, **218**, 220, 224f, 1124
- G proteins, **218**, 224f
- Graded potentials, **1072**, 1073f, 1078
- Gradients, solute, 989, 990f, 991
- Gradual model of speciation, 520f, 521
- Grafting, plant, 835–836
- Gram (unit), 50
- Gram, Hans Christian, 574
- Gram-negative bacteria, **574**, 575f, 584f
- Gram-positive bacteria, **574**, 575f, 584f
- Gram stain technique, **574**, 575f
- Grant, Peter and Rosemary, 21, 487
- Granum, **110**, 111f, 189f
- Grapefruit, 645f
- Grapes, 851f
- Grapes of Wrath, The* (book), 807f
- Graphs in Scientific Skills Exercises
- bar, 23, 179, 376, 483, 590, 629, 700, 762, 864, 1186, 1217
 - comparing two variables on a common x-axis of, 972
 - estimating quantitative data from, 538
 - histograms, 250, 283, 938
 - interpreting changes in slope in, 1049
 - line, 33, 157, 264, 411, 972, 1049, 1095, 1136, 1186, 1279
 - with log scales, 1136

- pie charts, 892
 scatter plots, 54, 136, 205, 513, 751, 1217
 sequence logos, 351
- Grass, phototropism in coleoptiles of, 847f, 848
- Grasshoppers, 464f, 710f, 712f, 905f, 923f, 942f, 1132f
- Grasslands, 783, 1175f
- Grassy stunt virus, 1263
- Graves' disease, 1010
- Gravitational motion, free energy and, 148f
- Gravitropism, **861f**
- Gravity
- axis formation and, 1060
 - blood pressure and, 931f–932f, 951
 - locomotion and, 1135
 - mechanoreceptors for sensing, 1112, 1115f
 - plant responses to, 861f
- Gray matter, **1087f**
- Gray tree frogs (*Hyla versicolor*), 500f, 514
- Great auk, 1264–1265
- Great Barrier Reef, 1282
- Greater bilby, 743f
- Greater prairie chickens (*Tympanuchus cupido*), 495f, 496, 1267f
- Great Salt Lake, 142, 585
- Great tits (*Parus major*), 740f
- Green algae, 101f, 596f, 599f, **610f**–611f, 614, 617, 618, 619f, 621, 663, 668f–669f
- Green fluorescent protein (GFP), 342f
- Greenhouse effect, **1278f**
- Greenhouse gases, 11, 48, 53f, 1170, 1278f–1283f
- Greening, plant, 843f–844f, 845
- Green manure, 817
- Green parrot snake, 1218f
- Griffith, Frederick, 315f
- Grizzly bears (*Ursus arctos*), 510f, 1268f, 1269, 1272–1273
- Grolar bears, 510f
- Gross primary production (GPP), **1241**, 1242f
- Ground meristem, 766
- Ground squirrels, 893, 1156, 1158, 1159f, 1193t, 1194f, 1195, 1213
- Ground tissue system, plant, 758, **763f**
- Groups, control and experimental, 20, 21f
- Growth. *See also* Plant growth
- as cell division function, 235f, 776, 777f
 - heterochrony and differential rates of, 544f–545f
 - hormonal regulation of, 1004f, 1009, 1010f
 - plant and animal, 894f
 - as property of life, 3f
 - vegetative, 830
- Growth, population. *See* Population growth
- Growth factors, **247**
- in cell cycle control system, 247, 248f
 - cell fate and, 1062–1064
 - in cell-signaling nuclear responses, 226f
 - induction and, 383
 - as local regulators in cell signaling, 215f, 216
- Growth hormone (GH), 1004f, 1008f, **1009**–1010
- Growth rings, tree, 773f
- Grus* species, 1144
- GTP (guanosine triphosphate), 172f–173f, 218f, 352f–353f
- GTPase, 229
- Guanine, 84, 85f, 86, 317f, 318, 341f
- Guano, 983f
- Guanosine triphosphate (GTP), 172f–173f, 218f, 352f–353f
- Guard cells, **763**, 770, 771f, 797f, 798
- Guichon Creek, 1274f
- Gulf of Carpentaria, 605f
- Gulf of Mexico dead zone, 1275f
- Gulf Stream, 1168f
- Gulls, 898f, 1151f
- Guppies (*Poecilia reticulata*), 483, 1152, 1153f, 1187f
- Gurdon, John, 428, 429f, 432
- Gustation, **1123f**–1124f
- Gutenberg, Johannes, 24
- Guttation, **793f**
- Gymnosperms, **623f**
- evolution of, 641f
 - evolution of seeds in, 639
 - gametophyte-sporophyte relationships in, 637f, 638
 - life cycle of pine and, 640f, 641
 - ovules and production of seeds in, 638f
 - phylogeny of, 622t, 635, 641, 642f–643f
- Gymnothorax dovi*, 729f, 1214f
- Gynandromorph, 313
- Gyres, ocean, 1168f
- H**
- H1N1 virus, 410–411, 1234
- H5N1 virus, 410, 1234, 1235f
- Habitat
- carrying capacity of, 1197, 1198f–1199f, 1198t, 1200
 - critical, 1269f–1270f
 - destruction of, in tropical rain forests, 651f, 652
 - fragmented, 1263, 1264f, 1270, 1271f
 - island, 1232, 1233f
 - loss of, as threat to biodiversity, 1263, 1264f
 - nitrogenous wastes and, 982f–983f
 - of red-cockaded woodpecker, 1269f–1270f
 - sympatric speciation and differentiation of, 515–516
- Habitat isolation, 508f
- Hadean eon, 530f, 532f–533f
- Haemophilus influenzae*, 448f
- Hagfishes, 719f, **723f**
- Haikouella*, 724f
- Hair, mammalian, 741, 920
- Hair cells, 1112, 1113f–**1114f**
- Hair color, polygenic inheritance, 281
- Hairy-cap moss, 626f
- Hakea purpurea*, 783
- Haldane, J. B. S., 526, 1158
- Half-life, **32**, **529**, 530f
- Hall, Jeffrey, 883
- Hallucigenia*, 706f
- Halobacterium*, 585
- Hamilton, William, 1157–1158
- Hamilton's rule, **1158f**–1159f
- Hammerhead shark, 890f
- Hamsters, 893f, 1095
- Hansen's disease, 65
- Haplodiploid sex determination system, 298f
- Haploid cells, **257**, 258f, 259
- Haplotypes, 466
- Haptophyte, 597f
- Hardy-Weinberg equation, 490–493
- Hardy-Weinberg equilibrium, 489, **490f**–491f, 492t, 493
- Hares, 1205f
- Haustoria, 656f
- Hawaiian Islands, 513, 543f, 544
- Hawaiian silversword plants, 543f, 558, 1183
- Hawkmoth, 825f, 869f, 1218f, 1219
- Hazel, 824f
- Hazel dormouse (*Muscardinus avellanarius*), 893f
- Hazelnut, 645f
- Head end, 680f
- Head, insect, 710f
- Head structure morphogen, 386f–387f
- Hearing, 1112f–1116f
- Heart attacks, 418f, 436, **937f**, 938–939
- Heartbeat rhythm, 928f
- Heartburn, 908
- Heart disease, 217, 418f, 428, 433, 436. *See also* Cardiovascular diseases
- Heart murmurs, **928**
- Heart rate, **927**, 928f
- Hearts, **923**
- atrial natriuretic peptide hormone released by, 996f
 - cardiac cycle of, 927f–928f, 930, 951
 - in circulatory systems, 923f–924f
 - effects of adrenal hormones on, 1012
 - insect, 710f
 - location of, for human embryo, 1043f
 - mammalian, in cardiovascular systems, 926f–928f
 - mollusc, 699f
 - regulation of rhythmic beating of, 928f
- Heartwood, 774f
- Heat, **46**, **143**–**144**
- as by-product of cellular respiration, 178
 - carbon dioxide and, 11
 - diffusion and, 132
 - metabolic rate and loss of, 890f
 - plant response to stress of, 865
 - temperature vs., 46
 - thermophiles and, 585f, 586
 - thermoreceptors and, 1111f
- Heat exchange adaptations, animal, 885f–889f
- Heat of vaporization, **47**
- Heat-shock proteins, **865**
- Heavy chains, **958f**–961f
- Heavy metals, bioremediation of, 1253, 1255f
- Hector's dolphins, 1191f, 1192
- Hedgehog growth factor, 1063–1064
- Height, polygenic inheritance, 281
- Heimlich maneuver, 906
- HeLa cancer cells, 248–249, 252
- Helianthus* species, 521f
- Helical viruses, 400f
- Helicases, **323f**, 326f, 327t
- Helicobacter pylori*, 584f, 912, 913f
- Helium, 30f, 35
- Helper T cells, **963**, 964f
- Hemagglutinin gene, 410–411
- Heme group, 175
- Hemichordata, 689f
- Hemings, Sally, 437
- Hemiptera, 712f
- Hemispheres, brain, 1093f, 1098, 1106
- Hemizygous organisms, 299
- Hemochromatosis, 920
- Hemocoel, **681f**, 697, 707, 717
- Hemocyanin, 947
- Hemocytes, 953
- Hemoglobin, **935**
- α -globin and β -globin gene families and, 453f, 455, 456f
 - in circulation and gas exchange, 947f–948f
 - cooperativity as allosteric regulation in, 160–161
 - dissociation curves of, 948f, 951
 - in erythrocytes, 935
 - as measure of evolution, 87, 89
 - polypeptides in, 337
 - as protein, 76f
 - protein quaternary structure and, 81f
 - sickle-cell disease and, 82f, 286f, 287, 500–501, 502f–503f, 505
- Hemolymph, 681, 707, **923f**, 981, 985f
- Hemophilia, **300**, 433, 936
- Hemorrhagic fever, 409
- Henslow, John, 472
- Hepatic portal veins, **910**
- Hepatitis B virus, 409, 974
- Hepatophyta (liverworts), 620f, **623**, 626f
- HER2 breast cancer, 220, 250, 392f–393f
- Herbicide resistance, 438
- Herbicides
- auxin in, 849
 - transgenic, 837–838
- Herbivores, **901**
- alimentary canals of, 912f
 - animals as, 673f
 - as biotic factors limiting species distributions, 1184f
 - dentition and diet in, 911f, 912
 - energetic hypothesis and biomass of, 1225f
 - evolutionary links between plants and, 648, 649f
 - insects as, 713
 - mutualistic digestive adaptations of, 913, 914f
 - plant defenses against, 867, 868f–869f
- Herbivory, 551, **867**, 868f–869f, **1219f**, 1220, 1256f
- Herceptin, 220, 250, 393f
- Hereditary factors, genes as, 269–270, 294f. *See also* Genes
- Hereditary nonpolyposis colon cancer (HNPCC), 394
- Hereditary variation, **255**. *See also* Genetic variation
- Hereditiy, **255**, 269–270. *See also* Inheritance; Mendelian inheritance
- Hermaphrodites, **691**, 705
- Hermaphroditism, **1020**, 1042
- Heroin, 40, 78, 1103f
- Herpes simplex viruses, 973t
- Herpesviruses, 405, 409, 973t
- Herring gull, 898f
- Hershey, Alfred, 316f, 317
- Heterochromatin, 330f, **332**, 371, 381
- Heterochrony, **544f**–**545f**
- Heterocysts (heterocysts), **582f**
- Heterokaryon mycelia, **658**
- Heteromorphic generations, **604**
- Heteroporous species, **631**, 638
- Heterotrophs, **188**, 581t, 594, 655, 673–674, 889, 894f, 1240f
- Heterozygote, **274**
- Heterozygote advantage, **500**, 501f–503f

- Heterozygote protection, 488
 Heterozygous organisms, **274**
Hexapoda, 710. *See also Insects*
 Hexoses, 68f
Hfr cells, 580f, 581
 Hibernation, 178, **893f**, 897
 Hierarchical classification, 554, 555f
 High-density lipoproteins (HDLs), **937**–938
 Highly conserved genes, 460
 High-throughput DNA technology, 9, 415f–417f, 443f, 444, 447
 Hindbrain, 1085, **1091f**–1092f
 Hinge joints, 1134f
 Hippocampus, 1095f, 1100, 1101f
 Hippopotamus, 88f
 Hirudin, 704
Hirudinea, 703
 Histamine, 955f, **956**, 971
 Histidine, 77f
 Histograms in Scientific Skills Exercises, 250, 283, 938
 Histone acetylation, **371f**
 Histone modifications, 371f, 372, 391
 Histones, **330f**
 HIV (human immunodeficiency virus), **406**, **973**. *See also AIDS*
 AIDS and, 398f
 antiviral drugs and, 409
 applying molecular clock to origin of, 567, 568f
 attacks on immune system by, 973f, 974
 biotechnology in diagnosis of, 433
 CCR gene and, 435
 cell-surface proteins and blocking entry of, into cells, 130f
 as emerging virus, 409–410
 G protein-coupled receptors and, 217f
 host range of, 401
 rapid reproduction of, 489
 replicative cycle of, 407f
 as retrovirus, 406t
 HIV-1 M strain, 567, 568f
 Hoary marmot (*Marmota caligata*), 164f
 Hodgkin's disease, 971, **1263f**
 Hoekstra, Hopi, 20, 21f, 22, 26
 Holdfasts, **602**, 603f
 Holoblastic cleavage, 1048
 Holothuroidea, 715f
Homarus americanus, 979
 Homeoboxes, **463f**–464f, 675
 Homeodomains, 463
 Homeostasis, **881**. *See also Thermoregulation*
 of blood calcium levels, 1011f
 as feedback regulation of animal internal environment, 881f–883f
 of glucose, 915, 916f, 917, 1004f, 1012f, 1013
 hormonal regulation of kidneys for, 994f–996f
 of human breathing, 946f
 of macaques, 897
 of marine iguana, 998
 osmoregulation for, 977f, 978
 peripheral nervous system in, 1088–1089
 thyroid, 1008, 1009f, 1010
 Homeotherms, 884
 Homeotic genes, **385f**, 463f–464f, **545f**–**546f**, 547. *See also Hox genes*
 Hominins, **748**
 Australopiths, 749, 750f
 bipedalism in, 750f
 derived characters of, 748
 earliest, 748f–749f
 early *Homo* genus, 750–751, 752f
Homo sapiens, 753f–754f
 Neanderthals, 752f–753f
 tool use in, 750
Homo erectus, 752–753
Homo ergaster, 752f
Homo florensisis, 754
 Homogenization, 96f
Homo genus, 746f, 750–751, 752f–754f
Homo habilis, 750–752
 Homologies, **479f**–**481f**, **558f**–**559f**
 Homologous chromosomes (homologs), **256**
 alleles in, 259
 in chromosomal basis of Mendelian inheritance, 294f, 295
 human, 256f–257f
 in meiosis, 260f
 in mitosis vs. in meiosis, 262, 263f, 264
 Homologous genes, 565f, 566
 Homologous structures, **479f**–**481f**
Homo naledi, 753f, 754
Homo sapiens, 554, 665t. *See also Humans*
 Homosporous species, **631**, 638
 Homozygote, **274**
 Homozygous organisms, **274**
 Honeybees, 661, 824f, 887, 1142f, 1143, 1146, 1147f, 1156
 Honeypot ant, 485
 Hook, flagellum, 576f, 577
 Hooke, Robert, 94
 Hookworms, 705
 Hopping, 1138
 Horizontal cells, 1118f, 1120
 Horizontal gene transfer, 568, **569f**–**570f**, **579f**–**580f**, 581, 583, 588, 689f
 Horizontal transmission, viral, 412
 Hormonal proteins, 76f
 Hormone cascade pathways, 1008, 1009f, 1010, 1014
 Hormones, **215**, **846**, **1000**. *See also Animal hormones; Plant hormones*
 animal vs. plant, 215–216, 894f. *See also Animal hormones*
 coordinate control of genes by, 375–376
 environment and, 1018
 in fight-or-flight responses, 212
 as intracellular chemical signals, 220, 221f
 kidney regulation by, 994f–996f
 in long-distance cell signaling, 215f, 216
 specificity of, 227, 228f
 Hornworts, **623**, 626f. *See also Bryophytes*
 Horowitz, Norman, 336f–338f
 Horses, 548, 549f
 Horseshoe crabs, 707, 708f
 Horsetails, 630f–632f, 633, 635
 Horvitz, Robert, 1058–1059
 Hosken, David, 1024f
 Host cells, endosymbiont, 534, 535f
 Host ranges, viral, **401**
 Hosts, parasite, **1220**, 1234
 Hosts, symbiont, **587**
 Hot spots, biodiversity, 1272f
 Hot springs, 585f, 586
Hox genes. *See also Homeotic genes*
 as animal development genes, 463f–464f, 675
 arthropod body plan and, 706f, 707
 cell fate and, 1064
 jaws and, 725f, 726
 lancelet, tunicate, and vertebrate, 722f
 in macroevolution of development, 545f–546f, 547
 origin of, 677
 in plants, 778f
 in treehoppers, 466
 HTLV-1 virus, 394
 Hubbard Brook Experimental Forest, 1252f, 1266f
 Human body
 bacteria in, 587, 588f
 brain in nervous system of, 1085f, 1091f–1096f. *See also Brains; Nervous systems*
 circadian rhythms in thermoregulation of, 882, 883f
 digestive systems. *See Digestive systems*
 ears of, 1113f
 endocrine glands and hormones of, 1004f, 1007f–1008f. *See also Animal hormones*
 Endocrine systems; Nervous systems
 evolution of human eye, 547, 548f
 excretory systems of, 985, 986f–987f
 eyes of, 1118f–1119f
 glucose homeostasis in, 915, 916f
 heterochrony and differential growth rates in skulls of, 544f
 hypothalamus in thermoregulation of, 888, 889f
 locomotion by interaction of muscles and skeletons of, 1132f
 lymphatic system of, 956f
 mechanoreceptors in skin of, 1110f
 metabolic rates of, 891
 osmoregulation of, 980
 overnourishment, obesity, and, 917f, 918
 regulation of growth of, 1009, 1010f
 skeleton of, 1134f
 two-solute model of kidney function, 989, 990f, 991
 Human chorionic gonadotropin (hCG), 969, 1035
 Human embryonic development. *See also Animal development*
- brains in, 1092f
 cilia and cell fate in, 1064f
 conception, pregnancy, and birth in, 1034, 1035f–1037f
 embryo image, 1043f
 gastrulation in, 1052, 1053f
 maternal immune tolerance in, 1037
 neuron competition in, 1099–1100
 Human environmental impacts
 on biodiversity, 1260f, 1261
 biodiversity crisis, 1260f–1262f. *See also Biodiversity*
 biome disturbances, 1172
 climate change, 1278f–1283f
 community disturbances, 1228, 1231f
 global change, 1265, 1266f, 1274, 1275f–1283f, 1284
 habitat loss and fragmentation, 1263, 1264f
 introduced species, 1264f
 melting of Arctic sea ice, 48f
 ocean acidification, 53f, 54
 overharvesting, 1264, 1265f
 spread of pathogens, 1234, 1235f
 threats to biodiversity from, 1263, 1264f–1266f
 Human genetics
 dominantly inherited disorders in, 287f
 genetic testing and counseling in, 287–288, 289f, 290, 293
 molecular tags and karyotypes of chromosomes in, 332f
 multifactorial disorders in, 287
 pedigree analysis in, 284f, 285
 recessively inherited disorders in, 285f–286f, 287
 skin pigmentation and, 281, 282f
 Human genome
 α-globin and β-globin gene families in, 453f, 455, 456f
 comparing genomes of other species with, 454f–455f, 459, 460f–461f, 462
 complete sequence for, 443f
 evolution of, 524, 566
 function of *FOXP2* gene in, 461, 462f
 gene density of fungal vs., 665t
 microarray chips containing, 448f
 sequencing of, 443f, 444, 447, 448f
 size, number of genes, gene density, and noncoding DNA of, 448f, 449
 types of DNA sequences in, 450f
 Human Genome Project, 87, 347, **443**–444, 449
 Human growth hormone (HGH), 418f, 419, 436, 1009–1010
 Human immunodeficiency virus (HIV). *See HIV*
 Human nutrition. *See also Animal nutrition*
 assessing nutritional needs for, 902f
 bacteria in, 587
 dietary deficiencies in, 902f
 essential nutrients for, 899f, 900t–901t
 transgenic crops and, 438–439
 Human papillomavirus (HPV), 974f
 Human population
 density-dependent population regulation of, by diseases, 1204f
 global carrying capacity for, 1209, 1210f, 1211
 growth of, 1207f–1210f, 1211, 1213
 survivorship curves for, 1194f
 Human reproduction. *See also Animal reproduction*
 conception, embryonic development, and birth in, 1034, 1035f–1037f
 contraception and abortion in, 1037, 1038f, 1039
 endocrine disruptors and, 1015
 female reproductive organs of, 1026, 1027f
 gametogenesis in, 1027, 1028f–1029f
 hormonal regulation of, 1030, 1031f–1032f, 1033–1034
 male reproductive organs of, 1025f, 1026
 maternal immune tolerance of embryo and fetus in, 1037
 reproductive technologies and, 1039f, 1040
 sexual response in, 1034
 Humans (*Homo sapiens*). *See also Human body*
 Human embryonic development; Human environmental impacts; Human genetics; Human genome; Human nutrition; Human population; Human reproduction
 analyzing polypeptide sequence data for monkeys and, 87, 89
 as anthropoid apes, 746–747

- apoptosis of white blood cells of, 229f
biodiversity and welfare of, 1262, 1263f
biological species concept and, 507f
blood pH of, 52f, 53
blood pressure of, 931f
brown algae as food for, 603
catabolism and diets of, 182f, 183
chromosomes of, 102, 235, 236f, 237, 256f–257f, 258
cilia in windpipes of, 13f
circulatory systems of. *See* Cardiovascular systems
cloning of, 430
derived characters of, 748
determining gene function by analyzing genomes of, 427f, 433–434
digestive system of. *See* Digestive systems
DNA microarray assays on tissue of, 426f
DNA sequencing of genome of, 415f, 416
ecosystem interaction with, 11
essential elements and trace elements for, 29t
ethical issues on silencing gene expression in, 427
evolution of culture in, 1159f, 1160
fossils of, 753f, 754
gene flow with Neanderthals and, 752f–753f
genomics and proteomics in study of, 86, 87f
glycoproteins and blood types of, 131
as *Homo sapiens*, 748f, 749
importance of insects to, 713
importance of seed plants to welfare of, 651f, 652
inactivated olfactory receptor genes of, 489
lymphatic systems of, 933f
origin of, 533f, 537
overlap of Neanderthals and modern, 33
plastic waste and, 1277
practical uses of fungi for, 670, 671f
primate phylogenetic tree and, 746f
prokaryotic impacts on, 587, 588f–591f
red algae as food for, 609f, 610f
reducing hunger and malnutrition in, with transgenic crops, 837, 838f
regulation of breathing in, 946f
regulation of molecular interactions in, 10f, 11
relationship of Neanderthals and, 752f–753f
sex chromosomes of, 298f, 299
skulls of chimpanzees and, 558
small intestine surface area for, 695f
sustainable development in Costa Rica and living conditions of, 1284, 1285f
transgenic crops and health of, 839
urban, 1274
water gain and loss in, 998
- Humboldt Current, 1168f
Hummingbird hawkmoth, 712f
Hummingbirds, 6, 522, 740f, 825f, 869f
Humoral immune response, 957f, 963, 964f–967f
Humpback whales, 903f
Humus, 806–807
Hundred Heartbeat Club, 1262f
Hunger, transgenic crops and reducing human, 837, 838f
Huntington's disease, 287, 431–433
Hurricane Katrina, 1172
Hutton, James, 469f, 471
Hybrid breakdown, 509f
Hybridization, 271, 518, 837, 839–841
Hybrid orbitals, 39f, 40
Hybrids, 508
 bears, 510f
 DNA in, 524
 reproductive barriers and sterility of, 509f
 speciation rates and, 521f, 522
 sterility of, 522–523
Hybrid zones, 516, 517f–519f, 520
Hydrangea, 282f
Hydras, 255f, 687f, 691f–693f, 904f, 1086f
Hydration shells, 49f
Hydrocarbons, 60, 61f, 671f
Hydrocarbon tail, chlorophyll, 194f
Hydrochloric acid, 51, 907f, 908
Hydrogen
 covalent bonding and, 36f–37f
 dinitrophenol and, 186
 electronegativity of, 45
 electrons of, 35
 as essential element, 29t, 64
 in organic compounds, 59f
 oxidation of organic molecules containing, 166–167
 in plant composition, 809
 in saturated and unsaturated fats, 73f, 74
Hydrogen bonds, 39
 in DNA structure, 86f
 floating of ice and, 48f
 in water molecules, 44, 45f–46f
 as weak chemical bonds, 38, 39f
Hydrogen ions, 51, 52f, 53
Hydrogenosomes, 600f
Hydrogen peroxide, 112
Hydrogen sulfide gas, 540
Hydrolagus colleti, 727f
Hydrolysis, 67
 of ATP, 151f, 152
 disassembling of polymers to monomers by, 67f
 enzymatic, 904, 908f
 by lysosomes, 107f, 108
Hydrolytic enzymes, fungal, 655
Hydronium ions, 51, 52f, 53
Hydrophilic substances, 49–50, 127f
 amino acids as, 76, 77f
Hydrophobic interaction, 81f
Hydrophobic substances, 49–50, 127f
 amino acids as, 76, 77f
Hydroponic culture, 810f
Hydrostatic skeletons, 1133f
Hydrothermal vents, 526f, 585, 587, 592, 914f, 1182f
Hydroxide ions, 51, 52f, 53
Hydroxy group, 63f
Hydrozoans, 692f–693f
Hyla versicolor, 500f, 514
Hylonomus, 735f
Hymen, 1026
Hymenoptera, 712f
Hypercholesterolemia, 139
Hypermastigote, 614f
Hyperosmotic solutions, 977–978, 991
Hyperpolarization, 1072f–1073f
Hypersensitive response, plant, 866, 867f
Hypertension, 939
Hypertonic solutions, 134f
Hyphae, fungal, 654, 655f–656f, 818
Hypoblast, 1052f–1053f
Hypocotyl, 829f–830f
Hypoosmotic solutions, 977–978
Hypothalamus, 888, 1004f, 1007, 1093f
 in homeostasis, 1088–1089
 in human brain, 1093f
 in kidney regulation, 994f–995f
 in neuroendocrine signaling, 1007f–1008f
 in regulation of mammalian reproduction, 1030, 1031f–1032f
 in stress responses, 1012f
 suprachiasmatic nucleus (SCN) in, 893f, 1015, 1094–1095
 in thermoregulation, 888, 889f
Hypotheses, 17. *See also* Inquiry Figures; Scientific Skills Exercises
 forming and testing of, in science, 17, 18f–19f
 phylogenetic trees as, 564f, 565
 theories and, 21–22, 483–484
Hypothyroidism, 1010
Hypotonic solutions, 134f
Hyracoidea, 745f
Hyracotherium, 548, 549f
- I**
- Ibex, 1266
Ibuprofen, 62f, 1001, 1013–1014, 1112
Ice
 floating of, on liquid water, 48f
 fossils in, 529f
 on Mars, 50f
 as solid water, 44
Icosahedral viruses, 400f, 401, 408, 412
Identical DNA sequences, 453f
Identical twins, 1036, 1061, 1162
Idioblasts, 868f
IgE antibodies, 970f
Iguanas, 888, 998
Ileum, 909
Imaging, brain, 1085f, 1096f
Imaging techniques, fetal testing, 289
Imatinib, 435
Imbibition, 829
Immigration, 1192, 1196, 1197f, 1206f, 1207, 1256f
 island equilibrium model and, 1232, 1233f
Immune defenses, plant, 866
Immune response
 overview of, 957f
 pathogen trigger of, 952f
 primary and secondary, 962, 963f
 trypanosome evasion of, 600–601
Immune systems, 953
 adaptations of pathogens to evade, 957, 971–972, 973f, 973t, 974, 976
 adaptive immunity defense against infection in, 963, 964f–969f, 970
 apoptosis in, 233
 diseases of, 229
 disruptions of, 970f–974f, 973f
 HIV/AIDS and, 398f, 406. *See also* AIDS; HIV
 immune rejection by, 969–970
 immunization and, 968f, 976
 innate immunity in, 952f–957f
 leukocytes in, 934f–935f
 lymphatic systems and, 933f
 maternal immune tolerance of embryo and fetus during pregnancy, 1037
 membrane carbohydrate cell-cell recognition in, 130f–131f
 pathogen recognition in, 952f, 953, 957f–963f
 in plants, 866
 prostaglandins in, 1001
 stem cells and, 431
 trematode camouflage and, 696
Immunity
 active and passive, 968
 maternal immune tolerance of embryo and fetus during pregnancy, 1037
Immunization, 968f, 976
Immunodeficiency diseases, 971, 972f, 973
Immunoglobulin (Ig), 958f–961f, 966
Immunological memory, 960, 962, 963f
Impala, 212f, 216–217
Imprinting, 1144, 1145f, 1152f–1153f
Inactivation, cell-signaling, 229
Inborn errors of metabolism, 336
Inborn immunodeficiency, 971
Inclusive fitness, 1157, 1158f–1159f
Incomplete dominance, 279f
Incomplete flowers, 824
Incomplete metamorphosis, 711, 712f
Independent assortment, law of, 274–275, 276f, 296, 297f, 302
Independent assortment of chromosomes, 265f
Independent variables, 21, 513
Indeterminate cleavage, 681, 682f
Indeterminate growth, 766f–767f
Indian corn, 451f
Indian Ocean Subtropical Gyre, 1168f
Indian pipe, 819f
Indian rice, 1263
Indoleacetic acid (IAA), 848. *See also* Auxin
Indolebutyric acid (IBA), 849
Indonesia, 1254f
Induced fit, 155f, 156
Induced pluripotent stem (iPS) cells, 431, 432f
Inducers, 368f, 369
Inducible enzymes, 368f, 369
Inducible operons, 368f, 369
Induction, 382f, 383, 1054
Inductive reasoning, 17
Inductive signals, cell fate determination and pattern formation by, 1061, 1062f–1063f, 1064
Industrialization, human population growth and, 1207f
Industrial toxins, 1275, 1276f
Inert elements, 35
Infant mortality, 1208–1209, 1284, 1285f
Infection
 adaptive immunity defense against, 963, 964f–969f, 970
 bacterial, 218f
 cytotoxic T cell response to, 966f, 967
 fungal, 670
 inflammation in, 956–957
Infection thread, bacterial, 816f, 817
Inferences, 1030
Infertility, 1039f
Inflammation, 937f, 938–939, 1013–1014, 1111–1112
 systemic and chronic, 956–957
Inflammatory response, 955f–956f
Inflorescences, 824

- Influenza viruses
antibody proteins and, 79f
antigenic variation of, 973
in density-dependent population regulation, 1204f
as emerging viruses, 410
immune system recognition and response to, 952
oseltamivir for, 414
structure of, 400f
as zoonotic, 1234, 1235f
- Information
alleles and, 293
B and T cells and DNA, 976
biotechnology and, 441
chromosomes and, 268, 313
DNA structure and inheritance, 334, 364
in eukaryotic cells, 93f
 F_1 hybrids, 524
genetic material as, 6, 7f–8f
genome and nervous system, 1106
genomics, 8–9
heritable, 1162
in mitosis, 252
phylogeny reconstruction with, 572
as theme of biology, 2, 3
- Information flow, intercellular, 1000f–1001f
- Information processing
cerebral cortex in, 1096, 1097f
ion movements and gradients and, 993f
neuron, 1067–1068, 1069f
problem solving and, 1146, 1147f
- Infrared receptors, 1111f
- Ingestion, 902, 903f
- Ingroups, 561f
- Inhalation, 944, 945f
- Inheritance. *See also* Mendelian inheritance; Sexual life cycles
of cancer predisposition, 394
chromosomal basis of. *See* Chromosomal basis of inheritance
of chromosomes and genes, 255
Darwinian theory on, 475f, 476
C. Darwin on, 14f–16f
DNA structure and, 334, 364
epigenetic, 372f, 373
expression and transmission of genetic information in, 7f–8f
genetics as study of, 255. *See also* Genetics
genetic variation and, 487
genomic imprinting and, 310f, 311
Lamarck's theory on, 471
learning and, 1162
molecular basis of. *See* Molecular basis of inheritance
of organelle genes, 311f
of X-linked genes, 299f, 300
- Inheritance of acquired characteristics principle, 471
- Inherited variation, 255
- Inhibin, 1031f
- Inhibiting hormones, 1004f, 1008
- Inhibition, 158–161f
- Inhibitors, 160f
- Inhibitory postsynaptic potential (IPSP), 1078
- Initials, cell, 766
- Initiation factors, 352f
- Initiation stage
regulation of transcription, 373f–378f, 379
regulation of translation, 378–379
transcription, 343f
translation, 352f
- Inland mouse (*Peromyscus polionotus*), 20f–21f
- Innate behavior, 1143
- Innate immunity, 953
antimicrobial peptides and proteins in, 953–954, 955f, 956–957
barrier defenses of, 953–954
cellular innate defenses of, 954, 955f
inflammatory response of, 955f–956f
invertebrate, 953f–954f
molecular recognition by, 953
overview of, 957f
pathogen evasion of, 957
pathogen recognition in, 952f
systemic and chronic inflammation in, 956–957
vertebrate, 954f–956f, 957
- Inner cell mass, 1052, 1053f
- Inner ear, 1113f
- Innocence Project, 24f, 437f
- Inorganic components, topsoil, 806, 807f
- Inositol triphosphate (IP₃), 225f
- Inquiry, scientific, 16. *See also* Inquiry Figures; Research Method Figures; Scientific inquiry
- Inquiry Figures. *See* list, xxii–xxiii
- Insecticide resistance, 496, 518
- Insects
alimentary canals in, 905f
anatomy and features of, 710f–711f
antiviral defense of, 954f
axis formation in, 1060
body plans of, 545f, 546
camouflage of, 468f, 476f
cleavage in, 1048
CO₂ absorption and, 1245
compound eyes of, 1117f, 1118
CRISPR-Cas9 and gene editing of, 427
defense mechanisms of, 28f
evolution by natural selection in, due to food source changes, 477f, 478
exoskeletons of, 1133
eyes of, 894f
flower pollination by, 649f, 822f–825f
in fossil record, 529f
gamete production and delivery in, 1024f
gas exchange of, 951
herbivory evolution in, 551
Hox genes in, 463f–464f
importance of, for humans, 713
innate immunity in, 953f–954f
insecticide resistance in, 496
malaria and, 606f
Malpighian tubules of, 985f
mechanoreceptors and hearing in, 1112f
nervous systems of, 1086f
neuroendocrine coordination in, 1006f, 1007
nonheritable variation in, 488f
open circulatory systems of, 923f
organogenesis in, 1055f
parasitic, 1220
phylogeny and diversity of, 689f, 708, 709f, 712f, 713
plant defenses against, 867, 868f–869f
pollination by, 522, 641f
sex chromosomes of, 298f
sex determination of, 298f
taste and smell in, 1123
thermoregulation in, 887f
tracheal systems for gas exchange in, 941, 942f
wildfires and, 1244f
zoopagomycete infection of, 662f
- Insertions (mutations), 358f, 359
- In situ* hybridization, 423, 424f
- Instability, free-energy change and, 147, 148f
- Insulation, animal thermoregulation and, 885
- Insulin, 916, 1004f
in diabetes mellitus, 916–917
exocytosis and, 139
in glucose homeostasis, 916f
in glucose metabolism, 10f, 216
neonatal diabetes and, 359
as polypeptide, 1001f
production of, by biotechnology, 436
as protein, 76f
in regulation of appetite and consumption, 917f
rough ER and, 105
stem cells and, 431
- Insulin-dependent diabetes, 917
- Insulin-like growth factor gene (*Igf2*), 310f, 311
- Insulin-like growth factors (IGFs), 1009
- Integral proteins, 129
- Integration
cellular, 121f
sensory, 1068f, 1108f, 1109
- Integrins, 119f, 129
- Integument, 638f, 826
- Integumentary systems, 885
- Intelligence, 1106
- Interactions
Cambrian explosion and feedback regulation, 685
climate change and positive feedbacks, 1189
diatoms and, 617
in eukaryotic cells, 93f
feedback mechanisms, 397
between hormones and environment, 1018
interspecific. *See* Interspecific interactions
- across kingdoms and domains, 813f
mycorrhizal, 657
within organisms, 10f
between organisms and physical environment, 10f–11f
oxygen transport, 951
of pancreatic cell, 142
physical environment and evolution, 485
phytochromes and shoot growth, 871
of plants with other kingdoms, 648, 649f
prokaryotic ecological, 586f, 587
species, 1214f–1221f, 1237
as theme of biology, 2, 3, 9
- Intercalated disks, 879f, 1131
- Intercellular communication. *See* Cell signaling
- Intercellular information flow, 1000f–1001f
- Intercellular joining function, membrane protein, 130f
- Interdisciplinary research teams, 9
- Interferons, 957
- Intermediate disturbance hypothesis, 1228, 1229f
- Intermediate filaments, 100f–101f, 102, 113t, 117
- Intermediate sexual (intersex) characteristics, 299
- Intermembrane space, 110
- Internal environments, animal, 874, 875f, 876, 881f–883f
- Internal factors, cell cycle control system, 246, 247f–248f
- Internal fertilization, 1022–1023, 1151. *See also* Fertilization, reproductive
- International Union for Conservation of Nature and Natural Resources (IUCN), 1261
- Internet resources, genome-sequence, 444, 445f, 446
- Interneurons, 1068, 1069f, 1088f
- Internodes, 761
- Interphase, 234, 237f–238f, 252
- Interphase nucleus transcription factories, 377, 378f
- Interpret the Data, 21f, 23, 29t, 33, 47f, 50, 54, 58, 89, 99, 136, 157, 158f, 179, 186, 194f, 205, 264, 501f, 505, 540f, 562f, 567f, 592, 635, 717, 773f, 804, 951, 963f, 998, 1018, 1021f, 1083, 1102f, 1115f, 1138, 1149f, 1171f, 1189, 1205f, 1213, 1217, 1243f, 1246f. *See also* Scientific Skills Exercises
- Intersex characteristics, 299
- Intersexual selection, 499f–500f, 1152
- Interspecific competition, 1215, 1216f–1217f, 1237
- Interspecific interactions, 1214f, 1215
character displacement and, 1216, 1217f, 1237
competition, 1215, 1216f–1217f, 1237
exploitation, 1217, 1218f–1219f, 1220
genomics and proteomics in, 88f
positive interactions, 1220f–1221f
- Interspecific mating, 507f. *See also* Mating
- Interstitial fluid, 875f, 923, 932, 933f, 956f, 981, 988–989, 990f, 991
- Intertidal zones, 1181f
- Intestinal bacteria, 912, 913f
- Intestines, 587, 695f
- Intracellular digestion, 904
- Intracellular receptors, cell-signaling, 220, 221f, 1018
- Intracellular recording, 1072f
- Intrasexual selection, 499f, 1152
- Intrauterine devices (IUDs), 1038f
- Intrinsic (physiological) factors, density-dependent population regulation by, 1204f
- Intrinsic rate of increase, 1197
- Introduced species, 818, 1223, 1264f, 1287
- Introns, 345f–347f, 346, 449, 488f
- Invagination, 1050f
- Inversions, chromosome, 307, 308f
- Invertebrates, 683, 687
action potential conduction speed in, 1076
chordates, 719f–722f
cnidarians, 687f, 691f–693f
deuterostomes, echinoderms, and chordates, 689f, 713, 714f–715f
digestive systems of, 717
ecdysozoans and arthropods, 688f–689f, 705f–712f, 713. *See also* Arthropods; Ecdysozoans
gamete production and delivery in, 1024f
hydrostatic skeletons of, 1133f
innate immunity in, 953f–954f

- lophotrochozoans, 687f–688f, 694, 695f–704f, 705. *See also* Lophotrochozoans
 mechanoreceptors in, to sense gravity, 1112
 nervous systems of, 1086f, 1087
 neuroendocrine signaling in, 1006f, 1007
 organogenesis in, 1055f
 osmoregulation in, 979, 980f
 parental care in, 1023f
 phylogeny and diversity of, 687f–689f
 sponges, 687f, 690f, 691
- In vitro* culturing, angiosperm, 836
In vitro fertilization (IVF), 436, 1039f
In vitro mutagenesis, 426
- Iodine, 29
 Iodine deficiencies, 1009
 Ion channel proteins, 1076
 Ion channel receptors, 220f
Ion channels, 135, 1070
 action potentials and gated, 1072f–1077f
 in mechanoreceptors, 1110
 neuron resting potential and, 1070f–1071f
- Ionic bonds, 37, 38f
 Ionic compounds (salts), 38f. *See also* Salts
 Ion movements and gradients, in life processes, 993f
 Ionotropic receptors, 1077, 1078f, 1079–1080
 Ion pumps, 137, 138f, 1070f–1071f
 Ions, 37, 38f, 934f, 993f, 1070t
 IP₃ (inositol triphosphate), 225f
 Iridium, 541
 Iris, 1118f
 Iron
 as limiting nutrient in aquatic biomes, 1243t
 plant deficiency in, 810f
 Iron overload, 920
 Iron oxide, 534
 Irrigation, 142, 808, 821
 Island equilibrium model, 1232, 1233f
 Island species, 483
 Isolated systems, 145, 149f
 Isoleucine, 77f
 Isoleucine synthesis, 161f
 Isomers, 61f–62f
 Isomorphic generations, 604
 Isoosmotic solutions, 977–978
 Isopods, 709
 Isotonic solutions, 134f
 Isotopes, 31, 32f, 33, 190
 Italy, age-structure pyramid for, 1209f
 Iteroparity, 1201f
 Ivanowsky, Dmitri, 399
 Ivory, 1265f
- J**
J. See Joule
 Jackson, Rob, 1223f
 Jacob, François, 366, 547
 Jacoby, Gordon C., 773f
 Japan, 1208
 Japanese canopy plant (*Paris japonica*), 448t, 449
 Japanese snails, 522
 Jasmine, 855
 Jasmonates, 846t, 855
 Jawfish, 1151f
 Jawless vertebrates, 723f–725f
 Jaws
 mammalian, 530, 531f–533f
 snake, 498, 499f
 vertebrate, 718, 723, 725f, 726
- Jefferson, Thomas, 437
 Jejunum, 909
 Jellies (jellyfish), 687f, 691f–692f, 922f
 Jellyfish gene, 342f
 Jenner, Edward, 968
 Jirtle, Randy, 372
 Joints, human, 1134f
 Joly, John, 794
 Jost, Alfred, 1030
 Joule (J), 46, 890
 J-shaped exponential growth curve, 1197f
 Jumping genes. *See* Transposable elements
 June solstice, 1167f
 Juniper, 643f
 Junk DNA. *See* Noncoding DNA
 Juvenile hormone (JH), 1006f, 1007
 Juxtaglomerular apparatus (JGA), 995, 996f
 Juxtamedullary nephrons, 986f, 991
- K**
 Kangaroo rat (*Dipodomys merriami*), 741f, 998
 Kangaroos, 743, 744f, 1135f, 1153f, 1178
 Kaposi's sarcoma herpesvirus, 974
 Kartagener's syndrome, 1064
 Karyogamy, 658f, 662f
 Karyotypes, 256f, 289f, 308f, 332f
 Katydids, 712f
 Kaufman, D. W., 22–23
 kcal. *See* Kilocalorie
 Kelp perch (*Brachyistius frenatus*), 1203f
 Kelps, 603, 804, 1189
 Keratin, 76f, 337, 735, 920
 Kestrels, 1201f
 Ketone compounds, 63f
 Ketoses, 68f
 Keystone species, 1226, 1270
 Kidneys, 985
 adaptations of vertebrate, to diverse environments, 741, 991f–993f
 evolution of, 991, 998
 homeostatic regulation of, 994f–996f
 hormonal regulation of, 1007f, 1008
 human cystic kidney disease, 1064
 osmoregulation by, in aquatic animals, 979f
 processing of blood filtrate in nephrons of, 987, 988f, 989
 solute gradients and water conservation by, 989, 990f, 991
 structure of, in mammalian excretory systems, 985, 986f–987f
- Killifish, 483
 Kilocalorie (kcal), 46, 890
 Kimberella, 535f, 536, 694
 Kinases, 219f, 220. *See also* Protein kinases; Receptor tyrosine kinases
 Kinetic energy, 46, 144, 145f, 163
 Kinetochore microtubules, 238f, 240f–241f, 244f, 252
 Kinetochores, 238f, 240f–241f
 Kinetoplastids, 600, 601f
 Kinetoplasts, 600
 King, Mary-Claire, 394
 King, Thomas, 428
 Kingdoms, taxonomy, 12f, 554, 555f, 568
 King penguins (*Aptenodytes patagonicus*), 740f, 884f, 1192f
 Kin selection, 1157, 1158f–1159f
 Kissimmee River Restoration Project, 1254f
 Klinefelter syndrome, 309, 1040
 Knee-jerk reflex, 1088f
 KNOTTED-1 gene, 778f
 Koalas, 743, 912f
 Kombu, 603
 Komodo dragon (*Varanus komodoensis*), 1042
 Korarchaeota clade, 586
 Krebs, Hans, 172
 Krebs cycle. *See* Citric acid cycle
 Krill, 710f
 K-selection, 1202
 Kudzu, 1264f
 Kuru, 412–413
- L**
 Labeling, GM products, 438–439
 Labia majora, 1026, 1027f
 Labia minora, 1026, 1027f
 Labor, childbirth and, 1036, 1037f
 Labrador Current, 1168f
 Lacks, Henrietta, 248–249
 lac operon, 368f, 369
 Lactase, 70
 Lactate, 180f, 181
 Lactation, 1036
 Lacteals, 909f–910f
 Lactic acid fermentation, 180f, 181
 Lactose, 69–70, 368f, 369
 Laetoli footprints, 750f
 Lagging strand, DNA, 324, 325f
 Lagonomorpha, 745f
 Lake Erie water snake (*Nerodia sipedon*), 496, 497f
 Lakes, 1177f–1179f, 1275, 1276f
 primary production in, 1242–1243
 Lake Vesijärvi, 1227f
 Lake Victoria, 515f, 519f, 520
 Lamarck, Jean-Baptiste de, 469f, 471
 Laminaria, 603f, 604
- Lampreys, 719f, 723f, 724, 1091f
 Lamp shells, 688f, 698f, 699
 Lancelets, 689f, 715, 719f, 720, 721f–722f
 Land
 colonization of, 536, 537f
 global human use of, 1209
 locomotion on, 1135f
 subsidence of, 808f
 Land plants. *See* Plants
 Landscape ecology, 1165f. *See also* Ecology
 biodiversity hot spots in, 1272f
 landscape fragmentation and edges in, 1270, 1271f
 movement corridors in, 1271f, 1272
 philosophy of nature reserves in, 1272–1273
 urban ecology and, 1273, 1274f
 zoned reserves in, 1273f
 Landscapes, 1165f
 Land snails, 700f, 702f
 Language
 brain function and, 1098f
 FOXP2 gene and, 461, 462f
 lap alleles, 505
 Larch, 643f
 Large intestine, 910, 911f–912f
 largemouth bass, 881f
 Large-scale disturbances, 1229f
 Large tree finch, 519
 Larva, 674f, 711f
 Larval dispersal, 538
 Larynx, 906f, 942, 943f
 La Sagrada Familia towers, 146f
 Late-acting dominant lethal alleles, 293
 Latency, viral, 973t
 Lateral geniculate nuclei, 1121f
 Lateral inhibition, 1120
 Lateralization, 1098
 Lateral line system, 725–726, 728f, 1116f
 Lateral meristems, 766f
 Lateral roots, 759f, 769f
 Latitude
 animal size and, 897
 sunlight intensity and, 1166f
 Latitudinal gradients, community diversity and, 1232f
 Law of conservation of mass, 1239
 Law of independent assortment, 274–275, 276f, 296, 297f, 302
 Law of segregation, 271f–275f, 272f–273, 296, 297f
 Laws of probability, 276, 277f, 278
 Laws of thermodynamics, 143, 145f, 146
 Laysan albatross (*Phoebastria immutabilis*), 1277f
 L-dopa, 1104
 Leaching, 806
 Leading strand, DNA, 324, 325f
 Leaf area index, 786f, 787
 Leaf-cutter ants, 668f, 813f
 Leaf primordia, 769f, 770, 771f
 Leafy liverworts, 626f
 Learned behaviors, 1147
 Learning, 1144
 associative, 1146f
 cognition, problem solving, and, 1146, 1147f
 development of learned behaviors, 1147
 inheritance and, 1162
 neuronal plasticity and, 1100, 1101f
 sleep and, 1094
 social, 1147f–1148f
 Leaves (leaf), 630, 758, 761
 abscisic acid in abscission of, 852
 anatomy of, in C₄ plants, 204f
 auxin in pattern formation of, 849
 ecosystem interaction of, 10f, 11
 effects of transpiration on wilting and temperature of, 798
 ethylene in abscission of, 854f
 evolution of, in vascular plants, 630, 631f
 green color of, 193f
 Hox genes in formation of, 777, 778f
 leaf area index and arrangements of, 786f, 787
 monocot vs. eudicot, 649f
 photosynthesis in, 189f, 190
 structure of, 761f–762f
 tissue organization of, 770, 771f
 Leber's congenital amaurosis (LCA), 1122
 Leber's hereditary optic neuropathy, 311
 Leeches, 703f, 704, 1086f

- Leeuwenhoek, Anton van, 1209
 Left atrium, 926f–927f
 Left ventricle, 926f–927f
 Leghemoglobin, 816
 Legless lizards, 553f–554f
 Legumes, 815f–816f, 817
 Lemurs, 746f
 Length, carbon skeleton, 60f
 Lens, 1118f, 1138
 Lenski, Richard, 578f
 Lenticels, 774
 Leopards, 554, 555f
 Lepidopterans, 712f
 Lepidosaurians, 736, 737f, 738
 Leprosy, 584f
 Leptin, 917f, 918
Leptogenys distinguenda, 1001f
Lepus americanus, 501f, 1205f
 Lettuce seed germination, 857f
 Leucine, 77f
 Leukemia, 309f, 394, 434, 1263f
 Leukocytes (white blood cells), 229f, 878f, 934f–**935f**
 Lewis, Edward B., 385–386
 Lewis dot structures, 36, 37f, 43, 65
 Leydig cells, 1031f
 Lichens, 663, **668f**–669f, 672, 813f, 1256f–1257f
 bioremediation using, 1253, 1255f
 Life. *See also* Animals; Organisms; Plants
 abiotic synthesis of organic molecules as origin of, 57f, 58
 biological molecules of, 66. *See also* Biological molecules
 biology as scientific study of, 3. *See also* Biology; Science
 carbon in organic compounds of, 64
 cell division as fundamental to, 235
 cells as fundamental units of, 5f, 6f, 93f. *See also* Cells; Eukaryotic cells; Prokaryotic cells
 cellular respiration and energy for, 164f, 165.
 See also Cellular respiration
 classification of diversity of, 12f–13f
 colonization of land by, 536, 537f
 conditions on early Earth and origin of, 525f–528f
 diversity of. *See* Biodiversity
 domains of, 12f–13f
 effects of speciation and extinction on, 537f–543f, 544
 as emergent property, 125
 essential elements and trace elements for, 29t
 evolution of, as theme of biology, 11. *See also* Evolution
 extension of, 233
 fossil record as history of, 529f. *See also* Fossil record
 geologic record and, 532f–533f
 history of, as limitation of natural selection, 504
 importance of water for. *See* Water
 levels of biological organization of, 4f–5f
 order as property of, 146f, 147
 origin of multicellular, 533f, 535f–536f
 origin of single-celled, 532f–535f
 photosynthesis as process that feeds, 188f. *See also* Photosynthesis
 phylogenies as evolutionary history of, 554f–556f. *See also* Phylogenies
 possible evolution of, on planets with water, 50f
 properties of, 3f
 silicon-based, 65
 tree of, 15f–16f. *See also* Tree of life
 unifying biological themes in, 3f–11f
 unity in diversity of, 13f, 26, 469, 473
 viruses and characteristics of, 398f, 399, 408
 web of, 570f
 Life cycles, **256**. *See also* Sexual life cycles
 of angiosperms, 646f, 647, 653, 826, 827f, 828
 of apicomplexan *Plasmodium*, 606f
 of blood fluke *Schistosoma mansoni*, 696f
 of brown alga *Laminaria*, 603f, 604
 of cellular slime mold *Dictyostelium*, 613f
 of ciliate *Paramecium caudatum*, 607f
 developmental events in, 1044
 of *Drosophila melanogaster* (fruit fly), 385f
 of fern as seedless vascular plant, 630f
 of fungi, 658f–659f, 662f, 664f, 666f
 of green algal chlorophyte *Chlamydomonas*, 611f
 of humans, 257f, 258
 of hydrozoan *Obelia*, 693f
 of moss, 624f
- of pine tree and gymnosperms, 640f, 641
 reproduction and, 256
 Life expectancy at birth, 1208–1209, 1284, 1285f
 Life histories, population, **1200**, 1201f–1202f
 Life tables, population, **1193t**
 Ligaments, **878f**
 Ligand binding, 217
 Ligand-gated ion channels, **220f**, **1077**, 1078f, 1079–1080
 Ligands, **217**, 223
 Light chains, **958f**–961f
 Light-detecting organs, 1117f
 Light detector, euglenid, 601f
 Light energy
 absorption of, determining primary production with, 1242f
 bioluminescence as, 143
 in energy flow and chemical cycling, 9f, 164f, 165, 1240f
 excitation of chlorophyll by, 195f
 global energy budget and, 1241
 in photosynthesis, 187f, 206, 207f. *See also* Light reactions
 primary production in aquatic ecosystems and limitations of, 1242
 properties of, 192f
 sunlight as, 143, 145, 150
 Light energy, plant responses to
 biological clocks and circadian rhythms in, 857, 858f, 859
 blue-light photoreceptors in, 855, 856f
 de-etiolation signal transduction pathway for, 843f–844f, 845
 germination and, 871
 photomorphogenesis and action spectrum of, 855
 photoperiodism and seasonal responses in, 859f–860f
 phototropism and, 847f–848f
 phytochromes as photoreceptors in, 856, 857f
 plant shoot architecture and, 785, 786f, 787
 stomatal opening and closing as, 797–798
 Light-harvesting complexes, **196f**
 Light microscope (LM), **94**
 Light microscopy (LM), 94f–95f
 Light reactions, **191**. *See also* Photosynthesis
 chemiosmosis of, in chloroplasts vs. in mitochondria, 199f–200f, 201
 cyclic electron flow in, 198f, 199
 determination of absorption spectrum for, 193f
 excitation of chlorophyll by light energy in, 195f
 linear electron flow in, 197f–198f
 most effective wavelengths for, 194f
 nature of sunlight and, 192f
 photosynthetic pigments as light receptors in, 192, 193f–194f, 195
 photosystems of, 195, 196f–198f, 199
 as stage of photosynthesis, 191f, 192, 206, 207f
 Light responses, rod cell, 1121f
 Lignin, **629**–630, 665, **764f**, 783
 Likens, Gene, 1252f
 Lily, 650f
 Limbic system, 1095f, 1096
 Limbs
 genes for formation of, 545f, 546
 as homologous structures, 479f, 480
 tetrapod, 718, 730, 731f
 vertebrate formation of, 1062, 1063f, 1064
 Limiting nutrients, **1242**, 1243f–1244f, 1243t
 Limnetic zone, **1179f**
 Limp cells, 790, 791f, 797f
 Limpets, 547f–548f
 LINE-1 retrotransposons, 452
 Lineage-based mechanisms, 777–778
 Linear electron flow, **197f**–198f
 Line graphs in Scientific Skills Exercises, 33, 157, 264, 411, 972, 1049, 1095, 1136, 1186, 1279
 Linkage groups, 306f
 Linkage maps, 305f–306f
 Linked genes, **301**
 genetic recombination and, 302, 303f
 identifying, 304
 inheritance of, 301f–302f
 mapping of, 305f–306f
 natural selection and genetic variation from recombination of, 305
 Linker DNA, 330f
 Linnaean classification, 554, 555f
- Linnaeus, Carolus, 470, 554
 Lionfish, 729f
 Lions, 912f
 Lipid bilayers. *See* Phospholipid bilayers
 Lipid rafts, 128
 Lipids, 66, **72**
 in cellular membranes, 102, 110, 127f, 128
 evolution of differences in cellular membrane composition of, 129
 fats as, 72, 73f, 74
 phospholipids as, 74f, 75
 in plasma membranes, 98f, 99
 smooth ER synthesis of, 104–105
 steroids as, 75f
 Tay-Sachs disease and, 280
 Lipid-soluble hormones, 1001f–1003f
 Lipopolysaccharides, 574, 976
 Literacy rate, Costa Rican, 1285
 Litter decomposition, 1248f
 Litter size, 1200, 1201f–1202f
 Littoral zone, **1179f**
 Liver, **909**
 in digestion, 909–910
 in energy storage, 915, 916f
 lowering plasma LDL levels by inactivating enzyme of, 938
 Liverworts, 620f, **623**, 626f. *See also* Bryophytes
 Living fossils, 633, 708f
 Lizards, 553f–554f, 735, 737f, 738, 925, 1021f, 1154f, 1216f, 1260f
 climate change and, 11f
 Loams, **806**
 Lobe-fins, 718, **728**, 729f, 730
 Lobes, brain, 1096, 1097f, 1098
 Lobotomy, 1098
 Lobsters, 707f, 708–709, 979
 Local biogeochemical cycles, 1249
 Local cell signaling, 215f, 216
 Local extinctions, 1262
 Local inflammatory response, 955f–956f
 Local regulators, **1000f**, 1001
 Lock-and-key specificity, viral, 401
 Locomotion, 993f, 1133f, **1135f**, 1136, 1138
 Locomotor play, 1159
 Locus, gene, **255**, 272
 Locusts, 1213
 Lodgepole pines, 1229f
 Logarithms, natural, 639
 Loggerhead turtles, 1194, 1195f
 Logistic equation in Scientific Skills Exercise, 1200
 Logistic population growth, 1197, 1198f–1199f, **1198t**, 1200
 Logos, DNA sequence, 351
 Log scales in Scientific Skills Exercise, 1136
 Lokiarchaeotes, 586
 Long-day plants, **859f**
 Long-distance cell signaling, 215f, 216
 Long Island Sound, 505
 Long-night plants, 859f, 860
 Long noncoding RNAs (lncRNAs), 380–**381**
 Long-term memory, **1100**, 1101f
 Long-term potentiation (LTP), **1101f**
 Long-loop domains, DNA, 331f, 332
 Loop of Henle, **987f**–990f, 998
 Loose connective tissue, 878f
 Lophophores, 683f, **684**, 694, 698f, 699
 Lophotrochozoans, **683f**, 684
 annelids, 703f–704f, 705
 characteristics of, 694
 ectoprocts and brachiopods, 698f, 699
 flatworms, 694, 695f–697f
 molluscs, 699f–702f
 phylogeny of, 687f–688f
 rotifers, 697f, 698
 Loricifera, 688f
 Lorises, 746f
 “Lost City” vent field, 527f
 Lovelock, James, 1259
 Low-density lipoproteins (LDLs), 139, 141, **937**–938
Loxodonta africana, 474f, 1197f, 1265f
 LSD, 1081
 Luminal A and luminal B breast cancer, 393f
 Luna moths (*Actias luna*), 43
 Lung cancer, 447
 Lung cells, newt, 7f, 238f–239f
 Lung disease, 951
 Lungfishes, 480f, 719f, 729

- Lungs, 728, **942**
 gas exchange in, 924f, 925, 942, 943f–946f
 ventilation of, 944, 945f–946f
- Lupines, 1255
- Lupus, 971
- Luteal phase, 1032f, 1033
- Luteinizing hormone (LH), 1004f, 1008f, **1030**, 1031f–1032f, 1033
- lux* genes, 397
- Lycophytes, **622**, 622t, 631, 632f, 633, 635
- Lyell, Charles, 469f, 471–473
- Lyme disease, 584f, 588f, 1234, 1235f
- Lymph, **933f**, 956f
- Lymphatic systems, 910, **933f**, 956f
- Lymph nodes, **933f**, 956f
- Lymphocytes, 934f–935f, **958f**. *See also* B cells; T cells
- Lymphoid stem cells, 935f
- Lymph vessels, 933f, 956f
- Lynx, 1205f
- Lyon, Mary, 300f
- Lysine, 77f
- Lysogenic cycle, **402**, 403f
- Lysosomal storage diseases, 108
- Lysosomes, 100f, **107f**–109f
- Lysozymes, 49f, 79f, 456, 457f, **953f**, 954
- Lytic cycle, **402f**, 414
- M**
- Macaques (*Macaca fuscata*), 897
- MacArthur, Robert, 1232, 1233f
- MacLeod, Colin, 315
- Macroevolution, **507**, **526**. *See also* Evolution
 adaptive radiations in, 542, 543f, 544
 colonization of land in, 536, 537f
 of development, 544f–546f, 547
 early Earth conditions for origin of life in, 526f–528f
 fossil evidence for, 525f, 526, 528, 529f–531f, 530
 gene flow, genetic drift, and natural selection in, 551
 geologic record of key events in, 532f–533f
 mass extinctions in, 540f–542f
 novelties and trends in, 547f–549f
 origin of multicellular organisms in, 533f, 535f–536f
 origin of single-celled organisms in, 532f–535
 plate tectonics and, 538f–539f, 540
 speciation and extinction rates of organisms in, 537f–543f, 544
- Macromolecules, 66f–**67f**, 526f–527f, 802
 in lysosomes, 107f, 108
 plasmodesmata and, 846
- Macronuclei, ciliate, 606, 607f
- Macronutrients, plant, **810**, 811t
- Macrophages, 107f, 121f, **878f**, **955f**, 956
- Macular degeneration, age-related, 432
- Madagascar orchids, 825f
- Mad cow disease, 83, 412
- Madreporite, sea star, 714f
- MADS-box genes, 545, 778f
- Maggot flies, 508f, 515–516, 903f
- Magnesium, 29t, 810
- Magnetic field, Earth's, 1111f, 1141
- Magnification, 94
- Magnificent frigatebird (*Fregata magnificens*), 1139f
- Magnolia tree, 650f
- Magnoliids, **649**, 650f
- Maiden veil fungus, 665f
- Maize (corn), 451f, 651
 alleles in, 293
 artificial selection of, 836f
 health of transgenic Bt, 839
 phylogeny of, 557
 precocious germination in, 852f
 proteins in, 899
 seeds, 829f–830f
- Major depressive disorder, **1102**
- Major histocompatibility complex (MHC) molecule, **959f**–960f, 963, 964f, 969–970
- Make Connections Figures. *See* list, xxii
- Malacidins, 589f
- Malacosoma americanum*, 897
- Malaria, 286f, 287, 501, 503f, 599f, 606f, 614, 713
- Malaysia, 1232f
- Malaysian orchid mantis (*Hymenopus coronatus*), 468f, 469
- Male gametophytes, angiosperm, 827f
- Males
- competition between, for mates, 1153f, 1154
 female mate choice and, 1151, 1152f–1153f, 1154
 hormonal regulation of reproductive systems of, 1031f
 hormones of, 999f, 1014, 1015f
 parental care by, 1151f
 reproductive anatomy of human, 1025f, 1026
 sex chromosomes of, 298f, 299
 sexual competition between, 499f–500f
 spermatogenesis in human, 1027, 1028f, 1031f, 1042
- Malignant tumors, **249f**
- Malnutrition, 837, 838f, 901–902
- Malpighian tubules, 710f, **985f**
- Malthus, Thomas, 469f, 475
- Maltose, 69f
- Mammals, **741**
 adaptations of kidneys of, 991f, 992
 adaptive radiation of, 542, 543f
 amniotic eggs of, 734, 735f
 axis formation in, 1060
 bats as, 15f
 brains in nervous systems of, 1091f. *See also* Nervous systems
 breathing in, 925, 945f–946f
 cardiovascular systems of. *See* Cardiovascular systems
 cellular respiration in hibernating, 178
 circadian clocks in hibernating, 893f
 circulation in, 924f, 925. *See also* Cardiovascular systems
 comparing genomes of, 454f–455f, 459, 460f–462f
 control of circadian rhythms in, 1094
 convergent evolution of, 481f, 744f
 derived characters of, 741f
 digestive systems of. *See* Digestive systems
 early evolution of, 741, 742f
 endangered or threatened, 1261, 1262f, 1288
 eutherians and primates as placental, 744, 745f–747f
 evolution of, 679
 evolution of melanocyte-stimulating hormone in, 1016
 extraembryonic membranes of, 1053f, 1054
 fertilization in, 1046f
 gas exchange adaptations of, 947f–949f
 genomic imprinting in, 310f, 311
 glia in brains of, 1069f
 hearts of, 926f–928f
 hominins and humans as, 748f–754f
 homologous structures in, 479f
 hormonal regulation of reproduction in, 1030, 1031f–1032f, 1033–1034. *See also* Animal reproduction; Human reproduction
 inactivation of X-linked genes in female, 300f
 ion concentrations inside and outside of neurons of, 1070t
 kidneys in excretory systems of, 985, 986f–987f.
See also Excretory systems; Kidneys
 marsupials, 743f–744f
 mechanoreceptors for hearing and equilibrium in, 1112f–1116f
 modeling neurons of, 1071f
 molecular clock for, 567f
 monotremes, 742, 743f
 nitrogenous wastes of, 982f
 opiate receptors in brains of, 1082
 organ systems of, 876f
 origination of cetaceans as terrestrial, 481f–482f
 origin of, 530, 531f–533f
 osmoregulation in, 980–981
 phylogeny of, 719f, 745f
 reproductive cloning of, 430f–431f
 respiratory systems of, 942, 943f–946f
 sex chromosomes of, 298f, 299
 taste in, 1123f–1124f
 thermoregulation in, 881f
- Mammary glands, 392f, 741, 1005f–1008f, 1016, **1026**–1027
- Mammoths, 421
- Manatee, 572, 1219f
- Mandibles, 709, 710f
- Mangold, Hilda, 1062f
- Mantises, 468f
- Mantle, **699f**
- Mantle cavity, **699f**
- Maple tree leaves, 762
- Mapping
 of brain activity, 1096f
 linkage, 305f–306f
- Map units, **305f**
- Maquis, 1174f
- Maraviroc, 217, 409
- Marchantia*, 620f, 626f
- March equinox, 1167f
- Marine animals
 adaptations of kidneys of, 992, 993f
 mass extinctions and, 541–542
 osmoregulation in, 978, 979f
- Marine benthic zones, **1182f**
- Marine biomes, 1177f, 1178, 1224f
 primary production in, 1242, 1243f, 1243t
- Marine birds, 982f
- Marine reserves, 1273f
- Marine snails, 538
- Marine worm, 940f
- Mark-recapture method, **1191f**
- Marmota caligata*, 164f
- Mars, 50f
- Marshall, Barry, 912
- Marsches, 1186
- Marsh gas, 585
- Marsupials, 481f, 540, 543f, **743f**–745f
- Marsupium, 743f
- Mass, 31
 conservation of, 1239–1240
 trophic levels and, 1240f, 1241
- Mass extinctions, **540f**–542f, 1287
 current sixth, 702f
 of dinosaurs, 736
 evolution and, 653
 life on earth and, 525
 speciation and, 522
 tropical deforestation and potential, 651f, 652
- Mass number, **31**
- Mast cells, 955f, 956, 970f
- Master regulatory genes, 545f–546f, 547. *See also* Homeotic genes; *Hox* genes
- Masting, 869f
- Mate choice, 499f–500f, 515f, 519, 1151, 1152f–1153f, 1154
- Mate choice copying, **1152**, 1153f
- Mate recognition, 508f
- Maternal age, Down syndrome and, 308–309
- Maternal alleles, 372
- Maternal chromosomes, 265
- Maternal effect genes, **386**
- Maternal inheritance, 311
- Maternal mRNAs, 387f
- Mating. *See also* Reproduction
 animal reproduction and, 1020f
 cell signaling in yeast, 213f, 214
 clumped dispersion and, 1192
 earthworm, 705
 external fertilization and, 1023
 genetic disorders from human, 285–286
 Hardy-Weinberg equilibrium and random, 492t
 human, 1034
 human sexual arousal and, 1081–1082
 hybrid zones and, 516, 517f
 insect, 711
 interspecific, and hybrids, 507f
 of pea plants, 270f, 271
 reproductive barriers to, 507, 508f–509f, 510
 reproductive cycles and, 1021f
 sexual selection and, 499f–500f
- Mating behavior. *See also* Courtship rituals
 applying game theory to, 1154f
 mating systems, 1149–1150, 1151f
 sexual selection and mate choice in, 1151, 1152f–1153f, 1154
- Mating systems, 1150, 1151f
- Mattole, 1174f
- Matter, 2, 3, 9, **29**–30. *See also* Energy and matter
- Matteuccia*, 632f
- Maturation-promoting factor (MPF), **245**, 246f
- Mauna Loa monitoring station, 1278f, 1279
- Maungatautari restoration project, 1254f
- Maximum likelihood, **563**
- Maximum parsimony, **562**, 563f, 564
- Mayer, Adolf, 399
- Maze experiments, 1146, 1147f
- McCarty, Maclyn, 315
- McClintock, Barbara, 451f, 459

- M checkpoint, 245f–247f
 Meadowlarks, 507f
 Meadow voles, 1155f
 Measles, 401, 409
 Measles virus, 968f
 Mechanical defense, prey, 1218f
 Mechanical isolation, 508f
 Mechanical signaling, 119
 Mechanical stimuli, plant responses to, 861, 862f
 Mechanical stress, plant responses to, 853f
 Mechanical work, 150, 152f
 Mechanoreceptors, 1110f, 1112f–1116f
 Mediator proteins, 374, 375f
 Medical records, 448
 Medicine. *See also* Drugs; Pharmaceutical products
 antibodies as tools in, 969f
 application of systems biology to, 447, 448f
 biotechnology in, 433, 434f–436f
 blocking HIV entry into cells in, 130f
 fungi in, 670
 genomics and proteomics in, 88f
 medical leeches in, 703f, 704
 plant-derived medicines in, 651t, 652
 radioactive tracers in, 31, 32f
 stem cells in, 431–432
 treatments of nervous system disorders in, 1102
 Mediterranean climate, 1168
 Medulla oblongata, 946f, 1093f
 Medusa, 691f, 692
 Medusozoans, 692f–693f
 Megapascal (MPa), 789
 Megaphylls, 631f, 635
 Megasporangia, 638f
 Megaspores, 631, 638f, 826, 827f
 Megasporocytes, 826
 Meiosis, 258
 in animal cells, 260f–261f
 crossing over and synapsis during, 260f, 262f
 DNA changes of yeast cells in, 264
 errors in, 306, 307f–309f
 gamete formation by, in sexual life cycles, 258
 genetic variation from gene alteration during, 489
 genome evolution and errors in, 455f–457f
 human gametogenesis and, 1027
 in human life cycle, 254, 257f, 258
 mitosis vs., 262, 263f, 264
 production of gametes by, 237
 stages of, 259f–262f
 in varieties of sexual life cycles, 258f, 259
 Meiosis I, 259f–260f, 262f–263f, 264
 Meiosis II, 259f, 261f, 263f, 264
Melanerpes formicivorus, 1162
 Melanin, 337
 Melanocyte-stimulating hormone (MSH), 1004f, 1008f, 1016, 1018
 Melatonin, 883f, 1004f, 1015
Melitaea cinxia, 1206f, 1207
 Membrane attack complex, 966f
 Membrane potentials, 137, 138f, 1069, 1070f–1071f.
See also Action potentials, neuron; Resting potentials, neuron
 Membrane proteins, 105, 127f–130f, 152f
 Membranes, amniotic egg extraembryonic, 734, 735f
 Membranes, cellular. *See* Cellular membranes
 Memory
 emotion and, 1096
 formation of, 1085
 neuronal plasticity and, 1100, 1101f
 sleep and, 1094
 Memory cells, 962
 Mendel, Gregor
 experimental, quantitative approach of, 270f, 271
 genes as hereditary factors of, 294f
 law of independent assortment of, 274–275, 276f
 law of segregation of, 271f–275f
 particulate model of inheritance of, 487
 Mendelian inheritance
 chromosomal basis of, 294f, 295
 environmental impacts on phenotypes and, 282f
 evolution of gene concept from, 361
 exceptions to, 310f–311f
 extending, for multiple genes, 281f–282f
 extending, for single gene, 278, 279f–280f
 genetic variation and, 487
 human patterns of inheritance and, 284f–289f, 290
 integrating, with emergent properties, 282–283
 law of independent assortment of, 274–275, 276f
 law of segregation of, 271f–275f
 laws of probability governing, 276, 277f, 278
 limitations of, 278
 making histograms and analyzing distribution patterns for, 283
 G. Mendel's experimental quantitative approach, 270f, 271
 Menopause, 1033
 Menstrual cycle, 1032f, 1033–1034
 Menstrual flow phase, 1032f, 1033
 Menstruation, 1032f
 Meristems, 766f–767f, 830, 849
 Meroblastic cleavage, 1048
 Merozoites, 606f
 Meselson, Matthew, 322f
 Mesenchyme cells, 1055
 Mesoderm, 680, 1050f–1051f
 Mesoglea, 691f
 Mesohyl, 690f
Mesonychoteuthis hamiltoni, 702
 Mesophyll, 189f, 203, 204f, 206f, 771f
 Mesozoic era, 530f, 533f, 539f, 679
 Messenger RNA (mRNA), 339. *See also* RNA
 alteration of ends of, 345f
 in analyzing gene expression, 423, 424f–428f
 bicoid, 387f
 in breast cancer, 392f
 cell fractionation and, 125
 effects of miRNAs and siRNAs on, 380f
 in gene expression, 8f, 84f
 genetic code and, 340f, 341
 maternal, 387f
 mutations affecting, 357f–358f, 359
 in plant cells, 208f
 polyribosomes and, 355f
 regulation of degradation of, 379
 synthesis of, in cell signaling, 226f
 synthesis of, in eukaryotic cell nucleus, 102
 synthesis of, in transcription, 342, 343f–344f
 in transcription and translation, 337, 339f
 in translation, 347f–350f, 352f
 viral, 401f, 402, 405f, 406f
 Metabolic defects, 336f–338f
 Metabolic pathways, 144. *See also* Metabolism
 evolution of, 163
 metabolic defects in, 336f–338f
 regulation of bacterial, 366f
 Metabolic rates, 890f–893f
 Metabolism, 144. *See also* Bioenergetics
 ATP energy coupling of exergonic and endergonic reactions in, 150, 151f–153f
 bioenergetics and metabolic rates of animal, 890f–893f
 catabolism and, 182f, 183
 effects of adrenal hormones on, 1012f, 1013–1014
 enzymatic catalysis of reactions in. *See* Enzymatic catalysis
 evolution of hormones regulating, 1016
 forms of energy for, 144, 145f
 free-energy change, equilibrium, and, 147, 148f–150f
 graphing reactions of, 157
 laws of thermodynamics and, 145f–146f, 147
 metabolic pathways of, 144
 nitrogenous wastes and, 983
 osmoregulation and, 980
 prokaryotic, 581t, 582f, 587
 protoctell, 527, 528f
 radioactive tracers in research on, 31–32
 regulation of cellular respiration and, 183f, 184
 role of enzymes as catalysts in, 75, 76f
 thermogenesis in animal, 887f–888f
 thyroid regulation of, 1009, 1015f
 Metabotropic receptors, 1080
 Metagenomics, 444, 583
 Metamorphosis, 674
 amphibian, 732f
 frog, 1015f
 insect, 711f, 1006f, 1007
 lancelet, 720
 tunicate, 721
 Metanephridium, 699f, 704f, 985f
 Metaphase (mitosis), 237, 239f, 243f, 252, 263f, 331f
 Metaphase chromosomes, 331f–332f
 Metaphase I, 260f, 263f
 Metaphase II, 261f
 Metaphase plate, 239f–240f, 262
 Metapopulations, 1206f, 1207
 Metastasis, 249f, 447–448
 Metazoans (Metazoa), 682, 683f, 684
 Meteorites, 527
 Methamphetamine, 62
 Methane
 carbon and bonds in, 59f
 combustion of, as redox reaction, 166f
 covalent bonding in, 37f
 molecular shape of, 39f, 40
 Methanogens, 585–586
Methanosarcina barkeri, 448t
 Methicillin, 478f
 Methicillin-resistant *Staphylococcus aureus* (MRSA), 214, 478f, 574, 589f, 590
 Methionine, 77f, 341f
 Methods, research. *See* Research Method Figures
 Methylated compounds, 63f
 Methylation, DNA, 371, 372f, 373, 391, 430
 Methyl group, 63f
 Methyl jasmonate, 855
 Methylsalicylic acid, 867f
 Mexico, 1208
 MHC (major histocompatibility complex) molecule, 959f–960f, 963, 964f, 969–970
 Mice. *See* Mouse
 Microarray analysis, 392f
 Microarray chips, human genome, 448f
 Microbial diversity, 1223f
 Microbiomes, 912, 913f
 Microcephaly, 409
 Microclimate, 1169–1170
 Microevolution, 487, 507. *See also* Evolution
 adaptive evolution by natural selection in, 497, 498f–503f, 504
 alteration of allele frequencies by natural selection, genetic drift, and gene flow in, 493, 494f–497f
 genetic variation and, 487f–488f, 489
 populations as smallest units of, 486f–487f
 speciation as conceptual bridge between macroevolution and, 507, 523. *See also* Macroevolution
 using Hardy–Weinberg equation to test, 489, 490f–491f, 492t, 493
 Microfibrils
 cellulose, 777f
 in plant cell walls, 118
 in structural polysaccharides, 70f
 Microfilaments, 115
 animal cell, 100f
 in animal cytokinesis, 241, 242f
 cytoskeleton structure and function and, 113t
 in morphogenesis, 1056f
 plant cell, 101f
 structure and function of, 115, 116f–117f
 Microglia, 1090f
 Micronuclei, ciliate, 606, 607f
 Micronutrients, plant, 810, 811t
 Microphylls, 631f
 Microplastics, 1163, 1277
 Micropyles, 647, 826
 MicroRNAs (miRNAs), 380f, 391, 678
 Microscopy, 94f–95f, 96
 Microsporangia, 638f, 826
 Microspores, 631, 638f, 826, 827f
 Microsporidians, 660f–661f
 Microsporocytes, 826
 Microtubule-organizing center, 240
 Microtubules, 114
 in animal cell, 100f
 in cell division, 238f–241f, 244f
 centrosomes, centrioles, and, 114f
 cilia, flagella, and, 114, 115f–116f
 cytoskeleton structure and function and, 113t
 in plant cell, 101f
 structure and function of, 114f–116f
 Microvilli, 98–99, 100f, 116f, 695f, 909f, 910
 Midbrain, 1085, 1091f–1092f
 Middle ear, 1113f
 Middle lamella, 118
 Midrib, 761
 Mifepristone (RU486), 1039
 Migration, 1140

- electromagnetic receptors and, 1111f
as fixed action pattern, 1140, 1141f
genetic variation in patterns of, 1156, 1157f
movement corridors and, 1271f, 1272
- Milk, mammalian, 741–742, 743f, 1005f–1008f, 1016
- Milk duct, 392f
- Milkweed, 645f, 653
- Miller, Stanley, 57f, 58, 526f
- Millipedes, 708, 709f
- Mimic octopus, 1219f
- Mimicry
endorphin, 1081
molecular, 40f, 78
in prey and predator adaptations, 1218f–1219f, 1237
as prey defensive adaptation, 868f
- Mimivirus*, 408
- Mimosa pudica*, 802, 862f
- Mimulus* species, 522f
- Mineralized dental elements, 724f, 725
- Mineralized organic matter, 529f
- Mineralocorticoids, 1004f, 1012f, **1014**
- Minerals, 899f, **900**, 901t
deficiencies of, in plants, 810, 811t, 812
mineralocorticoids and metabolism of, 1014
mycorrhizae and plant deficiencies of, 818
root architecture and acquisition of, 787
roots interaction with, 10f, 11
transpiration of, from roots to shoots via xylem, 792, 793f–795f, 796
vascular plant transport of, 787, 788f–791f
- Mines, restoration of, 1253f
- Miniaturization, gametophyte, 637f, 638
- Minimal medium, 336f–338f
- Minimum viable population (MVP), **1268**
- Minnows, 1143f, 1276
- Mirounga angustirostris*, 999f, 1267
- Miscarriages, 306, 1039
- Misfolding, protein, 83
- Mismatch repairs, **327**
- Missense mutations, **357**, 358f
- Mississippi River, 1275f
- Mistletoe, 819f
- Mitchell, Peter, 177
- Mites, 707, 708f
- Mitochondria, **109**
animal cell, 100f
animal hibernation and, 178
in apoptosis, 230f, 231
ATP synthase and, 186
chemical energy conversion by, 109–110, 111f
chemiosmosis in, 175, 176f, 177, 199f–200f, 201
dinitrophenol and, 186
electron transport chains in, 168–169
endosymbiotic origin of, 534, 535f
enzymes in, 161f
evolutionary origins of, 109, 110f
fungal cell, 100f
inheritance of genes of, 311
origin of, in endosymbiosis, 595, 596f–597f
plant cell, 101f, 209f
protist, 594
pyruvate in, 171f
using cell fractionation to study, 97
- Mitochondria DNA (mtDNA)
evolutionary rate of, 565
species identity in, 557f
- Mitochondrial matrix, **110**
- Mitochondrial myopathy, 311
- Mitosis, **236**. *See also* Cell cycle; Cell division
in animal cells, 238f–239f
in chromatin packing, 332f
in daughter cells, 234
evolution of, 243, 244f
in human life cycle, 257f, 258
information in, 252
meiosis vs., 262, 263f, 264
nuclear envelope during, 252
origin of term for, 237
in plant cells, 241, 242f–243f
in spermatogenesis, 1042
in varieties of sexual life cycles, 258f, 259
- Mitosomes, 600f
- Mitotic (M) phase, **237f**
- Mitotic spindles, **240f**–**241f**
- Mixotrophs, **594**
- Mobile genetic elements, evolution of viruses and, 408
- Mobile River basin, 1264
- Model organisms, **22**, **1044**. *See also* *Drosophila melanogaster*; *Escherichia coli* bacteria
Arabidopsis thaliana, 22, 774, 776f, 783
bread mold. *See* *Neurospora crassa*
Caenorhabditis elegans, 22, 705
in developmental biology, 1044
for DNA research, 316f, 317
mouse (*Mus musculus*), 22. *See also* Mouse
Neurospora crassa, 664f, 665f
scientific cooperation and, 22–23
for T. Morgan's experiments, 295f
- Models
atomic, 30f
community disturbance, 1228, 1229f
of covalent bonds, 36, 37f
electron orbital, 35f
exponential population growth, 1196, 1197f, 1207f, 1208
island equilibrium, 1232, 1233f
logistic population growth, 1197, 1198f–1199f, 1198t, 1200
molecular-shape, 39f
optimal foraging, 1149f
process of science, 19f
testing hypotheses with quantitative in Scientific Skills Exercise, 1150
- Modified leaves, 762f
- Modified roots, 760f
- Modified stems, 761f
- Mojica, Francisco, 253
- Molarity, **50**
- Molar mass, 50
- Molar ratios in Scientific Skills Exercise, 58
- Mold model organism. *See* *Neurospora crassa*
- Molds, **658f**–**659f**, 662f, 663
- Molecular basis of inheritance
chromatin packing of DNA and proteins in eukaryotic chromosomes, 330f–332f
discovery of double helix structure of DNA in, 314f, 317, 318f–320f
DNA replication and repair in. *See* DNA replication
evidence for DNA as genetic material in, 315f–317f, 318
evolution of gene concept from, 361
- Molecular biology
Arabidopsis thaliana as model organism for, 774, 776f
determination of microbial diversity using, 1223f
importance of viruses to, 400
measures of evolution in, 87, 89
mutants in, 845
of plant development, 775f–780f
- Molecular clocks, **566**, 567f–568f, 659f, 660
- Molecular formulas, 36, 37f, 59f
- Molecular genetics, in ecological forensics, 1265f
- Molecular genetic variation, 487, 488f
- Molecular homologies, 479–480, 558, 559f
- Molecular identification tags, 107
- Molecular-level herbivore defenses, plant, 868f
- Molecular mass, **50**
- Molecular recognition, immune system, 953, 957f
- Molecular systematics, 563f, 583, 682, 683f, 684.
See also Cladistics; Systematics; Taxonomy
- Molecular tags, 332f
- Molecules, **5f**, **36**. *See also* Compounds
biological. *See* Biological molecules
chemical bonds and formation of. *See* Chemical bonds
as level of biological organization, 5f
organic. *See* Organic compounds
origin of self-replicating, 526f–528f
regulation of interactions of, 10f
shape and function of, 39f–40f, 59f
structure of DNA and RNA, 7f–8f
- Moles, 1107f–1108f
- Moles (animal), 558f, 559
- Moles (mol), **50**, **58**
- Molluscs, 688f
bivalves, 699, 701f–702f
body plan of, 699f
cephalopods, 699, 701f, 702
chitons, 699f
in Ediacaran period, 535f, 536
eye complexity in, 547f–548f
gastropods, 542, 699, 700f–701f, 702
nervous systems of, 1086f
- protecting freshwater and terrestrial, from extinction, 702f
- Moloch horridus*, 737f
- Molothrus ater*, 1271, 1287
- Moltung (ecdysis), 683–684, **705**, 707, 894f
- Monarch butterflies (*Danaus plexippus*), 839, 1146f
- Monera kingdom, 568
- Monilophytes, **622**, 622t
- Monkey flowers, 522f, 834
- Monkeys, 56f, 87, 89, 746f–747f, 1122f. *See also* Chimpanzees
- Monocilia, 1064
- Monoclonal antibodies, **969**
- Monocots, **649f**–**650f**, 761, 769f–770f, 829f–830f
- Monocytes, 934f–935f
- Monod, Jacques, 366
- Monogamous mating, 1024, **1149**–1150, 1151f
- Monoglycerides, 910f
- Monohybrid crosses, **274**
- Monohybrids, **274**
- Monomers, **67f**
- Monophyletic groups, **560f**
- Monosaccharides, **68f**–**69f**
- Monosodium glutamate, 1123
- Monosomal cells, **307**
- Monosity X, 309
- Monotremes, 543f, **742**, 743f, 745f
- Monozygotic twins, 1036, 1061
- Monterey County, California, 614f
- Montmorillonite clay, 527, 528f
- Montreal Protocol, 1284
- Moon jelly, 922f
- Moose, 1205f
- Moray eel (*Gymnothorax dovi*), 729f, 1214f
- Morels, **663f**, 670
- Morgan, Thomas Hunt, 295f–296f, 301f–303f, 315
- Mormon tea, 642f
- Morning-after birth control pills, 1038f
- Morning sickness, 65, 1036
- Morphine, 40f, 78
- Morphogenesis, **381**–**382**, **1049**. *See also* Embryonic development; Pattern formation
apoptosis in, 1056–1057
cytoskeletons in, 1056f–1057f
developmental adaptations of amniotes in, 1053f, 1054
gastrulation in, 1044, 1049, 1050f–1053f
organogenesis in, 1044, 1049, 1054f–1055f
plant development and, 776–777, 778f
- Morphogen gradients, 386
- Morphogens, **386f**–**387f**
- Morphological homologies, 558
- Morphological isolation, 508f
- Morphological species concept, **510**
- Morphology
animal phylogeny and, 682, 683f, 684
fungal, 655f–656f
macroevolution of, 544f–546f, 547
species concepts and, 507
- Mortality rates. *See* Deaths
- Morton, Michael, 24f
- Mosaicism, 300f
- Mosquitoes, 409, 412f, 485, 496, 503f, 518, 606f, 712f, 713
- Mosquitofish (*Gambusia hubbsi*), 511f, 512
- Mosquito larva, 342f
- Mosses, 621f, **623**, 624f–627f, 628, 635, 637f. *See also* Bryophytes
- Mossy leaf-tailed gecko, 26
- Moths, 43, 476f, 551, 712f, 717, 824f, 1001, 1006f, 1007, 1110, 1111f
- Motile cilia, 1064
- Motility, prokaryotic, 576f, 577
- Motor, flagellum, 576f, 577
- Motor areas, cerebral cortex, 1096
- Motor cortex, 1097f, 1098
- Motor neurons, 1068, 1069f, **1088f**, 1128, 1129f–1130f
- Motor output stage, 1068f
- Motor proteins, 76f, **113f**, 115, 116f, 123f, 152f, 241f, 252
- Motor systems, **1088**
cardiac and smooth muscle in, 1131–1132
muscle function in, 1125, 1126f–1131f, 1132
sensory systems and, 1107f–1108f. *See also* Sensory systems
skeletal muscle contraction in, 1127f–1131f
skeletal systems and locomotion in, 1132f–1135f, 1136

- Motor unit, **1130f**
 Mountain lions, 1149
 Mountain pine beetles (*Dendroctonus ponderosae*), 1244f, 1245, 1280f
 Mountains, 1168, 1169f
 Mount Kilimanjaro, 1189
 Mount St. Helens, 636f, 637
 Mouse (mice), 22
 agouti gene and, 372f
 appetite regulation in, 918
 brains of, 1086f
 comparing human genome with genome of, 454, 455f, 460f–462f
 complete genome sequence for, 454, 455f
 density-dependent population regulation of, 1204f
 energy budgets of, 892
 FOXP2 gene evolution in, 461, 462f
 genomic imprinting of insulin-like growth factor gene of, 310f, 311
 homeotic genes in, 463f
 as model organisms. *See Mus musculus*
 modes of natural selection in, 498f
 osmotic homeostasis in desert, 981
 paw development of, 231f
 transfer of genetic trait between bacterial strains in, 315f
 Mouse (*Peromyscus polionotus*), camouflage case studies with, 2f, 20f–21f, 23
 Mouse model organism, 22
 Mouth formation, 1050f
 Movement, prokaryotic, 576f, 577
 Movement corridors, **1271f**, 1272
 MPF (maturation-promoting factor), **245**, 246f
mpges-1 gene, 376
 MRSA, 214, 478f
 Mucoromycetes, 660f, **663f**
 Mucous cells, 907f
 Mucus, **906**, 907f, 954
 Mucus escalator, 943
 Mule deer, 871, 1149
 Mules, 509f
 Muller, Hermann, 360
 Müllerian mimicry, **1218f**, **1219**
 Multicellular asexual reproduction, 255f
 Multicellular organisms, 5f, 93, 533f, 535f–536f, 675f–676f
 Multienzyme complexes, 161
 Multifactorial characters, **282f**
 Multifactorial disorders, human, 287
 Multigene families, 452, **453f**
 Multiple fruits, **831f**
 Multiple myeloma, 65
 Multiple sclerosis, 971
 Multiplication rule, **277f**, 278
 Multiprotein complexes, 174f, 175
 Mumps, 409
 Murchison meteorite, 527
Muscardinus avellanarius, 893f
 Muscle
 cardiac and smooth, 1131–1132
 contraction of, 1126, 1127f, 1128
 regulation of contraction of, 1128, 1129f–1130f
 skeletal. *See* Skeletal muscle
 Muscle cells, 117f, 383, 384f, 673, 915
 Muscle fibers, 879f, 1130, 1131t
 Muscle tissue, **879f**
 Muscular dystrophy, 299, 433
 Mushrooms, 654f, 655, 665f–667f, 670. *See also* Fungi
Mus musculus (mouse), 22. *See also* Mouse
 Mussels, 505, 701f, 702f, 1264
 Mustard plant model organism. *See Arabidopsis thaliana*
 Mutagens, **360**
 Mutant phenotypes, 295f–296f
 Mutants
 designing experiments using genetic, 1095
 interpreting data from experiments with genetic, 918
 in molecular biology, 845
 nutritional, in gene-enzyme relationship experiment, 336f–338f
 Mutations, **357f**
 in alterations of chromosome structure, 454f–455f
 in aquaporins causing diabetes insipidus, 995f
 in cancer development, 391f, 394
 cancer genes and, 388, 389f
 cellular slime mold, 613
 CRISPR-Cas9 and gene editing for, 426, 434–435
 of developmental genes, 545f–546f
 in duplication and divergence of gene-sized regions, 455f–457f
 in duplication of entire chromosome sets, 454
 effects of, during cell division, 389f–390f
 as embryonic lethals, 386
 as errors in proofreading, 327
 evolution and rate of, 334
 evolution of enzymes by, 159f
 in exon duplication and exon shuffling, 456, 457f
 in flowering, 779f–780f
 gene editing to correct, 360, 361f
 genetic variation from, 305f–306f
 genome evolution and, 454f–457f, 458–459
 Hardy-Weinberg equilibrium and, 492t
 of ion channel protein genes, 1076
 in mitochondrial DNA, 311
 molecular clock speed and, 566, 567f
 mutagens as cause of, 360
 natural selection and, 328
 nucleotide-pair substitutions, insertions, and deletions, 357, 358f, 359
 phenotypes and, 295f–296f, 306f
 plants and creation of, in molecular biology, 776
 point mutations, 357f–358f, 359
 in prokaryotes, 573, 578–579
 as source of alleles, 265
 as sources of genetic variation, 488–489
 transposable elements and, 459
 of viruses, 409, 414
 Mutualism, **587**, **1220**, 1256f–1257f
 bacterial, 587f
 in flower pollination, 825f
 fungal, 655, 661f, 667f–669f. *See also* Mycorrhizae
 as interspecific interaction, 1220f, 1221
 across kingdoms and domains, 813f
 mycorrhizae as plant-fungi, 787, 817, 818f
 nutrient limitations and, 1244
 plant-bacteria, 813f–816f, 817
 in vertebrate digestive systems, 912, 913f–914f
 Myasthenia gravis, 1129
 Mycelium (mycelia), 655f–659f, **656**, 662f
 Myctozoans, 612f–613f
Mycobacterium tuberculosis, 589, 957
 Mycorrhizae, **656**, **787**, **817**
 basidiomycetes in, 665
 biological augmentation using, 1255
 in colonization of land by plants, 536, 537f
 evolution of, 660
 genomic analysis of interactions of, 657
 as mutualism, 1220–1221
 nutrient limitations and, 1244
 plant nutrition and, 817, 818f
 plant roots and, 760
 as root-fungi mutualism, 787
 specialized hyphae in, 656f, 657
 strigolactones and, 855
 terrestrial plants and, 621
 Mycorrhizal associations, 760
 Mycosis, **670**
 Myelination, 1076f–1077f
 Myelin sheath, **1076f**–1077f
 Myeloid stem cells, 935f
Myllorhynchia fengjiaoae, 718f, 724
 Myoblasts, 383, 384f
 Myocardial infarctions, 937f, 938–939
 MyoD activator, 374f
myoD gene, 383, 384f
 Myofibrils, **1126f**
 Myoglobin, **949**, **1130**, 1131t
 Myopathy, 311
 Myosin, 76f, **117**, 241, 384f, 879f
 Myosin filaments, 1125, 1126f–1127f
 Myotonia, 1034, 1076
 Myriapods, **707**–708, 709f
Myrmecocystus, 485
Mytilus edulis, 505
 Myxini (hagfishes), 719f, 723f
 Myxobacteria, 213f
Myxococcus xanthus, 213f
- N**
 NAD⁺ (nicotinamide adenine dinucleotide), **167f**–168f, 172f–173f, 178, 180f, 181
 NADH, 172f–173f, 178, 180f, 181
 NADP⁺ (nicotinamide adenine dinucleotide phosphate), **191f**, 192, 206, 207f
 NADPH, **191f**, 192, 197f–198f, 206, 207f
 Naked mole rats, 1157f, 1158
 Naloxone, 1082
 Nanopores, 416
 Nasal glands, marine bird, 982f
 Nash, John, 1154
 National Cancer Institute, 447
 National Center for Biotechnology Information (NCBI), 444, 445f
 National Institutes of Health (NIH), 444, 447
 National Library of Medicine (NLM), 444
 National Medal of Science, 944
 Native Americans, 565
 Natural family planning, 1037, 1038f
 Natural killer (NK) cells, **955**
 Natural logarithms in Scientific Skills Exercise, 639
 Natural plastics, 590, 591f
 Natural range expansions, 1183, 1184f
 Natural selection, **14**, **473**. *See also* Adaptations; Evolution
 adaptations and, 472, 473f
 adaptive evolution and, 494
 Darwinian theory of descent with modification by, 14f–16f, 469–470, 473f–476f, 483–484
 of developmental genes, 545
 directional, disruptive, and stabilizing selection in, 497, 498f
 of ecological niches, 1215, 1216f
 evolution of drug resistance by, 478f
 evolution of enzymes by, 159f
 in evolution of life history traits, 1200, 1201f–1202f
 genetic variation for, from genetic recombination, 305
 Hardy-Weinberg equilibrium and, 492t
 insect evolution by, due to food source changes, 477f, 478
 key role of, in adaptive evolution, 498, 499f
 limitations of, in creating perfect organisms, 501f, 504
 in macroevolution, 551
 mutations and, 328
 predator role in, 26
 relative fitness and, 497
 of ribozymes, 528
 sexual reproduction, genetic variation, and, 266, 267f
 species selection as, 548–549
 Natural vs. supernatural explanations, 18
 Nature reserves
 philosophy of, 1272–1273
 zoned reserves and, 1273f
 Nature vs. nurture, 282f, 762
 Nautilus, chambered, 701f, 702
 ncRNAs, 379, 380f, 381
 Neanderthals (*Homo neanderthalensis*), 33, 88f, 461, 752f–753f
 Near vision, 1122f
 Nectar guides, 824f
 Nectaries, 813f
 Nectarine, 645f
 Negative and positive correlations, 834
 Negative feedback, **882**, **1005**
 in density-dependent population growth, 1203
 in endocrine system feedback regulation, 1005–1006
 in feedback regulation, 10f
 in homeostasis, 882
 Negative gene regulation, bacterial, 369
 Negative gravitropism, 861
 Negative pressure breathing, **945f**, 946
Neisseria gonorrhoeae, 576, 584f
 Nematocysts, **691**, 692f
 Nematode model organism. *See Caenorhabditis elegans*
 Nematodes, 689f, 705f, 706, 1058f–1059f, 1133f
 Nemertea, 688f
Nemoria arizonaria, 488f
Neodenticula seminae (diatom), 1170
 Neon, 35f
 Neonatal diabetes, 359
 Neoproterozoic era, 530f, 676f–677f
 Neornithes, 739
 NEP. *See* Net ecosystem production
 Nephrons, **986f**

- Bowman's capsule in, 987f
evolution adaptations of, 991f–992f
processing of blood filtrate to urine by, 987, 988f, 989
solute gradients and water conservation in, 989, 990f, 991
structure of mammalian kidneys and, 986f–987f
- Nereimyra punctata*, 703f
- Neritic zones, **1182f**
- Nernst equation, 1071f
- Nerodia sipedon*, 496, 497f
- Nerve cells, 673
- Nerve cord, 710f, 720f, 722f
- Nerve gas, 1081
- Nerve nets, 692, 1086f
- Nerves, **1086**
- Nervous systems, **880**, **1000**. *See also* Central nervous system; Peripheral nervous system
- cerebral cortex control of voluntary movement and cognitive functions in, 1096, 1097f–1099f
 - disorders of, 1102f–1104f
 - endocrine system coordination with, 1000f, 1001, 1006f–1008f
 - faulty apoptosis in diseases of human, 231
 - genome and, 1106
 - Huntington's disease and, 287
 - long-distance cell signaling in, 215f, 216
 - memory, learning, and changes of synaptic connections in, 1099, 1100f–1101f
 - neurons and cell signaling in, 880f. *See also* Neurons
 - organization of, 1086f, 1087
 - regulation of blood pressure by, 931
 - regulation of digestion by, 915
 - regulation of heart rhythm by, 928
 - regulation of human breathing by, 946f
 - regulation of skeletal muscle contraction by, 1128, 1129f, 1130
 - research methods for studying brains and, 1085f
 - synaptic and neuroendocrine signaling of, 1000f, 1001. *See also* Neuroendocrine signaling
 - vertebrate, 1087f–1090f
 - vertebrate brain in, 1091f–1096f
- Nervous tissue, **879f**
- Nests
- of birds and dinosaurs, 564f, 565
 - red-cockaded woodpecker, 1269f–1270f
- Net ecosystem production (NEP), **1242**
- climate change effects on, 1244f, 1245
- Net primary production (NPP), **1241**, 1242f, 1259
- climate change effects on, 1244f, 1245
 - in terrestrial ecosystems, 1243f–1244f, 1245
- Neural crest, **722**, 723f, 1054f, **1055**
- Neural pathways, 1121f
- Neural plate, 1054f
- Neural tube birth defects, human, 902f
- Neural tubes, 1054f, **1055**
- Neuraminidase, 410, 414
- Neurodegenerative diseases, 413
- Neuroendocrine signaling. *See also* Endocrine systems; Nervous systems
- coordination of endocrine and nervous systems in, 1000f, 1001, 1006f–1008f
 - endocrine glands and hormones for, 1004f
 - feedback regulation in of, 1005–1006
 - invertebrate, 1006f, 1007
 - simple pathway of, 1005f
 - vertebrate, 1007f–1008f
- Neurofibrillary tangles, 1104f
- Neurohormones, 1000f, **1001**, 1005f–1007f
- Neuromuscular junctions, 1080
- Neuronal plasticity, **1100f**
- Neurons, **879f**, **1068**
- action potentials of, as signals conducted by axons, 1072f–1077f
 - in cell signaling by animal nervous systems, 880f
 - chemical and electrical signals of, 1067f, 1068
 - communication between cells and, at synapses, 1077, 1078f–1080f, 1081t, 1082
 - exocytosis and, 139
 - in human eye, 1118f
 - ion pumps, ion channels, and resting potential of, 1070f–1071f
 - in nervous systems, 1085f, 1086, 1088f, 1089.
 - *See also* Nervous systems
- in neuroendocrine signaling, 1000f, 1001
- olfactory, 1124, 1125f
- organization of, 1084
- plasticity of, in memory and learning, 1099, 1100f–1101f
- in sensory reception, 1108f–1109f
- structure and function of, in information transfer, 1068f–1069f
- Neuropathy, 311
- Neuropeptides, **1081t**
- Neurospora crassa* (bread mold), 336f–338f, 664f, 665t
- Neurotransmitters, **1001**, **1068**
- as chemical messengers of neurons, 1068
 - exocytosis and, 139
 - mechanisms of terminating, 1080f
 - synaptic signaling by, 1077, 1078f, 1080
 - types of, 1080–1082, 1081t
- Neurulation, 1054f, 1055
- Neutralization, 965f
- Neutral mutations, 567
- Neutral variation, **489**
- Neutrons, **30f**, 31
- Neutrophils, 934f–935f, **955f**
- Newborn screening, 289–290
- New Caledonian crows, 1099
- New Guinea, 742
- Newton, Isaac, 22
- Newts, 7f, 238f–239f
- New World monkeys, 746f–747f
- New York City, Catskill Mountain purchase by, 1263
- New Zealand, restoration projects in, 1254f
- Next-generation DNA sequencing, 415f–417f, 443f
- Nicotinamide adenine dinucleotide (NAD⁺), **167f**–168f, 172f–173f, 178, 180f, 181
- Nicotinamide adenine dinucleotide phosphate (NADP⁺), **191f**, 192, 206, 207f
- Nicotine, 1080, 1103f, 1220
- Night length, flowering and, 859f, 860
- Nirenberg, Marshall, 341
- Nitrates, 1275f
- deforestation effects on, 1252f
 - in nitrogen cycle, 1251f
- Nitric oxide (NO), 220, 224, 931, **1001**, 1026, 1081t, 1082
- Nitrification, 815f
- Nitrifying bacteria, 815f, 1251f
- Nitrite, in nitrogen cycle, 1251f
- Nitrogen
- algal blooms and, 1242, 1243f
 - bacteria in plant acquisition of, 814f–816f, 817
 - bryophyte reduction of leaching of, from soil, 627f
 - as essential element, 29t, 64
 - as limiting nutrient, 1242, 1243f, 1243t, 1244
 - nutrient enrichment and pollution by, 1275f
 - in organic compounds, 59f
 - prokaryotic chemical recycling of, 586
 - soil, in ecological succession, 1230, 1231f
 - soil fertilization and, 805, 808
- Nitrogen cycle, **815f**, 821, 1251f, 1257f
- Nitrogen fixation, **582**, **586**, **815f**
- bacterial, 814f–816f, 817, 821, 1244
 - biological augmentation using, 1255
 - bryophyte, 626f, 627
 - forest floor moss and, 635
 - lichens and, 668–669
 - in nitrogen cycle, 1251f
 - prokaryotic, 582, 592
- Nitrogenous bases, 84, 85f, 317f, 318. *See also* Nucleotides
- Nitrogenous wastes, 977–978, 982f–983f
- Nitrogen oxide emissions, 1266
- NMDA receptors, 1101f
- NO (nitric oxide), 220, 224, 931, **1001**, 1026, 1081t, 1082
- Nobel Prize winners
- B. Marshall and R. Warren, 912
 - B. McClintock, 451
 - C. Nüsslein-Volhard, E. Wieschaus, and E. Lewis, 386
 - for discovery of ncRNAs, 380
 - for discovery of Toll receptor in insects, 954
 - E. Sutherland, 216
 - F. Jacob, 547
 - F. Sanger, 416
 - G. Beadle and E. Tatum, 337
 - H. zur Hausen, 974
- J. Gurdon and S. Yamanaka, 430, 432
- J. Hall, M. Rosbash, and M. Young, 883
- J. Watson, F. Crick, and M. Wilkins, 320
- N. Tinbergen, 1140
- P. Mitchell, 177
- R. Axel and L. Buck, 1124
- S. Brenner, R. Horvitz, and J. Sulston, 1058–1059
- S. Prusiner, 413
- Nociceptors, **1111**–1112
- Nodes, lymph, 933f
- Nodes, plant stem, **761**
- Nodes of Ranvier, **1076f**–1077f
- Nodules, **816f**, 817
- Nomarski microscopy, 95f
- Nonbreeding adults, territoriality and, 1204f
- Noncoding DNA, 449, 450f–451f, 452
- Noncoding RNAs (ncRNAs), 379, 380f, 381
- Noncompetitive inhibitors, **158**, **159f**
- Nondisjunction, **307f**, 309
- Nonequilibrium model, community, **1228**
- Nonheritable variation, 488f
- Nonidentical DNA sequences, 453f
- Non-insulin-dependent diabetes, 917
- Nonkinetochore microtubules, 238f, 240f, 241, 252
- Non-native species, 1264f
- Nonpolar covalent bonds, **37**
- Nonpolar side chains, 76, 77f
- Nonrenewable resources, human population size and, 1210f, 1211
- Nonsense mutations, **358f**, 359
- Nonshivering thermogenesis, 887f
- Nonsister chromatids, 257f, 262, 264, 266f
- Nonspontaneous processes, 146
- Nonsteroidal anti-inflammatory drugs (NSAIDs), 1013–1014
- Nonsteroid hormones, 376
- Nontemplate DNA strand, 340f
- Nonvascular plants. *See* Bryophytes
- Norepinephrine (noradrenaline), 1004f, **1012f**–1013f, 1081t
- Nori, 609f, 610
- Normal range, homeostatic, 882
- North America, 743–744
- North Atlantic Subtropical Gyre, 1168f
- Northern coniferous forests, **1175f**
- Northern red maple tree leaves, 762
- Northern white rhinoceros (*Ceratotherium simum cottoni*), 1266
- North Pacific Subtropical Gyre, 1168f
- Nosema ceranae*, 661
- Notation system, gene, 295
- No-till agriculture, **809**
- Notochords, **720f**, **1054f**, 1055
- Novelties, evolutionary, 547, 548f
- NPP. *See* Net primary production
- N-terminus, 78f, 352, 371f
- Nucifraga columbiana*, 1146
- Nuclear envelopes, 100f–101f, **102**, 103f, 109f, 252, 332, 339f, 355
- Nucleariids, 614, **659**
- Nuclear lamina, **102**, 103f, 117, 332
- Nuclear magnetic resonance (NMR) spectroscopy, 83
- Nuclear matrix, 102, 326, 332
- Nuclear responses, cell-signaling, 226f
- Nuclear transplantation, animal cloning and, 428, 429f–430f
- Nucleases, **327**
- Nucleic acid hybridization, **416**
- Nucleic acid probes, **423**, 433
- Nucleic acids, **84**. *See also* DNA; RNA
- components of, 84, 85f
 - digestion of, 908f
 - genes, nucleotides, and, 84f. *See also* Genes
 - as genetic material, 315. *See also* DNA
 - as macromolecules, 66
 - as nucleotide polymers, 85
 - roles in, gene expression, 84f. *See also* Gene expression
 - separating, with gel electrophoresis, 420f
 - structures of molecules of, 86f
 - viral, 400, 401f–407f, 406t
- Nucleoids, **97f**, **577**
- Nucleolus, 100f–101f, **102**, 103f
- Nucleomorphs, 597f
- Nucleosides, 84, 85f
- Nucleoside triphosphates, 324
- Nucleosomes, **330f**

- Nucleotide excision repairs, 327, 328f
 Nucleotide-pair insertions and deletions, 358f
 Nucleotide-pair substitutions, 357, 358f
 Nucleotides, 84. *See also* Nucleic acids
 coding and noncoding, 345f–347f
 as components of nucleic acids, 84, 85f
 in DNA-sequencing techniques, 415f–417f
 DNA vs. RNA, 337
 evolutionary significance of altered DNA, 328
 in genetic code, 7f–8f, 340f–341f
 genomics and proteomics in study of, 86, 87f
 mutations as base-pair substitutions, insertions, and deletions of, 357, 358f, 359
 ratios of, 317f, 318
 in telomeres, 328, 329f
 variability of, in genetic variation, 488f
 Nucleus, atomic, 30f, 31
 Nucleus, cell, 102
 animal cell, 100f
 cell division of, 236, 243, 244f. *See also* Cell cycle; Cell division
 cell-signaling responses in, 226f
 ciliate types of, 606, 607f
 DNA in eukaryotic cell, 97, 102, 103f
 fungal cell, 100f
 hormone receptors in, 1002f–1003f
 plant cell, 101f
 regulation of gene expression and architecture of, 377, 378f
 reproductive cloning by transplantation of eukaryotic, 428, 429f–430f
 Nucleus accumbens, 1096f, 1103f
 Nudibranchs, 700f, 1020f
 Number, offspring, 1200, 1201f–1202f
 Nursing, 1005f–1008f, 1036
 Nurture vs. nature, 282f, 762
 Nüsslein-Volhard, Christiane, 386, 387f
 Nutrient cycling. *See also* Energy flow and chemical cycling
 biogeochemical cycles, 1249f–1252f
 decomposition and nutrient cycling rates in, 1248f, 1249
 in Hubbard Brook Experimental Forest, 1252f
 Nutrient enrichment, global, 1274, 1275f
 Nutrients
 cycling of. *See* Energy flow and chemical cycling
 enrichment experiments with, 1242, 1243f, 1243t
 essential, 899f, 900t–901t, 901f
 limiting, 1242, 1243f–1244f, 1243t
 plant and animal absorption of, 895f
 prokaryotic recycling of, 586f
 small intestine and, 125
 uptake of, 898
 Nutrition, 899. *See also* Animal nutrition; Plant nutrition
 essential elements and trace elements for, 29t
 Eukarya kingdoms and, 12f, 13
 fungal, 655–656
 prokaryotic, 581t, 582f
 protist, 594
 Nymphs, 711
- O**
- Oak Ridge National Laboratory, bioremediation of, 1255f
 Oak trees, 614f, 650f, 1201f
Obelia, 692f–693f
 Obesity, 372f, 917f, 918, 1018
ob gene, 918
 Object play, 1159
 Obligate aerobes, 582
 Obligate anaerobes, 181, 582
 Observations
 of evolutionary change, 477f–478f
 scientific, 17f, 19f
 in Scientific Skills Exercise, 812
 Occam's razor, 562
 Occipital lobe, 1085, 1097f
 Ocean acidification, 53f, 54–55
 Ocean currents, climate and, 1168f–1169f
 Oceanic pelagic zone, 1181f
 Oceans
 acidification of, 53f, 54
 climate and currents of, 1168f–1169f
 marine benthic zones of, 1182f
 as marine biome, 1177f, 1178
 moderation of climate by, 47f
 pelagic zones of, 1181f
 plastic waste in, 1277f
 primary production in, 1242, 1243f, 1243t
 tides of, 1181f
 trawling of, as community disturbance, 1231f
 Ocello, 1117f
 Ocelloid, 594f
Ochotona princeps, 1280f
 Ocotillo, 799f
 Octopus, 688f, 699, 701f, 702, 1219f
Odocoileus virginianus, 1271
 Odorant receptors (ORs), 1124, 1125f
 Odorants, 1123–1124, 1125f
 Offspring
 life history traits in survival of, 1200, 1201f–1202f
 survival of, 1023f
 Oil. *See also* Fossil fuels
 conodonts and, 725
 Oil spills, 591f. *See also* Fossil fuels
 Okazaki fragments, 324, 325f
 Old World monkeys, 746f–747f
 Olden, Kenneth, 27
 Oleander, 799f
 Olfaction, 1123–1124, 1125f
 Olfactory bulb, 1091f, 1095f, 1124, 1125f
 Olfactory receptor genes, human, 489, 566
 Oligochaetes, 703
 Oligodendrocytes, 1076f–1077f, 1090f
 Oligotrophic lakes, 1179f
 Omasum, 914f
 Ommatidia, 1117f
 Omnivores, 901, 911f, 912
 Oncogenes, 388, 389f, 391f
Oncorhynchus keta, 89
Oncorhynchus kisutch, 89, 1200
Oncorhynchus nerka, 978f
 One gene–one enzyme hypothesis, 336–337, 338f, 665
 One gene–one polypeptide hypothesis, 337
 One gene–one protein hypothesis, 337
 One-shot reproduction, 1200
 Onion, 252
On the Origin of Species by Means of Natural Selection (Darwin, C.), 14f, 469, 473, 483–484, 487
 Onychophorans, 689f
 Oocytes, 1026, 1027f, 1029f
 Oogenesis, 1027, 1029f
 Oonoria, 1029f
 Oomycetes, 604f
 Oparin, A. I., 526
 Oparin–Haldane hypothesis, 526
 Open circulatory systems, 699f, 707, 923f
 Open systems, 145, 150f
 Operant conditioning, 1146
 Operators, 366, 367f
 Operculum, 728f
 Operon model, 366
 Operons, 367
 basic concept of, 366, 367f
 inducible, 368f, 369
 positive gene regulation and, 369f, 370
 repressible, 367f, 368–369f
Ophisaurus apodus, 553f–554f
 Ophiuroidea, 714f, 715
Ophrys speculum, 822f
 Opiates, 40f, 78, 1082
 Opioids, 1103f
 Opisthokonts, 613–614, 659
 Opium poppy, 868f
 Opossums, 743
 Opposable thumb, 744
 Opposite phyllotaxy, 786
 Opsin, 1119f, 1122
 Opsonization, 965f
 Optic chiasm, 1121f
 Optic disk, 1118f
 Optic nerves, 1121f
 Optic neuropathy, 311
 Optimal conditions, enzymatic catalysis, 157, 158f
 Optimal foraging model, 1149f
 Oral cavity, 905, 906f, 908f
 Orangutans, 746f–747f, 750
 Orbitals, electron, 35f, 36, 39f, 40
 Orchid mantis, 468f, 469
 Orchids, 650f, 822f, 825f
 Order, as property of life, 3f, 146f, 147
 Orders, taxonomy, 554, 555f
- Ordovician period global climate change, 629
 Organelles, 5f, 94
 as enzyme locations, 161f
 of eukaryotic cells, 97f–101f
 inheritance of genes in, 311f
 as level of biological organization, 5f
 lysosomal digestion of, 107f, 108
 plastids in plant cells, 111
 of prokaryotic cells, 97f, 98
 using electron microscopy to study, 94
 Organic acid, 63f
 Organic chemistry, 57f, 58
 Organic compounds. *See also* Biological molecules
 abiotic synthesis of, 57f, 58, 526f–527f
 ATP as, 64
 bonding of carbon atoms in, 58, 59f, 60
 carbon in, as backbone of life, 56, 64
 chemical functional groups and, 62f–63f
 diversity of, 60f–62f
 organic chemistry as study of, 57f, 58
 in plant cells, 209f
 working with moles and molar ratios of, 58
 Organic fertilizers, 808, 983
 Organic phosphate, 63f
 Organismal cloning
 of animals, 428, 429f–430f
 of animal stem cells, 428, 430f–432f
 of plants, 428
 Organismal ecology, 1165f. *See also* Ecology; Organisms
 Organismal-level herbivore defenses, plant, 869f
 Organisms, 4f. *See also* Animals; Fungi; Life; Plants
 acidic and basic conditions affecting, 51, 52f–53f, 54
 adaptations of, to environments, 468f. *See also* Adaptations
 Cambrian explosion in numbers of, 536f
 carbon in organic compounds of, 56, 64
 cells as fundamental units of, 6f, 93f. *See also* Cells
 climate change effects on, 1280f
 cloning of. *See* Organismal cloning
 differential gene expression in multicellular. *See* Differential gene expression
 DNA in development of, 7f–8f
 ecology as interactions between environment and. *See* Ecology
 ecosystem interactions of, 10f–11f
 effects of continental drift on, 539–540
 effects of sickle-cell disease on, 503f
 effects of speciation and extinctions on diversity of, 537f
 elemental ratio in, 43
 environment interactions with, 1165, 1178, 1183f–1186f
 genes shared between, 26
 genomics, bioinformatics, and proteomics in study of genomes of, 9
 geographic distributions of, 539–540
 imperfection of, and evolution, 505
 inherited DNA and development of, 7f–8f
 interactions of, as theme in biology, 10f–11f
 as level of biological organization, 4f
 model. *See* Model organisms
 multicellular, 5f
 as open systems, 145
 origin of mammalian, 530, 531f, 532
 origin of multicellular, 533f, 535f–536f
 origin of single-celled, 532f–535f
 possible effects of transgenic crops on nontarget, 839
 regulation of molecular interactions within, 10f
 single-celled, 5f
 in topsoil, 807
 transgenic. *See* Transgenic animals; Transgenic plants
 Organization
 amino acid structures and, 91
 apoptosis in, 233
 of cell, 6f
 chemical waste and, 43
 digestive tracts of invertebrates, 717
 DNA structure and inheritance, 334
 emergent properties of, 4–6
 enantiomer effectiveness and, 65
 flowers as emergent property, 841
 functionality of forms, 551
 of fungi relationships, 672

- gastrula emergent properties, 1066
of hair and keratin, 920
of lens of eye, 1138
levels of biological, 4f–5f
life as emergent property, 125
lignin evolution, 783
in loop of Henle, 998
of neurons, 1084
oxidative phosphorylation and, 186
photosynthesis and shoot architecture, 804
in plant life cycle, 653
sickle-cell disease and, 505
structure and function in, 6
as theme of biology, 2, 3
viral structure and function, 414
of walking and breathing, 756
water as versatile solvent and, 55
- Organizer of Spemann and Mangold, 1062f
Organ-level herbivore defenses, plant, 868f
Organ of Corti, **1113f**
Organogenesis, **1036f**, 1044, **1049**, 1054f–1055f
Organs, **5f**, **759**, **876t**
 digestive. *See* Digestive systems
 embryonic germ layers and, 1051f
 endocrine system, 1003, 1004f. *See also* Endocrine glands
 excretory, 985, 986f–987f
 eyes and light-detecting, 1117f–1119f
 floral, 823f–824f
 human reproductive, 1025f–1027f
 immune system rejection of transplanted, 969–970
 as level of biological organization, 5f
 organogenesis of, 1044, 1049, 1054f–1055f
 plant roots, stems, and leaves as, 759f–762f
 reverse positioning of human, in situus inversus, 1064f
 smooth muscle in vertebrate, 1131–1132
- Organ systems, **876**
 internal exchange surfaces of, 875f
 mammalian, 876t
- Orgasm, 1034
- Orientation
 honeybees, 1142f
 leaf, 787
 migratory, 1156, 1157f
 plant cell expansion, 777f
- Origin-of-life studies, 57f, 58
- Origin of Species, *The* (Darwin, C.), 14f, 469, 473, 483–484, 487
- Origins of replication, **242**, 243f, **322**, 323f
- Ornithine, 338f
- Orthologous genes, **565f**, 566
- Orthoptera, 712f
- Oryza sativa, 438, 509f, 651, 817, 838, 850–851, 1263
- Osculum, **690f**
- Oseltamivir (Tamiflu), 414
- Osmoconformers, **978**
- Osmolarity, **978**, 989, 990f, 991, 998
- Osmoreceptors, 1110
- Osmoregulation, **134**, **978**
 challenges and mechanisms of, 978f–980f, 981
 energetics of, 980
 excretion and. *See* Excretory systems
 homeostasis by, 977f, 978
 ion movement and gradients and, 993f
 osmosis and, 134f–135f
 osmosis and osmolarity in, 978
 salinity and, 1185f
 transport epithelia in, 981, 982f
- Osmoregulators, **978f**
- Osmosis, **134**, **788**, 977
 diffusion of water by, across plant plasma membranes, 788, 789f–791f
 effects of, on water balance, 133f–135f
 osmolarity and, 978
- Osmotic pressure, blood, 933f
- Osteichthyans, **728f**–**729f**, 730. *See also* Fishes
- Osteoblasts, 878f, 1134
- Osteoclasts, 1134
- Osteons, 878f
- Ostriches, 992f
- Otoliths, 1115f
- Otters, 1189
- Ouabain, 1084
- Outer ear, **1113f**
- Outgroups, **561f**, 572
- Ovalbumin, 76f
- Oval window, **1113f**
- Ovarian cancer, 447
- Ovarian cycle, **1032f**, 1033
- Ovaries, angiosperm, **644f**–**646f**, 647, **823f**–**824f**, 830f–831f. *See also* Fruits
- Ovaries, human, 257f, 258, 1004f, 1014, 1015f, **1026**, 1027f
- Overgrazing, 1231
- Overharvesting, 702f, 727–728, 1264, 1265f
- Overnourishment, 917–918
- Overproduction, offspring, 475f, 476
- Oviducts, **1026**, 1027f
- Oviparous organisms, **727**
- Oviraptor dinosaurs, 564f, 565
- Ovoviparous organisms, **727**
- Ovulate cones, 640f, 641
- Ovulation, **1021**, 1035f
- Ovules, 636, **638f**, **823f**
- Owl-mouse predation study, 23
- Owls, 920, 1218
- Oxidation, 112, 165, **166f**
- Oxidative fibers, 1130–1131
- Oxidative phosphorylation, 168, **169f**, 174f–177f, 186
- Oxidizing agents, **166f**
- Oxygen
 atmospheric, in animal evolution, 677
 catabolic pathways and, 165
 in circulation and gas exchange, 947f–949f
 covalent bonding and, 36, 37f
 development of photosynthesis and atmospheric, 532f–534f
 diffusion of, across capillary walls, 932
 in double circulation, 924f, 925
 in ecosystem interaction, 10f, 11
 electronegativity of, 37, 45
 as essential element, 29t, 64
 in gas exchange, 921, 939t, 940
 in human breathing, 946
 plants production of, 619
 in mammalian circulation, 926f
 metabolic rate and, 890f
 in net ecosystem production, 1242
 in organic compounds, 59f
 in oxidation, 166f
 Permian mass extinction and low levels of, 540
 in photosynthesis, 41f
 in plant cells, 209f
 in plant composition, 809
 as product of photosynthesis, 188, 206, 207f
 role of, in prokaryotic metabolism, 582
 species distributions and availability of, 1185
 thyroid hormone and consumption of, 179
 transport of, 951
- Oxytocin, 1004f–**1005f**, 1007f, 1037f
- Oystercatcher, 1161
- Oyster drills, 542
- Oysters, 699, 701f, 1020
- Ozone depletion, 1283f, 1284
- P**
- p21* gene, 390
- p53* gene, **389**, 390f–391f
- P680 chlorophyll *a*, 196, 197f
- P700 chlorophyll *a*, 196, 197f, 198
- Pacemaker, heart, 928f
- Pacific Island land snails, 702f
- Pacific salmon (*Oncorhynchus* species), 89
- Pac-man mechanism, 241f
- Paedomorphosis, 544, **545f**, 732
- Paedophryne swiftorum*, 1164f
- Paine, Robert, 1226f
- Pain receptors, **1111**–**1112**
- Pair bonding, 1144, 1155f
- Pakicetus*, 482f
- Paleoanthropology, **748**
- Paleogene period, 538
- Paleontology, 13f, 88f, **470f**, 471
- Paleozoic era, 530f, 533f, 539f, 677f, 678
- Palisade mesophyll, 771f
- Pallium, avian, 1099f
- Palumbi, S. R., 557f
- Pampas, 1175f
- PAMP-triggered immunity, 866
- Pan-Cancer Atlas, 448
- Pancreas, **909**, 1004f
 cellular interactions of, 142
- in digestion, 909
- exocytosis and, 139
- in glucose homeostasis, 916f
- rough ER and, 105
- Pancrastaceans, **708**, 709f–712f, 713
- Pandemics, **410**
- Pandoravirus*, 408
- Pangaea, **482**–**483**, **539f**, 551
- Pan genus, 746f. *See also* Chimpanzees
- Panthera pardus*, 554, 555f
- Panthera tigris altaica*, 1288
- Panther chameleons (*Furcifer pardalis*), 735f
- Paper, 651
- Papaya, 757
- Paper wasps, 712f
- Papillae, 1124f
- Papillomaviruses, 394
- Pappochelys*, 737
- Papua New Guinea, 1164f
- Parabasalids, **600f**
- Parabronchi, 944, 945f
- Parachutes, seed and fruit, 832f
- Paracrine signaling, 215f, **1000f**, 1001
- Parahippus*, 548, 549f
- Parakeets, 1136
- Paralogous genes, 565f, **566**
- Paramecium*, 13f, 93f, 134, 135f, 607f, 617, 1199f, 1215
- Paraphyletic groups, **560f**
- Parapodia, 703
- Parasites, 584f, **587**, **1220**
 acanthocephalans, 698
 animals as, 673f
 antigenic variation and, 972
 apicomplexans, 605, 606f
 arachnids, 708f
 cercozoans, 609
 entamoebas, 613
 flatworms, 696f–697f
 fungi as, 655, 660, 663, 665, 669f–670f
 insects as, 713
 lampreys as, 723f, 724
 nematodes, 705f, 706
 plants as, 818, 819f, 820
 protist, 598f, 600f, 614
 in zoonotic diseases, 1234
- Parasitism, **587**, **1220**
- Parasitoid wasps, 869f
- Parasympathetic division, peripheral nervous system, 928, 1088f–**1089f**
- Parathion, 158
- Parathyroid glands, 1004f, **1011f**
- Parathyroid hormone (PTH), 1004f, **1011f**
- Parenchyma cells, **764f**, 769f, 770
- Parental alleles, genomic imprinting and, 310f, 311
- Parental care, 1023f, 1150, 1151f, 1200, 1201f–1202f
- Parental types, **302**
- Parietal cells, 907f
- Parietal lobe, 1085, 1097f
- Paris Agreement, 1283
- Paris japonica*, 448t, 449, 843
- Parkinson's disease, 65, 83, 231, 361, 413, 431–432, 671, 1081, **1104**
- Parsimony, 562, 563f, 564
- Parthenogenesis, **697**–**698**, **1020**, 1021f
- Partial pressure, **939**
- Particulate model of inheritance, 487
- Parus major*, 740f
- Passeriformes, 740f
- Passive immunity, **968**
- Passive transport, 126, **133**
 active transport vs., 137f
 diffusion as, 132, 133f
 facilitated diffusion as, 135f, 136
 interpreting scatter plots on glucose uptake as
 facilitated, 136
 in plant cells, 209f
 of water across plant plasma membranes, 788, 789f–791f
 water balance and osmosis as, 133f–135f
- Patella vulgata*, 547f–548f
- Paternal alleles, 372
- Paternal chromosomes, 265
- Paternity
 certainty of, 1150, 1151f
 tests for, 437
- Pathogen-associated molecular patterns (PAMPs), **866**

- Pathogenicity trait, bacterial, 315f
Pathogens, **587, 953, 1234**
 adaptations of, in immune system evasion, 957, 971–972, 973f, 973t, 974, 976
 alteration of community structure by, 1234, 1235f
 bacterial, 315f, 583f–584f, 585, 587, 588f
 B cells and antibodies as responses to extracellular, 964, 965f–966f
 cytotoxic T cell response to cells infected by, 966f, 967
 fungi as, 655, 663, 669f–670f
 immune system recognition and response to, 952f, 953, 957f–958f
 innate immunity evasion by, 957
 plant defenses against, 866, 867f
 prokaryotic, 587, 588f
 viruses as, 398f–400f, 401, 408, 409f–413f
Pathways
 nervous system, 880
Pathways, sensory, 1108f–1109f
Pattern
 evolutionary, 470, 483
 taxonomy based on, 470
Pattern formation, **384, 385f–387f, 777, 778f, 849, 1062**. See also Morphogenesis
Paulinella chromatophora, 608f, 609
 Pauling, Linus, 317–318
 Pavlov, Ivan, 1146
Pax-6 gene, 423
 Pc, 198f, 199
 PCSK9 enzyme, 938
 PDGF (platelet-derived growth factor), 247, 248f
 Pea aphids (*Acyrtosiphon pisum*), 570
 Peacocks, 499f
 Pea fruit, 831f
 Pea plants, G. Mendel's experiments with, 269f–276f
 Pearl mussels, 702f
 Peat, **627f**, 628, 633–634, 1249, 1259
 Pectin, 118
Pediastrium, 610f
 Pedigrees, **284f**, 285
 Pedipalps, 708
 Pelagic zone, **1177f**
 Pellicle, 601f
Peltigera, 813f
 Penguins, 14f, 739, 740f, 873f, 874f, 884f, 892, 1192f
 Penicillin, 159, 478, 574–575, 670
Penicillium, 658f
 Penis, 1025f, **1026**, 1034, 1081–1082
 Pentoses, 68f
 PEP carboxylase, **203**, 204f
 Pepsin, 158f, **907f**
 Pepsinogen, **907f**
 Peptide bonds, 75, **78f**, 353f
 Peptides
 antimicrobial, 953–954, 955f, 956–957
 Peptidoglycan, **574, 575f**
 Per capita birth rate, 1196–1198
 Per capita death rate, 1196–1198
 Per capita rate of increase, 1196–1198
 Perception, **1109, 1121f**
 Perch, 979f, 1203f
 Perennials, 766
 Pericarp, 830–831
 Pericycle, **768, 769f**
 Periderm, **763, 774**
 Perilymph, 1115f
 Periodic table of elements, 34f
 Peripheral nervous system (PNS), **1069, 1081, 1086**
 central nervous system and, 1086, 1087f–1090f
 structure and function of vertebrate, 1088f–1089f
 Peripheral proteins, **129**
 Peripheral vision, 1122f, 1123
 Perissodactyla, 745f
Perissodus microlepis, 500, 501f
 Peristalsis, **906, 1133f**, 1135
 Peristome, **625**
 Peritubular capillaries, **987f**
 Periwinkles, 1263f
 Permafrost, 1176f
 Permease, 368f
 Permian mass extinction, 540f, 541
Peromyscus polionotus, 2f, 20f–21f, 23
 Peroxisomes, 100f–101f, **112f**
 Personal genome analysis, 433
 Personalized medicine, 88f, **433–434**
 Pertussis, 218f
 Pesticides, 1275, 1276f
 DDT, 158
 transgenic, 837–838
 Pest resistance, plant, 418f, 438
 Petals, **644f, 823f**
 Petioles, **761**
Petromyzon marinus, 724
 Petromyzontida (lampreys), 719f, 723f, 724
 PET scanners, 31, 32f
 Pévet, Paul, 893f
Pfu polymerase, 421
 P (parental) generations, **271f**
 P granules, 1059f
 pH, **52**
 acid precipitation and, 1265, 1266f
 adjusting soil, 808–809
 buffers and, 52–53
 enzymatic catalysis and, 157, 158f
 and hemoglobin dissociation, 948f
 of human cerebrospinal fluid, 946
 pH scale and, 51, 52f
 protein denaturation and, 82f, 83
 species distributions and soil, 1186
 sucrose uptake by plant cells and, 142
 PHA (polyhydroxyalkanoate), 590, 591f
 Phage λ , 403, 404f
Phages, **315, 401**
 capsids of, 400f, 401
 Cas9 protein and, 360, 361f
 defense against, 404f
 in DNA research, 315f–316f, 317
 in fighting infection, 872
 prophages and temperate, 402, 403f
 replicative cycles of, 402f–404f
 in transduction, 579f
 virulent, 402f
 Phagocytic cells, 955f, 956
Phagocytosis, **107, 140f, 953f**
 cellular integration of, 121f
 as endocytosis, 139, 140f
 immune systems and, 953f, 955f, 956, 965f
 lysosomes and, 107f
Phalacrocorax harrisi, 506f, 507, 511
 Phanerozoic eon, 530f, 533f, 539f
 Pharmaceutical products
 biotechnology in production of, 435, 436f.
 See also Drugs; Medicine
 as environmental toxins, 1276, 1277f
 fungal, 670
 species and genetic diversity and, 1262, 1263f
 Pharmacogenetics, 434
 Pharyngeal clefts, **720f**
 Pharyngeal slits, **720f–721f**
Pharyngolepis, 725f
 Pharynx, 696f, **906f**, 908f
 Phase changes, plant development, 778, **780f**
 Phase-contrast microscopy, 95f
 Phenobarbital, 104
 Phenolics, 868f
Phenotypes, **274**
 DNA transformation and, 315
 dominant alleles and, 279–280
 gene concept and, 362
 gene expression as link between genotypes and, 335–336
 genetic mapping and, 305f
 genetic variation and, 487f–488f
 genotypes vs., 274f, 282f, 283
 impact of environment on, 282f
 making histograms and analyzing distribution patterns of, 283
 mutant, 295f–296f, 328
 proteins and, 335
 relative fitness and, 497
 Phenylalanine, 77f, 289–290, 341, 492–493
 Phenylketonuria (PKU), 289–290, 492–493
 Phenylthiocarbamide (PTC) pedigree analysis case, 284f, 285
Pheromones, **658, 670, 1001f**, 1023, **1142, 1143f**
 Philadelphia chromosome, 309f
 Philippine eagle, 1262f
Phloem, **629, 763, 785**
 primary growth and, 769f
 resource acquisition and, 785f
 sugar-conducting cells of, 765f
 sugar transport from sources to sinks via, 799, 800f–801f
 symplastic communication through, 802
 vascular plant, 629–630
 in vascular tissue systems, 763
 Phloem sap, **799, 800f–801f**
Phoca hispida, 44f
Phoebastria immutabilis, 1277f
Phoenicopterus ruber, 14f, 740f
 Phosphatases, 223
 Phosphate group, 63f, 84, 85f
 Phosphates, in phosphorus cycle, 1251f
 Phosphodiesterase, 229, 233
 Phosphofructokinase, 183f, 184, 186
 Phospholipid bilayers, 74f, 75, 98f, 99, 102, 110, 127f, 132
Phospholipids, **74**
 in cellular membranes, 102, 110, 127f, 132
 Golgi apparatus and, 106
 movement of, in cellular membranes, 128f, 129
 in plasma membranes, 98f, 99
 structure of, 74f, 75
Phosphorus
 as essential element, 29t, 64
 as limiting nutrient, 1242, 1243f, 1243t, 1244
 plant deficiency in, 818
 soil fertilization and, 805, 808
Phosphorus cycle, 1251f
 Phosphorylated intermediates, **151, 152f**
Phosphorylation
 in cell-signal responses, 226f
 in cell-signal transduction, 222f, 223
 in light reactions of photosynthesis, 191f
Phosphorylation cascade, **222f**, 226f
Photic zone, **1177f**
 Photoautotrophs, 188f, 581t, 594
 Photoheterotrophs, 581t
 Photomorphogenesis, **855**
 Photons, **192f, 195f**
 Photoperiodism, **859f–860f**
 Photophosphorylation, **191**
 Photoprotection, 195, 199
 Photopsins, 1122
 Photoreceptors, **1117f–1119f**
 Photorespiration, **203, 211**
 Photosynthates, 759
Photosynthesis, **188**
 alternative mechanisms of carbon fixation in, 203, 204f–206f
 in aquatic ecosystems, 1242
 Calvin cycle of, 201, 202f
 in carbon cycle, 1250f
 cellular respiration vs., 190. See also Cellular respiration
 cercozoan, 608f, 609
 chemical reactions in, 41f
 chloroplasts in, 5f, 109–110, 111f
 climate change and, 211
 conversion of light energy to chemical energy of food by, 189f–191f
 cyanobacteria and, 584f
 determining rate of, with satellites, 1242f
 development of, and atmospheric oxygen, 533, 534f
 in energy flow and chemical cycling, 9f, 164–165, 211, 1240f
 evolution of adaptations for resource acquisition and, 784f–786f, 787
 as gas exchange, 895f
 importance of, 188f, 206, 207f
 lichens in, 188f–669f
 light reactions of. See Light reactions
 maximizing surface area for, 695f
 as plant nutritional mode, 894f
 principles of, 163
 prokaryotic, 577f
 protist, 594, 599f–600f, 614, 615f
 red and green algae, 609f–610f
 scale of, 122f
 shoot architecture and, 804
 stramenopile, 602
 sunlight availability and, 1185, 1186f
 two stages of, 191f, 192
 in vascular plants, 631
 water loss compromise with, 787
 in working plant cells, 209f
 zonation of aquatic biomes and, 1177f–1178f
 Photosystem I (PS I), **196, 197f–198f**
 Photosystem II (PS II), **196, 197f–198f**

- Photosystems, 195, 196f–198f, 199
 Phototrophs, 581t
 Phototropin, 856f
 Phototropism, 847f–848f
 pH scale, 51, 52f
 Phycoerythrin, 609
Phyla, taxonomy and, 554, 555f
 angiosperm, 648f
 bryophyte, 626f
 gymnosperm, 642f–643f
 plant, 622t
Phylogeny, 786f, 849
 Phylogenetic bracketing, 564f, 572
 Phylogenetic trees, 555. *See also* Evolutionary trees; Phylogenies
 analyzing sequence-based, to understand viral evolution, 411
 of animals, 683f
 application of, 557f
 of bilaterians, 717
 of chordates, 719f
 cladistics in construction of, 559, 560f–561f
 of eukaryotes, 612f
 as hypotheses, 564f, 565
 linking classification and phylogeny with, 555f–556f
 of mammals, 745f
 maximum parsimony and maximum likelihood in, 562, 563f, 564
 of primates, 746f
 of prokaryotes, 583f
 proportional branch lengths in, 561, 562f
 of protists, 598f
 of tetrapods, 731f
 tree of life and, 15f–16f
 visualizing, 556f
Phylogenies, 554
 of amniotes, 734f
 of angiosperms, 648f–650f, 653
 of animals, 682, 683f, 684
 of chordates, 719f
 constructing phylogenetic trees for, 559, 560f–564f, 565. *See also* Phylogenetic trees
 documentation of, in genomes, 565f, 566
 of eukaryotes, 612f
 of fungi, 660f–667f
 gymnosperm, 641, 642f–643f
 as hypotheses, 564f, 565
 inferring, from morphological and molecular data, 558f–559f
 investigating tree of life with, 553f–554f, 568, 569f–570f
 of maize, 557
 of mammals, 745f
 molecular clocks and evolutionary time in, 566, 567f–568f
 nitrogenous wastes and, 982f–983f
 of plants, 623f
 practical applications of, 557f
 of primates, 746f
 of prokaryotes, 583f
 of protists, 597, 598f–599f
 systematics and, 554
 taxonomy and evolutionary relationships in, 554, 555f–556f, 568, 569f
 of tetrapods, 731f
Physical reconstruction, ecosystem, 1253f–1254f
Physiological thermostats, 888, 889f
Physiology, 873f–874
Phytoalexins, 866
Phytochemicals, 195
Phytochromes, 856
 in circadian rhythms, 858–859
 in plant signal transduction pathways, 844f
 in seed germination, 856, 857f
 in shade avoidance in plants, 857, 871
Phytophthora species, 604, 614f, 1234
Phytoplankton, 584f. *See also* Plankton
 in biomass pyramids, 1247f, 1248
 in carbon cycle, 1250f
 dinoflagellate, 605f
 green algae, 610
 nitrogen pollution and blooms of, 1275f
 primary production by, 1242, 1243f, 1243t
 seasonality and, 1167
Phytoremediation, 809
Picoides borealis, 1269f–1270f
Pie charts in Scientific Skills Exercise, 892
Pied flycatchers (*Ficedula hypoleuca*), 519
Pigmentation
 DNA methylation and, 372f
 gene expression and, 335f, 336
 plant, 311f
 of Siamese cats, 364
 skin, 281, 282f
Pigments
 as photosynthetic light receptors, 192, 193f–194f, 195
 in photosystems, 196f–200f, 201
 respiratory, 947f–948f, 949
 visual, 1122
Pikas, 1280f
Pili, 576, 580f, 581
Pill bugs, 709
Pilobolus, 663f
Pimephales promelas, 1276
Pineal gland, 1004f, 1007f, 1015, 1093f
Pineapple, 206f, 831f
Pine trees, 640f, 643f, 1229f, 1244f, 1245, 1280f
Pin flower, 835f
Pinocytosis, 140f
Pinworms, 705
Piping plover (*Charadrius melanotos*), 1190f
Pisaster ochraceus, 1226f
Pistils, 644f, 823f
Pitch, 1114
Pitcher plants, 819f
Pitch pine canker, 669
Pith, 763, 770f, 783
Pithovirus sibericum, 408
Pituitary dwarfism, 1010
Pituitary gland, 1007, 1030, 1031f–1032f, 1093f
 in human endocrine system, 1004f
 in kidney regulation, 994f–995f
 in neuroendocrine signaling, 1007f–1008f
Pit vipers, 737f, 1111f
Pivot joints, 1134f
Piwi-interacting RNAs (piRNAs), 380–381
PKU (phenylketonuria), 289–290, 492–493
Placenta, 742, 1035f
Placental mammals. *See* Eutherians (placental mammals)
Placental transfer cells, 620f
Placoderm fossil, 533f
Placoderms, 726f
Placozoans, 687f
Plains, 1175f
Planarians, 687f, 694, 695f–696f. *See also* Flatworms
Planes, plant cell division, 776–777
Planets, possible evolution of life on other, 50f
Plankton, 608, 710f. *See also* Phytoplankton
Plantae kingdom, 12f, 568, 599f, 609, 619f, 621
Plant cells. *See also* Eukaryotic cells
 cell fate in pattern formation, 777, 778f
 cell signaling in, 215f
 cellular activities of, 208f–209f
 cell walls of, 118f
 chloroplasts in, 109, 110f–111f
 common types of, 763, 764f–765f
 cytoplasmic streaming in, 117f
 division and expansion of, in growth, 776, 777f
 as eukaryotic cells, 101f
 gene expression and control of differentiation of, 778f
 mitosis and cytokinesis in, 241, 242f–243f
 photosynthesis in. *See* Photosynthesis
 plant cloning from single, 428. *See also* Transgenic plants
 plasmodesmata as cell junctions in, 119f, 120
 sucrose uptake by, 142
Plant development
 adaptations of, 894f
 auxin in, 849
 cell division and cell expansion in growth and, 776, 777f
 gene expression and control of cell differentiation in, 778f
 genetic control of flowering in, 779f–780f
 growth, morphogenesis, and cell differentiation in, 775f, 776
 model organisms in the study of, 774, 776f
 morphogenesis and pattern formation in, 777, 778f
 phase changes in, 779, 780f
Plant growth
 adaptations of, 894f
 cell division and cell expansion in, 776, 777f
 meristem generation of cells for, 766f–767f
 plant development and, 775–776
 primary, 768f–771f
 regulators of. *See* Plant hormones
 secondary, 772f–775f
Plant hormones (plant growth regulators), 846t.
 See also Hormones
 abscisic acid, 846t, 852f, 863
 animal hormones vs., 216, 894f
 auxin, 846t, 847f–849f, 850, 854f, 861
 brassinosteroids, 845, 846t, 854–855
 cytokinins, 846t, 850f
 in de-etiolation (greening) responses, 845
 ethylene, 846t, 852, 853f–854f, 864f
 florigen, 860f
 gibberellins, 846t, 850, 851f
 jasmonates, 846t, 855
 in long-distance cell signaling, 216
 overview of, 846t
 as plant growth regulators, 846–847
 strigolactones, 846t, 850, 855
Plant nutrition
 essential elements for, 809, 810f, 811t
 mutualisms for, 812, 813f–819f, 820
 nutritional modes in, 894f
 photosynthesis and modes of, 188f
 soil as complex ecosystem for, 805f–809f
 unusual adaptations for, 806, 818, 819f, 820
 vascular plant acquisition of water and minerals, 787
 vascular plant transport of water and minerals, 787, 788f–791f
Plant responses
 to attacks by pathogens and herbivores, 866, 867f–869f
 to environmental stresses, 862–863, 864f, 865
 to gravity, 861f
 to light, 855, 856f–860f
 to mechanical stimuli, 861, 862f
 plant hormones and, 845, 846t, 847f–854f, 855
 signal-transduction pathways linking signal reception to, 843f–844f, 845
Plants. *See also* Angiosperms; Plant development; Plant growth; Plant hormones; Plant nutrition; Plant responses; Plant structure; Seed plants
 adaptations of, that reduce terrestrial nutrient limitations, 1244
 adaptations of, to toxic elements, 30f
 adaptive radiations of, 543f, 544
 alternation of generations in life cycles of, 258f, 620f
 in Archaeplastida supergroup, 599f, 609
 bioremediation using, 1253, 1255f
 cells of, 6f, 208f–209f. *See also* Plant cells
 cellulose as structural polysaccharide for, 70f–71f, 72
 chemical communication by, 845–846
 climate change and, 11, 1279, 1280f–1281f, 1282
 cloning of, 428
 community stability and diversity of, 1223f
 crop. *See* Crop plants
 defensive adaptations of, 1219–1220
 derived traits of, 620f–621f
 diseases of. *See* Diseases, plant
 in domain Eukarya, 12f
 in ecosystem interaction, 10f, 11
 elements in composition of, 809
 endangered or threatened, 1261
 essential elements and trace elements for, 29
 evolutionary mystery of flowering, for C. Darwin, 477
 evolution from green algae, 617, 618, 619f, 621
 fossil of, 529f
 fungal mutualisms with, 665, 667f, 668, 813f.
 See also Mycorrhizae
 fungal pathogens of, 663, 669f
 gametophyte-sporophyte relationships in, 637f, 638
 genetic engineering of transgenic, 418f, 438
 genomics and proteomics in study of, 88f
 global climate change and species distributions of, 1170, 1170f
 habitat loss and, 1263–1264
 immune response in, 866, 867f

- Plants (continued)
- importance of insects to, 713
 - inheritance of organelle genes in, 311f
 - introduced, 818
 - kingdom and domain mutualisms with, 813f
 - land colonization by, 536, 537f
 - life challenges and solutions for, 894f–895f
 - nematode parasites of, 705
 - nonvascular, 623, 624f–627f, 628
 - nutrition of, 12f, 13
 - origin, diversification, and phylogeny of, 621, 622f–623f, 622t
 - pathogens of, 1234
 - as photoautotrophs, 188f
 - photosynthesis of. *See* Photosynthesis
 - polyploidy in, 307
 - protists as pathogens of, 614f
 - reproduction of. *See* Angiosperm reproduction
 - resource acquisition for vascular, 784f–786f, 787
 - salinity and species distributions of, 1186
 - starch as storage polysaccharide for, 70f, 71
 - sympatric speciation in, 514f–515f
 - terrestrial adaptations of, 619f, 621
 - vascular. *See* Transport in vascular plants; Vascular plants
 - water balance of cells of, 134f, 135
 - water transport in, 46f
- Plant structure
- cells in, 763, 764f–765f
 - diversity in, 759
 - hierarchy of organs, tissues, and cells in, 758f–765f
 - meristem generation of cells for growth of, 766f–767f
 - plant development and, 775f–780f
 - primary growth of roots and shoots of, 768f–771f
 - secondary growth of stems and roots in woody plants, 772f–775f
- Plaque, arterial, 937f, 939
- Plasma, **934f**, 935
- Plasma cells, 961, 962f, 970f
- Plasma membranes, **98**, 109f. *See also* Cellular membranes
- animal cell, 100f
 - chemiosmosis in prokaryotic, 175, 176f, 177
 - electron transport chains in prokaryotic, 168
 - of eukaryotic cells, 98f, 99
 - hormone receptors in, 1003f
 - ion gradients and transport of ions across, 993f
 - microfilaments in, 116f
 - movement across plant cell, 209f
 - nuclear envelopes as, 102
 - plant cell, 101f
 - of prokaryotic cell, 97f
 - receptor proteins in, 217f–220f
 - short-distance and long-distance transport across, 787, 788f–791f
- Plasmids, **418**, **577**
- in antibiotic resistance of bacteria, 581
 - in bacterial conjugation, 580f, 581
 - evolution of viruses and, 408
 - prokaryotic, 577f
 - as recombinant DNA, 418f, 419–420
- Plasmodesmata, **119**
- as cell junctions in plants, 119f, 120
 - macromolecules and, 846
 - in plant cells, 101f
 - in plant local cell signaling, 215f
 - in plasmatic communication, 802f
- Plasmoidal slime molds, 612f
- Plasmodium* (protist), 599f, 606f, 614, 713, 953
- Plasmogamy, **658f**
- Plasmolysis, **135**, **790**
- Plasticity, neuronal, **1100f**
- Plastics, natural, 590, 591f
- Plastic waste, 1163, 1277f
- Plastids, **111**
- endosymbiotic origin of, 534, 535f
 - eukaryotic endosymbiosis and evolution of, 596f–597f
- Plastocyanin (Pc), 198f, 199
- Plastoquinone (Pq), 198f
- Plateau phase, sexual, 1034
- Platelet-derived growth factor (PDGF), 247, 248f
- Platelets, 10, 878f, 934f–**935f**
- Plate tectonics, **538f**–539f, 540
- Platyhelminthes (flatworms). *See* Flatworms
- Platypus, 742, 1110–1111
- Play, 1159
- Pleasure, brain activity and, 1103f
- Pleiotropy, 280
- Pleurozium schreberi*, 635
- Plumule, 829
- Pluripotent cells, **431**
- Pneumatophores, 760f
- Pneumocystis jirovecii*, 973–974
- Pneumonia, 315f, 579
- Poaching, elephant, 1265f
- Podium, sea star, 714f
- Poecilia* species, 517f
- Poecilia reticulata* (guppies), 483, 1152, 1153f, 1187f
- Poikilotherms, 884
- Point mutations, **357f**–**358f**, 359, 388, 389f, 488–489
- Poison dart frog, 1218f
- Pokeweed, 830f
- Polar bears (*Ursus maritimus*), 11, 510f
- Polar covalent bonds, **37f**, **45**
- Polarity, 877f
- Polar molecules, **44**–**45**
- Polar side chains, 76, 77f
- Polar transport, auxin, 848f, 849
- Polio, 408–409, 968f, 976
- Pollen cones, 640f, 641
- Pollen grains, 636, **638f**, 646f, 647, 649f, **826**, 827f, 841
- Pollen tubes, 825f, **826**, 827f
- Pollination, **638**, **825**
- angiosperm cross-pollination, 646f, 647
 - asexual reproduction vs., 833
 - coevolution of flowers and pollinators in, 825f
 - cross-pollination in breeding plants, 837
 - flowers and angiosperm, 644f
 - flower shape and insect, 649f
 - genetic engineering of flowers to force self-pollination, 839–840
 - by insects, 641f
 - insects in, 713
 - mechanisms for preventing self-, 834, 835f
 - mechanisms of, 824f–825f
 - G. Mendel's techniques of, 270f–271f
 - seed plant, 638f
- Pollinators
- coevolution of flowers and, 825f
 - reproductive isolation and choice of, 522f
- Pollution
- biomanipulation and, 1227f
 - coral reefs and, 693
 - ecosystem services and, 1263
 - molluscs and water, 702–703
 - nutrient, 1274, 1275f
 - ocean acidification and, 53f, 54
 - plastic, 1163, 12771f
 - prokaryotes and bioremediation of, 591f
 - Toxins, 1275, 1276f–1277f
- Polyadenylation signal sequence, 345f
- Polyandry, 1149, 1151f
- Poly-A tail, **345f**
- Polychaetes, 703
- Polychoa dubium*, 449
- Polychlorinated biphenyls (PCBs), 1275, 1276f
- Polydactyly, 280, 292
- Polygamous mating, **1149**–**1150**, 1151f
- Polygenic inheritance, **281**, 282f, 287
- Polygyny, 1149–1150, 1151f
- Polymerase chain reaction (PCR), **420**
- amplification of DNA using, 420, 421f, 422f
 - bacteria for, 589
 - diagnosing diseases with, 433–434
 - in estimating reproductive rates, 1194, 1195f
 - extreme thermophile archaea in, 585, 1263
 - in forensic science, 436, 437f
 - in genomic analysis of fetuses, 1040
 - in prokaryotic analysis, 583
 - in RT-PCR analysis, 424, 425f
 - in sequencing human digestive system microbiome, 912, 913f
 - in vitro* amplification of DNA using, 422f
- Polymerases, 401
- Polymerization, protein, 240
- Polymers, **67f**
- Polymorphisms, 427, 433
- Polynucleotides, **84**, **85f**
- Polypeptide backbone, 78f
- Polypeptides, **75**, 1001f
- amino acid monomers of, 75, 76f–77f
- as amino acid polymers, 78f
- analyzing sequence data of, in Scientific Skills Exercise, 89
- mutations affecting, 357f–358f, 359
- one gene–one polypeptide hypothesis on, 337
- proteins as composed of, 78f
- synthesis of, in translation, 337, 339f
- synthesizing multiple, with polyribosomes in translation, 355f
- targeting, to specific locations, 354f, 355
- translation stages in synthesis of, 350f–353f
- Polyphemus moth (*Antheraea polyphemus*), 1001
- Polyphyletic groups, **560f**
- Polyplacophora (chitons), 699f
- Polyploidy, **307**, **514**–**515f**
- Polyps, 391f, **691f**, 1019f
- Polyribosomes (polysomes), **355f**
- Polysaccharides, **70f**–**72f**, 106
- Polyspermy, **1045**
- Polytomies, 569f
- Polytrichum*, 626f–627f
- Pongo* species, 746f
- Pons, 946, **1093f**
- Poplar trees, 774, 838
- Population conservation
- conflicted demands in, 1270
 - critical habitat in, 1269f–1270f
 - extinction risks in small populations, 1266, 1267f–1268f, 1269
- Population cycles, 1205f, 1206
- Population dynamics, 1191f, 1192, **1205f**–**1206f**, 1207, 1256f. *See also* Population growth
- Population ecology, **1165f**. *See also* Ecology
- demography of population vital statistics in, 1193t, 1194f–1195f
 - determining population size using mark-recapture method in, 1191f
 - human population in, 1207f–1210f, 1211, 1213
 - population density and dispersion in, 1191f–1192f, 1193, 1202, 1203f
 - population dynamics in, 1191f, 1192, 1205f–1206f, 1207
 - population growth models in, 1196, 1197f–1199f, 1198t, 1200. *See also* Population growth
 - population growth regulation in, 1202, 1203f–1206f, 1207
 - as study of populations in environments, 1190f, 1191. *See also* Populations
- Population growth. *See also* Populations
- density-dependent regulation of, 1202, 1203f–1206f, 1207, 1213
 - ecological impact of, 1213
 - exponential model of, 1196, 1197f, 1207f, 1208
 - of human population, 1207f–1210f, 1211, 1213
 - logistic model of, 1197, 1198f–1199f, 1198t, 1200
 - population dynamics and, 1191f, 1192, 1205f–1206f, 1207
 - using logistic equation to model, 1200
- Population-level herbivore defenses, plant, 869f
- Populations, **4f**, **490**, **1165f**, **1191**
- climate change effects on, 1281f
 - C. Darwin on natural selection and, 14f–16f
 - demographics of, 1193t, 1194f–1195f
 - density and dispersion of, 1191f–1192f, 1193, 1202, 1203f, 1256f
 - determining size of, using mark-recapture method, 1191f
 - diffusion of, of molecules, 132
 - dynamics of, 1191f, 1192, 1205f–1206f, 1207, 1256f
 - effective size for, 1268
 - evolution of genetic variation in, 266, 267f
 - extinction risks in small, 1266, 1267f–1268f, 1269
 - gene pools of, 490f
 - genetic diversity of, 1261f
 - growth of. *See* Population growth
 - Hardy–Weinberg equilibrium and size of, 492t
 - human, 1207f–1210f, 1211, 1213
 - as level of biological organization, 4f
 - life histories of, 1200, 1201f–1202f
 - minimum viable size for, 1268
 - natural selection and evolution of, 475f, 476
 - population ecology as study of, 1190f, 1191.
 - See also* Population ecology
 - using Hardy–Weinberg principle to test microevolution in, 490, 491f, 492–493

- Populus tremuloides*, 791f, 833f
 Porcupine, 1218f
 Pore complexes, 102, 103f
 Pores, nuclear, 102, 103f, 123f
 Pores, plasmodesmatal, 802f
 Porifera (sponges). *See* Sponges
Porphyra, 609f, 610
 Porphyrin ring, 194f
 Porpoises, 481f–482f
 Portal vessels, 1008f
 Positional information, 384, 1062, 1063f–1064f
 Position-based mechanisms, plant, 778
 Positive and negative correlations, 834
 Positive feedback, 882, 1006
 in climate change, 1189
 in endocrine system feedback regulation, 1006
 in feedback regulation, 10
 in homeostasis, 882
 Positive gene regulation, bacterial, 369f, 370
 Positive gravitropism, 861f
 Positive interactions, 1220f–1221f
 Positive pressure breathing, 944
 Positron-emission tomography (PET), 31, 32f, 1096
 Possum, 743f
 Posterior pituitary gland, 1004f, 1007f, 1008
 Postganglionic neurons, 1089
 Postsynaptic cells, 1068f
 Postsynaptic neurons, 1068f, 1079f, 1101f
 Postsynaptic potentials, 1077–1078, 1079f
 Post-translational protein modifications, 354
 Postzygotic barriers, 509f, 510
 Potassium, 29t, 805, 808
 Potassium ion channel protein, 135
 Potassium ions, 797f, 798, 1070t, 1071f
 Potato blight, 867
 Potatoes, 651, 843f–844f
 Potential, cell developmental, 1060, 1061f
 Potential energy, 32, 144, 145f, 163
 Potential range, 1184
 Pq, 198f
 Prairie chickens, 495f, 496
 Prairies, 1175f, 1264
 Prairie voles, 1155f
 Precapillary sphincters, 932f
 Precipitation
 climate change and, 11
 climographs of, 1171f
 evaporation and, 47
 global patterns of, 1166f
 mountains, rain shadow, and, 1169f
 primary production in terrestrial biomes and,
 1243f, 1244, 1244f
 in water cycle, 1250f
 Precocious germination, 852f
 Predation, 1217, 1256f
 allopatric speciation and, 511f, 512
 camouflage and, 468f
 camouflage case studies and, 20f–21f, 23
 density-dependent population regulation by,
 1204f
 genetic variation in, 1155, 1156f
 as interspecific interaction, 1217, 1218f–1219f
 population cycles and, 1205f, 1206
 as risk, 1149
 top-down model of trophic control and, 1227f
 Predators
 adaptations of, 1217–1218, 1219f, 1237
 animals as, 673f
 as biotic factors limiting species distributions,
 1184f
 cephalopods as, 701f, 702
 evolution of animal, 677f
 insects as, 713
 mass extinctions and, 542
 natural selection and role of, 26
 plant recruitment of, as herbivore defense, 869f
 Predictions, scientific, 17, 18f, 19f, 493
 Predisposition, cancer and inherited, 394
 Preganglionic neurons, 1089
 Pregnancy, human, 1034
 conception and trimesters of, 1035f–1037f
 detecting disorders during, 1039–1040
 detecting human, 969
 DNA methylation and, 372f
 ectopic, 1039
 endocrine disruptors and, 1015
 prevention of, 1037, 1038f, 1039
 Pre-mRNA, 339f, 345f–346f, 373f
 Prepucse, 1025f, 1026
 Pressure
 hearing and, 1114
 receptors for, 1110f
 root, 793f, 794
 water potential and, 788–790
 Pressure-flow hypothesis, 800, 801f
 Pressure potential, 789
 Presynaptic cells, 1068f
 Presynaptic neurons, 1068f, 1079, 1080f, 1101f
 Prey
 adaptations of native predators to introduced,
 1217
 defensive adaptations of, 1218f–1219f, 1237
 genetic variation in selection of, 1155, 1156f
 Prezygotic barriers, 508f–509f, 510
 Priapula, 688f
 Primary cell walls, 118
 Primary cilium, 114
 Primary consumers, 1240f
 trophic efficiency of, 1246, 1247f, 1248
 Primary electron acceptors, 196f
 Primary growth, plant, 766, 783
 meristem generation of cells for, 766f–767f
 of roots, 768f–769f
 of woody stems, 772f, 775f
 Primary immune response, 962, 963f
 Primary meristems, 766
 Primary motor cortex, 1097f
 Primary oocytes, 1029f
 Primary producers, 1240f, 1257f
 Primary production, 1241
 in aquatic ecosystems, 1242, 1243f, 1243t
 in arctic tundra ecosystem, 1238f, 1244,
 1256f–1257f
 climate change effects on, 1244f, 1245
 determining, with satellites, 1242f
 ecosystem energy budgets in, 1241, 1242f
 global, 1241, 1242f
 gross and net, 1241, 1242f
 in terrestrial ecosystems, 1243f–1244f, 1245
 Primary roots, 759
 Primary somatosensory cortex, 1097f
 Primary structure, protein, 80f
 Primary succession, 1229, 1230f–1231f
 Primary transcripts, 339
 Primary visual cortex, 1121f
 Primases, 323f, 324, 326f, 327t
 Primates. *See also* Humans
 cloning of, 430
 derived characters of, 744, 746
 HIV in, 567
 living, 746f–747f
 in mammalian phylogeny, 745f
 phylogenetic tree of, 746f
 Primers, 323f, 324
 Primitive streak, 1052f
 Primordial germ cells, 1029f
 Principle of conservation of energy, 145f, 146
 Printing press, 24
 Prions, 412, 413f
 Probability
 laws of, 276, 277f, 278
 principle of maximum likelihood and, 563
 Problem solving, 1146, 1147f
 Problem-Solving Exercises. *See* list, xxi
 Proboscidea, 745f
 Proboscis, 688f, 712f, 825f
 Procambium, 766
 Process, evolutionary, 470, 483
Prochlorococcus, 552
 Producers, 9, 188f, 614, 615f
 Production efficiency, 1246f
 Products, 41, 651
 Progesterone, 1004f, 1014, 1015f, 1030, 1032f
 Progesterone receptor (PR), 392f–393f
 Progestins, 1014, 1015f, 1038
 Proglottids, 697f
 Programmed cell death. *See* Apoptosis
 Projections, body surface area and, 695f
 Prokaryotes
 adaptive abilities of, 573f, 574
 archaea as, 585f, 586
 bacteria as, 583, 584f, 585
 beneficial and harmful impacts of, on humans,
 587, 588f–591f
 bioremediation using, 1255f
 cell signaling in, 213f, 214
 cells of. *See* Prokaryotic cells
 chemiosmosis in, 175, 176f, 177
 as decomposers, 188
 ecological roles of, in biosphere, 586f–587f
 electron transport chains in, 168
 as endosymbionts, 534, 535f
 evolution of glycolysis in, 182
 genetic diversity in, 578f–580f, 581
 genome sizes and number of genes for, 448t, 449
 horizontal gene transfer in genomes of, 569, 570f
 hydrothermal vents, energy, and, 592
 land colonization by, 536
 nutritional and metabolic adaptations of, 581t,
 582f
 origin of, 532f–534f
 photosynthesis in, 188f
 phylogeny of, 583f
 structural and functional adaptations of,
 574f–577f, 578
 taxonomy of, 568, 569f
 Prokaryotic cells, 6, 97. *See also* Cells
 cell-surface structures of, 574, 575f–576f
 DNA replication in, 322f–327f
 eukaryotic cells vs., 6f, 97f–98f, 99. *See also*
 Eukaryotic cells
 evolution of cell division of, 243, 244f
 programming of, by viral DNA, 315f–316f, 317
 regulation of transcription in, 366f–369f, 370
 structure of, 97f
 transcription and translation in, 337, 339f, 342,
 343f–344f, 355f
 Prolactin, 1004f, 1008f, 1016
 Prolactin-releasing hormone, 1008
 Proliferative phase, 1032f, 1033
 Proline, 77f, 341–342
 Prometaphase, 237, 238f, 243f, 252, 331f
 Promiscuous mating, 1149
 Promoters, 342, 343f
 Proof, hypotheses and, 18
 Proofreading, DNA, 327, 328f
 Propanal, 63f
 Properties, chemical, 34f, 35
 Properties, emergent. *See* Emergent properties
 Prophages, 403
 Prophase (mitosis), 237, 238f, 243f, 252, 263f, 331f
 Prophase I, 260f, 262f–263f, 266f
 Prophase II, 261f
Propithecus verreauxi, 746f
 Prop roots, 760f
 Prostaglandins, 1001, 1037f, 1111–1112
 Prostate cancer, 397
 Prostate cells, 397
 Prostate glands, 1025f, 1026
 Prosthetic groups, 175
 Proteases, 907
 Proteasomes, 379
 Protected areas, 1272f–1273f
 Protective secretions, 898
 Protein Data Bank, 444
 Protein interaction networks, 446, 447f
 Protein kinase A, 223, 224f
 Protein kinases, 222f–224f, 228f, 229
 Protein phosphatases, 223
 Proteins, 75. *See also* Amino acids
 amino acids of, 67, 75, 76f–78f. *See also* Amino acids
 antibiotics and prokaryotic synthesis of, 577
 antifreeze, 888
 in bacterial binary fission, 242, 243f
 biotechnology in production of, 435, 436f
 blood plasma, 934f, 935
 cadherin in choanoflagellates and animals, 676f
 in cell-signaling nuclear responses, 226f
 cell-signaling receptor, 217f–220f
 in cellular membranes, 127f–130f
 cellulose-synthesizing, 619f
 as composed of polypeptides, 78f. *See also*
 Polypeptides
 Conserved Domain Database (CDD) of structures
 of, 445f
 denaturation and renaturation of, 82f, 83
 digestion and absorption of, 908f–909f
 DNA-binding, 91
 in DNA replication, 326f, 327t
 DNA vs., as genetic material, 315, 316f, 317
 domains of, 347f

- Proteins (continued)
- in egg yolks, 91
 - in electron transport chains, 174f, 175
 - enzymes as, 75, 76f, 153, 159f
 - essential amino acids in, 899
 - evolution and divergence of, 91
 - evolution of genes for, with novel functions, 456, 457f
 - expressing cloned genes for, 423
 - facilitated diffusion and, 135f, 136
 - florigen as, 860f
 - folding and post-translational modifications of, 354
 - folding of, in cells, 83
 - four levels of structure of, 79, 80f–81f
 - as fuel for catabolism, 182f
 - functions of types of, 66f, 76f
 - gene expression and, 7f–8f
 - genotypes and, 335
 - human dietary deficiencies in, 901
 - identifying genes coding for, 445f, 446
 - innate immune response and, 957
 - as macromolecules, 66
 - as measures of evolution, 87, 89
 - mediator, 374, 375f
 - motor. *See* Motor proteins
 - nonenzyme, 337
 - nucleic acids in gene expression and synthesis of, 84f
 - packing of DNA and, into chromosomes, 330f–332f
 - phenotypes and, 335
 - phosphorylation of, in cell-signal transduction, 222f, 223
 - in photosystems, 196f–200f, 201
 - plant antifreeze, 865
 - plant heat-shock, 865
 - post-translational modification of, in plant responses, 845
 - prions as infectious, 412, 413f
 - producing, with gene cloning, 418f, 419
 - in prokaryotic flagella, 576f, 577
 - protein interactions with, 221
 - proteomics in study of, 9, 86, 87f, 446
 - regulation of eukaryotic processing and degradation of, 378–379
 - regulatory, 378–379, 383, 384f
 - in replication of DNA telomeres, 328
 - repressor, 367f
 - scaffolding, 228f, 229
 - separating, with gel electrophoresis, 420f
 - structures of, 78, 79f
 - synthesis of. *See* Protein synthesis
 - synthesis of, in plant cells, 208f
 - systems biology in studying networks of, 446, 447f
 - transcription factors, 343f, 344
 - translation elongation factors, 352, 353f
 - translation initiation factors, 352f
 - translation release factors, 352, 353f
 - transport. *See* Transport proteins
 - in transport and mechanical work, 152f
 - using data on, to test hypotheses on horizontal gene transfer, 570
 - viral movement, 802f
 - viruses and, 400f, 402f–403f
 - visualizing, 79f
 - water-soluble, 49f
- Protein sequences, 444, 445f, 446
- in Scientific Skills Exercise, 570
- Protein synthesis. *See also* Gene expression
- evidence for, in study of metabolic defects, 336f–338f
 - gene concept and, 361–362
 - genetic code in, 340f–342f
 - mutations during, 357f–358f, 359
 - by ribosomes, 102, 103f, 104
 - summary of, 356f
 - via transcription, RNA processing, and translation, 337, 339f. *See also* RNA processing; Transcription; Translation
- Proteobacteria, 584f
- Proteoglycans, 118, 119f
- Proteomes, 9, 446
- Proteomics, 9, 86, 87f–88f, 446
- Proterozoic eon, 530f, 533f
- Prothoracicotrophic hormone (PTTH), 1006f, 1007
- Prothrombin, 936f
- Protista, kingdom, 568, 594
- Protists, 12f, 594
- contractile vacuoles of, 108
 - in domain Eukarya, 12f, 13
 - ecological roles of symbiotic and photosynthetic, 614f–615f
 - endosymbiosis in evolution of, 594–595, 596f–597f, 608f, 609
 - excavates, 597, 598f, 600
 - origin of, 593
 - origin of fungi in, 659f, 660
 - photosynthesis in, 188f
 - phylogeny of, 597, 598f–599f
 - plants, 599f, 609. *See also* Plants
 - red and green algae, 599f, 609f–611f
 - SAR clade, 599f, 601f–608f, 609
 - sexual life cycles of, 258f, 259
 - as single-celled eukaryotes, 594
 - structural and functional diversity of, 594f
 - unikonts, 599f, 611, 612f–613f, 614
- Protocol, 526, 527, 528f
- Protoderm, 766
- Protoneema, 624f, 625
- Protonephridia, 694, 984f, 985
- Proton gradients, 176f, 177
- Proton-motive force, 176f, 177
- Proton pumps, 138f, 788, 789f, 848
- Protons, 28, 30f, 31
- Proto-oncogenes, 388, 389f, 391f
- Protoplasts, 789
- Protostome development, 681, 682f, 685
- Proviruses, 406, 407f
- Proximal control elements, 374
- Proximal tubule, 987f–988f
- Proximate causation, 1140
- Prozac, 1081, 1103
- Prusiner, Stanley, 413
- Pseudemys nelsoni*, 884f
- Pseudocoelomates, 681
- Pseudogenes, 450, 480
- Pseudomonas aeruginosa*, 582f
- Pseudemys hermannsburgensis*, 981
- Pseudopodia, 117, 140f, 599f, 607, 608f, 690
- Pseudostratified columnar epithelium, 877f
- Psilotum*, 632f, 633
- P site (peptidyl-tRNA binding site), 350f, 352f–353f
- Psychedelic rock gecko (*Cnemaspis psychedelica*), 1260f
- Psychoactive drugs, 1081
- PTC pedigree analysis case, 284f, 285
- Pteraspis*, 725f
- Pterois volitans*, 729f
- Pteropus mariannus*, 1262f
- Pterosaurs, 736, 1135
- Puberty, human, 1030
- PubMed, 26
- Puffballs, 665f
- Puffer fish, 813f
- Pulmocutaneous circuit, 924f, 925
- Pulmonary circuit, 924f–926f
- Pulp, fruit, 831
- Pulse, 930
- Punctuated equilibria, 520f, 521
- Puncture vine, 832f
- Pundamilia* species, 515f, 519f, 520
- Punnett squares, 273f, 274, 281f–282f, 292–293
- Pupa, 711f
- Pupil, 1118f
- Pure elements, 37
- Purines, 84, 85f, 320f
- Purple sulfur bacteria, 188f
- Pus, 956
- Pusztai, 1175f
- Pygmy date palm, 650f
- Pyramids
- age-structure, 1209f
 - ecological, 1246, 1247f, 1248
- Pyrenean ibex (Capra pyrenaica pyrenaica)*, 1266
- Pyrimidines, 84, 85f, 320f
- Pyrococcus furiosus*, 421, 585, 589
- Pyrophorus noctophanus*, 143f
- Pyruvate
- ATP yield in oxidation of, 177f
 - in fermentation, 181f, 182
 - oxidation of, as stage of cellular respiration, 168, 169f
- oxidation of, to acetyl CoA, 171f–172f
- oxidation of glucose to, by glycolysis, 170f–171f
- Python molurus bivittatus*, 887, 888f
- Pythons, 887, 888f, 892
- YY hormone, 917f
- Q**
- Q (ubiquinone), 175
- Qinling golden snub-nosed monkeys, 56f
- Qualitative data, 17f
- Quantitative approach, G. Mendel's, 270f, 271
- Quantitative characters, 281, 282f
- Quantitative data, 17f. *See also* Scientific Skills Exercises
- Quantitative RT-PCR (qRT-PCR), 424–425
- Quaternary structure, protein, 81f
- Quillworts, 631, 632f, 633
- Quorum sensing, 213–214
- R**
- RAAS (renin-angiotensin-aldosterone system), 995, 996f
- Rabbits, 914
- Radial canal, sea star, 714f
- Radial cleavage, 681, 682f
- Radial glia, 1090
- Radial symmetry, 644f, 649, 679, 680f
- Radiation, 885f
- alterations of chromosome structure by, 307
 - animal heat exchange and, 885f
 - cancer and, 388, 394
 - as cancer treatment, 249
 - DNA damage from, 328
 - mutagenic, 360
- Radicle, 829f–830f
- Radioactive isotope decay curve in Scientific Skills Exercise, 33
- Radioactive isotopes, 31–33, 316f, 317, 529, 530f
- Radioactive tracers, 31, 32f
- Radiolarians, 608f
- Radiometric dating, 32–33, 529, 530f
- Radula, 699f
- Raft spider, 45f
- Rain, acidic, 55
- Rain shadow, 1169f
- Random dispersion, 1192f, 1193
- Random fertilization, 266, 305
- Random mating, 492t
- Random mutations. *See* Mutations
- Randomness, entropy and, 146
- Range expansions, species, 1183, 1184f
- Ranges, actual and potential, 1184
- Rangifer tarandus*, 490f, 1021, 1256f–1257f, 1281f
- Raphides, 868f
- Rapid eye movements (REMs), 1094
- ras* gene, 389, 390f–391f
- Raspberry fruit, 831f
- Ras protein, 389, 390f
- Rates, speciation, 520f–521f, 522
- Ratfish, 719f, 726, 727f
- Ratites, 739, 740f
- Rattlesnakes, 1084, 1111f
- Ravens, 1147
- Ray-finned fishes, 719f, 728f–729f, 1091f
- Rays, 719f, 726, 727f
- Reabsorption, 984f
- Reactants, 41
- Reaction-center complexes, 196f
- Reading frame, 341, 358f
- Realized niches, 1215, 1216f
- Reasoning
- deductive, 18
 - inductive, 17
- Receptacle, flower, 823f
- Reception, sensory, 1108f, 1109
- Reception stage, cell-signaling, 216
- cell-surface transmembrane receptors in, 217f–220f
 - intracellular receptors in, 220, 221f
 - ligands, ligand binding, and receptor proteins in, 217
- overview of, 216f
- in plant signal transduction pathways, 844f
- plasma membrane proteins as receptors in, 217f–220f
- Receptive fields, 1120–1121
- Receptor-mediated endocytosis, 140f

- Receptor potential, **1109**
 Receptor proteins, **76f**
 Receptors
 antigen, **958f–961f**
 dendrites as, **1068**
 glutamate, **1101f**
 hormone, **1000f–1004f**, **1018**
 opiate, **1082**
 sensory, **1108f–1111f**, **1112**
 somatosensory, **1097f**, **1098**
 Toll-like, **955f**, **976**
 Receptor tyrosine kinases (RTKs), **219f**, **220**, **222**, **250**
 Recessive alleles, **272**, **273f–276f**, **280**, **285f–286f**, **287**, **293**, **500**. *See also* Alleles
 Recessively inherited human disorders, **285f–286f**, **287**
 Recessive traits, **271f**, **272t**, **285f**, **299f**, **300**
 Reciprocal altruism, **1158–1159**
 Reciprocal eco-evolutionary effects, **1187f**
 Recombinant bacteria, **418f**
 Recombinant chromosomes, **266f**
 Recombinant DNA, **418**
 in DNA cloning and gene cloning, **418f**, **419**
 ethical issues on, **438–439**
 hirudin from leeches and, **704**
 using restriction enzymes to make, **419f–420f**
 Recombinants (recombinant types), **302**
 Recombinase, **960**, **961f**
 Recombination. *See also* Recombinant DNA
 linkage maps based on frequency of, **305f–306f**
 of linked genes, **302**, **303f**
 natural selection and genetic variation from, **305**
 of unlinked genes, **302f**
 Recombination frequencies, **305f–306f**, **313**
 Reconstruction, ecosystem, **1253f–1254f**
 Recovery, seed plants and, **636f**
 Recruitment, motor neuron, **1130**
 Recruitment of predatory animals, plant, **869f**
 Rectum, **911**
 Red alga (*Chondracanthus harveyanus*), **1222**
 Red algae, **596f**, **599f**, **609f**, **610**
 Red-bellied black snakes, **1217**
 Red blood cells. *See* Erythrocytes
 Red-cockaded woodpecker (*Picoides borealis*), **1269f–1270f**
 Red-green color blindness, **299f**
 Red light, plant responses to, **856**, **857f**, **860f**
 Red lionfish (*Pterois volitans*), **729f**
 Red mangrove, **852f**
 Red maple tree leaves, **762**
 Red-necked phalaropes, **1151f**
 Redox (oxidation-reduction) reactions, **165**, **166f–168f**, **190–191**
 Red-tailed hawk, **14f**
 Red-tailed racer snake (*Gonyosoma oxycephala*), **1053f**
 Red tide, **605f**
 Reduced hybrid fertility, **509f**
 Reduced hybrid viability, **509f**
 Reducing agents, **166f**
 Reduction, **165**, **166f**, **201**, **202f**
 Reductionism, **4**
 Redundancy, genetic code, **341**, **357**, **489**
 Redwood trees, **255f**
 Reefs, ectoproct, **698**
 Reference genome, **443**
 Reflexes, **906f**, **1087**, **1088f**
 Refractory period, **1075**
 Regeneration, **705**, **713–714**, **1020**
 Regenerative medicine, **432**
 Regional adaptive radiations, **543f**, **544**
 Regional conservation, **1270**, **1271f–1274f**
 Regional human population patterns, **1208**
 Regression lines in Scientific Skills Exercises, **54**, **205**, **751**
 Regulation. *See also* Osmoregulation
 of animal digestion, energy storage, and appetite, **914**, **915f–917f**, **918**
 by animal endocrine and nervous systems, **880f**
 of biological clocks, **1094–1095**
 of biological rhythms, **1015**
 of blood pressure, **930–931**
 of cell-signaling responses, **226–227**, **228f**, **229**
 of cellular respiration via feedback mechanisms, **183f**, **184**
 of cleavage, **1049**
 by endocrine glands, **1011f–1015f**, **1016**
 of enzymatic catalysis, **159**, **160f–161f**
 extracellular matrix role in, **119**
 feedback, of endocrine systems, **1005–1006**
 feedback in, of molecular interactions, **10f**
 of gene expression. *See* Gene regulation
 of growth, **1004f**, **1009**, **1010f**
 of heart rhythm, **928f**
 homeostatic feedback, **881f–883f**
 hormonal, of mammalian sexual reproduction, **1030**, **1031f–1032f**, **1033–1034**
 hormone cascade pathways in, **1008**, **1009f**, **1010**, **1014**
 of human breathing, **946f**
 kidney, **994f–996f**
 of muscle contraction, **1128**, **1129f**, **1130**
 of neurons in sensory reception, **1108f**
 plant and animal, **894f**
 of population growth, **1202**, **1203f–1206f**, **1207**
 as property of life, **3f**
 thyroid, **1008**, **1009f**, **1010**
 Regulator animals, **881f**
 Regulatory genes, **367f**
 Regulatory proteins, **378–379**, **383**, **384f**, **1128**, **1129f**, **1130**
 Regulatory T cells, **971**
 Reinforcement, hybrid zone, **518**, **519f**
 Rejection, immune system, **969–970**
 Relatedness, altruism and, **1158f–1159f**
 Relative abundance, species, **1222**. *See also* Species diversity
 Relative fitness, **497**
 Relay molecules, **216f**, **217**
 Relay proteins, **228f**, **229**
 Release factors, **352**, **353f**
 Release stage, phage lytic cycle, **402f**
 Releasing hormones, **1004f**, **1008**
 Renal cortex, **986f**
 Renal medulla, **986f**
 Renal pelvis, **986f**
 Renaturation, protein, **82f**, **83**
 Renin-angiotensin-aldosterone system (RAAS), **995**, **996f**
 Repair, DNA, **327**, **328f**
 Repetitive DNA, **450f**
 Replication fork, DNA, **323f**
 Replicative cycles, viral
 of animal viruses, **404**, **405f**, **406t**, **407f**
 general features of, **401f**, **402**
 of phages, **402f–404f**
 Repolarization, **1075**
 Repressible enzymes, **368f**, **369**
 Repressible operons, **367f**, **368–369**
 Repressors, **367f**, **374**
 Reproduction. *See also* Life cycles; Mating; Sexual life cycles
 animal behavior evolution and, **1148**, **1149f–1154f**, **1161**
 bacterial rate of, **592**
 as cell division function, **235f**
 crustacean, **709**
 C. Darwin on natural selection and, **14f–16f**
 delayed human, in population growth, **1208**
 density-dependent population regulation by rates of, **1204f**
 effective population size and, **1268f**, **1269**
 evolution and differential success in, **266**, **267f**
 fungal, **657**, **658f–659f**
 genetic disorders from human, **285–286**
 heterochrony and differential reproductive development, **544–545f**
 insect, **711**
 iteroparity vs. semelparity in, **1200**, **1201f**
 life history traits in, **1200**, **1201f–1202f**
 overproduction of offspring and natural selection, **475f**, **476**
 plant and animal, **895f**. *See also* Angiosperm reproduction; Animal reproduction
 prokaryotic binary fission, **577–578**
 as property of life, **3f**
 protist, **594**
 protocell, **527**, **528f**
 rapid, as source of genetic variation in viruses, **489**
 rapid prokaryotic, and mutation, **573**, **578f**, **579**
 rates of, **1194**, **1195f**, **1204f**, **1208**, **1213**
 sexual, as source of genetic variation, **489**
 sexual vs. asexual, **255f**
 of triploid organisms, **268**
 Reproduction, plant. *See* Angiosperm reproduction
 Reproductive barriers
 in hybrid zones, **518**, **519f**, **520**
 reproductive isolation and types of, **506–507**, **508f–509f**, **510**
 Reproductive cloning, **430f–431f**
 Reproductive cycles, animal, **1021f**
 Reproductive cycles, human, **1032f**, **1033–1034**
 Reproductive isolation, **508**
 allopatric speciation and, **511f–512f**, **513**
 hybrid zones and, **516**, **517f–519f**, **520**
 pollinator choice and, **522f**
 reproductive barriers in, **506–507**, **508f–509f**, **510**
 sexual selection and, **515f**
 Reproductive leaves, **762f**
 Reproductive organs, human
 female, **1026**, **1027f**
 gametogenesis and, **1027**, **1028f–1029f**
 male, **1025f**, **1026**
 Reproductive rates, **1194**, **1195f**, **1204f**, **1208**, **1213**
 Reproductive success, **1024**, **1042**
 Reproductive technologies, **1039f**, **1040**
 Reptiles, **719f**, **735**
 adaptations of kidneys of, **992**
 amniotic eggs of, **734**, **735f**
 birds, **738f–740f**
 breathing in, **925**
 characteristics of, **735f**, **736**
 crocodilians, **737f**, **738**
 evolution of, **679**
 extraembryonic membranes of, **1053f**
 hearing and equilibrium in, **1116**
 lepidosaurs, **737f**, **738**
 in Mesozoic era, **533**
 origin and evolutionary radiation of, **736**
 thermoregulation in, **887**, **888f**
 turtles, **737f**
 Research Method Figures. *See list*, xxiii
 absorption spectrum determination, , **193f**
 Reservoirs
 carbon, **1250f**
 nitrogen, **1251f**
 nutrient, **1249f**
 phosphorus, **1251f**
 water, **1250f**
 Residual volume, **945–946**
 Resolution, **94**
 Resolution phase, sexual, **1034**
 Resource acquisition, vascular plant, **784f–786f**, **787**. *See also* Transport in vascular plants; Vascular plants
 Resource competition, density-dependent population regulation by, **1204f**
 Resource partitioning, **1215**, **1216f**
 Respiration, cellular. *See* Cellular respiration
 Respiration, plant and animal, **895f**
 Respiratory diseases, human, **1204f**
 Respiratory distress syndrome (RDS), **943**, **944f**
 Respiratory media, **939t**, **940**
 Respiratory pigments, **947f–948f**, **949**
 Respiratory surfaces, **940**
 Respiratory systems. *See also* Gas exchange
 adaptations of, **947f–949f**
 breathing to ventilate lungs in, **944**, **945f–946f**
 effects of adrenal hormones on, **1012**
 internal exchange surfaces and, **875f**
 lungs and components of, **942**, **943f**
 respiratory distress syndrome of, **944f**
 Response
 homeostatic, **882**
 immune, **952f**, **957f**, **962**, **963f**
 inflammatory, **955f–956f**
 Response pathways, endocrine system, **1000f–1004f**
 Response stage, cell-signaling, **217**
 cell-signaling specificity and coordination of responses in, **227**, **228f**
 increasing signaling efficiency in, **228f**, **229**
 nuclear and cytoplasmic responses in, **226f–227f**
 overview of, **216f**, **217**
 regulation of responses in, **226–227**, **228f**, **229**
 signal amplification in, **226–227**
 signal termination in, **229**
 Response to environment, **3f**, **894f**. *See also* Environment
 Rest-and-digest responses, **1089**
 Resting potentials, neuron, **1069**
 formation of, **1069**, **1070f**
 modeling of, **1071f**

- Resting potential state, action potential, 1074f, 1075
 Restoration ecology, 1253f
 biological augmentation in, 1255
 biomanipulation of trophic levels in, 1227f
 bioremediation in, 1253, 1255f
 worldwide projects of, 1254f
 Restriction enzymes, 404, 419
 making recombinant DNA plasmids using, 419f–420f
 polymerase chain reaction and, in gene cloning, 421, 422f
 Restriction fragments, 419–420
 Restriction sites, 419f
 Resurrection
 of extinct species, 1266
 Reticular fibers, 878f
 Reticular formation, 1094f
 Reticulum, 914f
 Retina, 1118f, 1122, 1138
 Retinal, 1119f–1120f
 Retinitis pigmentosa, 495
 Retrotransposons, 451f
 Retroviral vectors, gene therapy using, 434f
 Retroviruses, 406t, 407f
 Reverse transcriptase, 406, 407f, 425f
 Reverse transcriptase-polymerase chain reaction (RT-PCR), 424, 424, 425f, 433
 Reward system, brain, 1103f
 Reward vs. risk, foraging behavior and, 1149
 R groups, amino acid, 75, 76f–77f
 Rhabditophora, 694, 695f–697f, 698
Rhagoletis mendax, 508f
Rhagoletis pomonella, 508f, 515–516
 Rhesus monkeys, 89
 Rheumatoid arthritis, 971f
 Rhinoceros, 1199f, 1266
 Rhizarians, 599f, 606–607, 608f, 609
 Rhizobacteria, 814f–816f, 817
Rhizobium bacteria, 592, 814f–816f, 817
 Rhizoids, 625
 Rhizomes, 761f
Rhizophorus stolonifer, 662f, 663
 Rhizosphere, 814f
 Rhodophytes, 609f, 610
 Rhodopsin, 1119f–1121f
 Ribbon model, 79f
 Ribbon worms, 688f
 Ribonucleic acid. *See* RNA
 Ribose, 85
 in ATP, 150, 151f
 as monosaccharide, 68f
 in nucleic acids, 85f
 Ribosomal RNA (rRNA), 349, 350f
 in eukaryotic cell nucleus, 102
 evolutionary rate of, 565
 gene family of, 453f
 interpreting comparisons of sequences of, 595
 in molecular systematics, 583
 self-splicing in production of, 346
 Ribosomes, 102, 339
 animal cell, 100f
 identifying binding sites on, with sequence logos, 351
 plant cell, 101f
 in plant cells, 208f
 polyribosomes and, 355f
 prokaryotic, 577
 in prokaryotic and eukaryotic cells, 97f
 in protein synthesis, 102, 103f, 104
 protein synthesis in, 84
 in RNA virus replicative cycle, 405f
 rough ER and, 105
 structure of, 103f, 349, 350f
 in translation, 337, 339f, 349, 350f, 352f–353f
 Ribozymes, 153, 346, 528
 Ribulose, 68f
 Rice (*Oryza sativa*), 438, 509f, 651, 817, 838, 850–851, 1263
 Rieseberg, Loren, 521f
 Right atrium, 926f–927f
 Right ventricle, 926f–927f
 Ringed seals (*Phoca hispida*), 44f
 Ring structures
 of carbon skeletons, 60f
 of cellulose-synthesizing proteins, 619f
 of glucose, 69f
 Ringworm, 670
 Rising phase, action potential, 1074f, 1075
 Risk factors, cardiovascular disease, 938
 Risk vs. reward, foraging behavior and, 1149
 Riverine wetlands, 1179f
 River otters, 881f
 Rivers, 1180f
 RNA (ribonucleic acid), 84. *See also* Messenger RNA; Nucleic acids; RNA processing; Transfer RNA
 in circadian clock genes during hibernation, 893f
 components of, 84, 85f
 development of self-replicating, 528
 in DNA replication, 323f, 324
 elongation of strands of, 344f
 in eukaryotic cells, 102
 gene density in genomes and, 449
 in gene expression, 8f
 in insect infection, 954f
 interpreting sequences of, 595
 noncoding, in gene regulation, 379, 380f, 381
 in plant cells, 208f
 post-transcriptional modification of, 345f–347f
 in regulation of cleavage, 1049
 ribosomal RNA gene family, 453f
 roles of, in gene expression, 84f
 sequencing of, 426f
 structure of, 86f
 synthesis of, in transcription, 337, 339f, 342, 343f–344f
 viral. *See* RNA viruses
 RNA enzymes. *See* Ribozymes
 RNA interference (RNAi), 380, 427
 RNA polymerases, 342, 343f–344f, 373f, 374
 RNA processing, 345
 alteration of mRNA ends in, 345f
 eukaryotic transcription and, 373f, 374
 evolutionary importance of introns in, 346, 347f
 in gene expression and protein synthesis, 337, 339f–340f
 regulation of eukaryotic, 378f
 ribozymes in, 346
 split genes and RNA splicing in, 345f–347f
 summary of eukaryotic, 356f
 RNA sequencing (RNA-seq), 425f, 426, 448
 RNA splicing, 345f–347f, 378f
 RNA transcript, 343f–344f
 RNA viruses
 classes of, 406f
 emerging viral disease and, 409–410
 HIV as, 406, 407f. *See also* HIV
 replicative cycles of, 401f, 402, 404, 405f
 retroviruses as, 406t, 407f
 structure of, 400f, 401
 Robin, European, 14f
 Rochman, Chelsea, 1163
 Rock python, 903f
 Rocks
 dating of, 529, 530f
 nonvascular plants and weathering of, in Ordovician period climate change, 629
 species distributions and, 1186
 weathering of, in phosphorus cycle, 1251f
 Rod, ATP synthase, 175f
 Rodents, 745f, 914
 Rods (photoreceptor), 1119f–1121f, 1122–1123, 1138
 Rod-shaped prokaryotes, 97f, 574f
 Rolling circle replication, 580f
 Root caps, 768f
 Rooted phylogenetic trees, 556f, 557
 Root hairs, 758, 759f–760f, 778f, 792
 Root pressure, 793f, 794
 Roots, 630, 758–759
 apical meristems of plant, 621f
 architecture of, and acquisition of water and minerals, 787
 bacterial mutualism with, 592
 compositions of bacterial communities of, 814f
 drought responses of, 863–864
 evolution of, in vascular plants, 63
 fungal mycorrhizae and, 787
 gravitropism in, 861f
 monocot vs. eudicot, 649f
 mycorrhizae and plant, 656f, 657
 nitrogen-fixing bacteria and legume, 815f–816f, 817
 primary growth of, 768f–769f
 rhizoids vs., 624
 secondary growth of, 772f–774f
 seedling, 830f
 soil texture and, 806
 structure of, 759f–760f
 transport of water and minerals from, to shoots via xylem, 792, 793f–795f, 796
 Root systems, 759f–760f
 Rosbash, Michael, 883
 Rosy periwinkle (*Catharanthus roseus*), 1263f
 Rotifers, 687f, 697f, 698
 Rotor, ATP synthase, 175f
 Rough ER, 100f–101f, 104, 105f, 109f
 Round dance, honeybee, 1142f
 Round window, 1114, 1115f
 Roundworms, 689f, 705f, 706, 1058f–1059f, 1133f
 Rous, Peyton, 394
Rozella allomycis, 661f
 R plasmids, 581
 r-selection, 1202
 RTKs (receptor tyrosine kinases), 219f, 220, 222, 250
 RU486 (mifepristone), 1039
 Rubella, 409
 RuBP carboxylase, 201, 202f
 Ruffed grouse (*Bonasa umbellus*), 1271
 Rule of multiplication, 491
 Rumen, 914f
 Ruminants, 914f
 Running, 1135–1136
 Runoff
 experimental, and nutrient cycling, 1252f
 in nitrogen cycle, 1251f
 in water cycle, 1250f
Rupicapra rupicapra, 901f
 Rusts, 665
 Rusty-patched bumblebee (*Bombus affinis*), 1170f
 Ryther, John, 1243f

S

- Saccharomyces cerevisiae* (yeast)
 budding of, 659f
 cell signaling in, 213f, 214
 DNA changes in cells of, in meiosis, 264
 genome size and number of genes of, 448t, 449
 human uses of, 670–671
 protein interaction network of, 447f
 toxic wastes of, in winemaking, 1204f
 Saccule, 1115f
 Sac fungi, 663f–664f, 665t
 Safety issues
 on biotechnology, 438–439
 on plant biotechnology and genetic engineering, 839–840
 Saguaro cactus (*Carnegiea gigantea*), 1178, 1183f
 Sahara Desert, 525f, 526
Sahelanthropus tchadensis, 748f, 749
 Salamanders, 509f, 513, 544, 545f, 719f, 731, 732f, 921f, 1066, 1086f
 Salicin, 651
 Salicylic acid, 867
 Salinity
 extreme halophiles and, 573f, 585
 lap alleles and, 505
 osmosis, water balance, and, 134
 plant responses to, 142, 865
 soil salinization and, 808
 species distributions and, 1185f, 1186
 Saliva, 906
 Salivary glands, 905, 906f
 Salmon, 89, 438, 978f, 979, 1200
Salmonella species, 588
Salmo salar, 89
 Saltatory conduction, 1076f–1077f
 Salt marshes, 1186, 1221f, 1247
 Salt marsh hay (*Spartina patens*), 1186
 Salts (ionic compounds), 38f
 in blood plasma, 934f
 diffusion of, across capillary walls, 932, 933f
 ion gradients and transport of, 993f
 osmoregulation of, 977f–982f
 Salt stress, plant responses to, 865
 Salt water, 977f, 979f, 982f
 Salty tastes, 233, 1123f–1124f
 Sampling techniques, population, 1191f
 San Andreas fault, 539
 Sand dollars, 235f, 689f, 715
 Sandhill crane (*Grus canadensis*), 1144
 Sandy inland mouse (*Pseudomys hermannsburgensis*), 981

- Sanger, Frederick, 416
 Sapwood, 774f
 SAR clade, 599f, **601f**-608f, 609
 Sarcomeres, 879f, **1126f**
 Sarcoplasmic reticulum (SR), **1128f**-1129f
 Sarcopterygii (lobe-fins), 728, 729f, 730
 Sargasso Sea, 1242, 1243t
 Sarin, 158, 1080
 Satellites, determining primary production with, 1242f
 Satiety center, 917f
 Saturated enzymes, 156
 Saturated fats, 73f, 74, 128f
 Saturated fatty acids, **73f**, 74
 Savannas, 750, **1174f**
 Savory tastes, 1123f-1124f
 Sawfish, 1020
 Scaffolding proteins, **228f**, 229
Scala naturae (scale of nature), Aristotle's, 470
 Scale bar in Scientific Skills Exercise, 99
 Scale-eating fish (*Perissodus microlepis*), 500, 501f
 Scales
 fish, 728
 reptile, 735
 Scallops, 701f
 Scanning electron microscope (SEM), **94**, 95f, 96
 Scanning electron microscopy (SEM), 95f
 Scarlet fever, 403
 Scatter plots in Scientific Skills Exercises, 54, 136, 205, 513, 751, 1217
Sceloporus species, climate change and, 11f
Schindleria brevipinguis, 719
Schistosoma mansoni, 696f
 Schistosomiasis, 696f
 Schizophrenia, 372f, **1102f**
 Schmidt-Nielsen, Knut, 1136
 Schwann cells, **1076f**-1077f, 1090f
 Science, **16**
 biology as study of life by, 3. *See also* Biology
 cooperative approach and model organisms in, 22-23, 24f. *See also* Model organisms
 diverse viewpoints in, 24
 inquiry process of, 17, 18f-21f, 22. *See also* Case studies; Inquiry Figures
 medical. *See* Medicine
 methods. *See* Research Method Figures
 skills. *See* Scientific Skills Exercises
 society, technology, and, 23, 24f
 Scientific inquiry, 16-20. *See also* Case studies; Inquiry Figures; Research Method Figures; Scientific Skills Exercises
 Scientific method, 17, 18f-21f, 22. *See also* Case studies; Inquiry Figures; Research Method Figures; Scientific Skills Exercises
 Scientific notation in Scientific Skills Exercise, 1082
 Scientific Skills Exercises. *See list*, xxi
 Scion, **835**-836
 Sclera, 1118f
 Scleireids, 764f
Sclerenchyma cells, **764f**, 770
Sclerenchyma tissue, 868f
 Scolex, 697f
 Scorpions, 707, 708f
 Scrapie, 412
Scr gene, 545
 Scrotum, **1025f**
 Scrub jays, 1099, 1162
 Scutellum, 829f
Scyphozoans, 687f, 691f-692f
 Sea anemones, 692f-693f
 Seabirds, 1238f, 1244
 Sea cucumbers, 715f
 Sea daisies, 713, 714f
 Sea horse, 729f
 Sea lampreys, 723f, 724
 Sea lettuce, 610f
 Sea lilies, 715
 Seals, 44f, 874f, 949f
 Sea otters, 1189
 Sea slugs, 700f, 1020f
 Seasonality, 1167f
 Seasonal turnover, lake, 1178f
 Sea spiders, 707-708
 Sea squirts, 721f
 Sea stars, 689f, 713, 714f, 898f, 940f, 1086f, 1192f, 1226f
 Sea urchin (*Centrostephanus rodgersii*), 1281f
 Sea urchins, 509f, 689f, 713, 715f, 1044f-1047f, 1184f-1185f, 1189
 Sea wasps, 692f
 Seawater, 977f, 979f, 982f
 Seaweed, 599f, 602, 603f, 604, 609f, 610, 1184f
 Secondary cell walls, **118**
 Secondary consumers, **1240f**
 trophic efficiency of, 1246, 1247f, 1248
 Secondary endosymbiosis, **596f**-597f
 Secondary growth, plant, **766**, 783
 cork cambium and periderm production in, 774
 evolution of, 774
 meristem generation of cells for, 766f-767f
 vascular cambium and secondary vascular tissue for, 772f-775f
 Secondary immune response, **962**, **963f**
 Secondary oocytes, **1029f**
 Secondary production, **1246**
 in arctic tundra ecosystem, 1256f-1257f
 production efficiency in, 1246f
 in salt marsh ecosystem, 1247
 trophic efficiency and ecological pyramids in, 1246, 1247f, 1248
 Secondary structure, protein, **80f**
 Secondary succession, **1230**-**1231**
 Secondary vascular tissue, 772f-774f
 Second law of thermodynamics, 143, 145f, **146**, 1239
 Second messengers, **223**, **844**
 calcium ions, inositol trisphosphate, and
 diacylglycerol as, 224, 225f
 cyclic AMP as, 223f-224f
 in hormone pathways, 1002, 1003f
 in plant signal transduction, 844f, 845
 Secretin, 915f, 1005f
 Secretion, excretory system, **984f**
 Secretions
 animal hormone, 1001f-1004f
 cell signaling and. *See* Animal hormones;
 Neurohormones
 digestive, 898, 907f-908f, 909-910, 915f
 protective, 898
 Secretory phase, 1032f, 1033
 Secretory proteins, 105
 Secretory systems, prokaryotic, 577
 Secretory tubules, marine bird, 982f
 Sedentarians, 703f-704f, 705
 Sedimentary strata, 470f, 529f
 Seed coat, **828f**-829f
 Seedless vascular plants, **622**
 gametophyte-sporophyte relationships in, 637f, 638
 importance of, 633f, 634
 life cycles of, 630f
 origin and traits of, 628f-631f
 phylogeny of, 622f, 631, 632f, 633
 Seedling development, 829, 830f
 Seed plants. *See also* Angiosperms; Gymnosperms;
 Plants
 adaptations of, 653
 angiosperms, 637f, 638, 644f-650f. *See also* Angiosperms
 gymnosperms, 637f-643f
 importance of, to Earth's ecosystems, 636f
 importance of, to human welfare, 651f, 652
 phylogeny of, 623f
 seeds and pollen grains as terrestrial adaptations of, 637f-638f, 639
 threats to biodiversity of, 651f, 652
 Seeds, **622**-623, **636**-**637**, **828**
 abscisic acid in dormancy of, 852
 development of, 826, 827f-829f
 dispersal of, 832f
 dormancy of, 639
 evolutionary advantage of, 639
 fruits and angiosperm, 645f
 gibberellins in germination of, 851f
 glyoxysomes in, 112
 phytochromes in germination of, 856, 857f
 plant seedlings development from, 828f-830f
 strigolactones in germination of, 855
 Segmentation, 1066
 Segmented worms, 688f
 Segregation, law of, 271f-275f, 296, 297f
 Seizures, 1076
 Selective breeding, 474, 475f, 841
 Selective permeability, **131**, 132f, 1071f
 Self-assembly, protocell, 527, 528f
 Self-assembly stage, phage lytic cycle, 402f
 Self-fertilization, 834, 835f, 840-841, 1042
 Self-incompatibility, **834**, 835f, 840-841
 Selfing, 834, 835f, 840-841
 Self-pollination, 271f
 Self-pruning, 786
 Self-replicating molecules, 526, 527f-528f
 Self-splicing, 346
 Self-thinning, 801
 Self-tolerance, 961
 Semelparity, **1200**, 1201f
 Semen, **1026**, 1034
 Semicircular canals, **1113f**, 1115f, 1116
 Semiconservative model, DNA replication, **321f**-322f
 Semilunar valves, **927f**
 Seminal vesicles, 1025f, **1026**
 Seminiferous tubules, **1025f**
 Senescence, **853**-854
 Senile dementia, 83
 Sensitive period, **1144**, 1145f
 Sensitive plants (*Mimosa pudica*), 802, 862f
 Sensors, homeostatic, **882f**
 Sensory adaptation, **1109**-1110
 Sensory areas, cerebral cortex, 1096, 1097f-1098f
 Sensory input, 1068f, 1096, 1097f-1098f
 Sensory neurons, 1068, 1069f, **1088f**
 Sensory pathways, 1108f-1109f
 Sensory reception, **1108f**, 1109
 Sensory receptors, **1108f**-1111f, 1112
 Sensory systems
 animal and plant, 894f
 arthropod, 707f
 mechanoreceptors for hearing and equilibrium in, 1112f-1116f
 motor systems and, 1107f-1108f. *See also* Motor systems
 muscle function and, 1125, 1126f-1131f, 1132
 sensory receptors in, 1108f-1111f, 1112
 shark, 727
 skeletal systems, locomotion, and, 1132f-1135f, 1136
 snake, 738
 taste and smell receptors in, 1123f-1125f
 visual receptors in, 1117f-1122f, 1123
 Sensory transduction, **1109**, 1120f
 Sepals, **644f**, **823f**
 Separase, 240
 Separate electron orbitals model, 35f
 Septa, **656f**
 September equinox, 1167f
 Septic shock, 957, 976
 Sequence-based phylogenetic tree in Scientific Skills Exercise, 411
 Sequence logo in Scientific Skills Exercise, 351
 Sequencing by synthesis, 415f-417f. *See also* DNA sequencing
Sequoia *giganteum*, 774f
Sequoia trees, 643f, 774f
 Serial endosymbiosis, **534**, 535f
 Serine, 77f, 222
 Serotonin, 1081t
 Serpentine plant communities, 30f
 Sertoli cells, 1031f
 Serum, 934
 Seta, **625**
 Set point, homeostatic, **882f**
 Severe combined immunodeficiency (SCID), 434f, 971
 Sewage treatment, 586, 591
 Sex
 chromosomal basis of, 298f, 299
 genomic imprinting and, 310f, 311
 Sex attractant, 43
 Sex chromosomes, **257**
 aneuploidy of, 309
 human, 256f-257f, 258
 patterns of inheritance of, 298f-300f
 Sex determination, 1030
 Sex hormones
 endocrine disruptors and, 1015
 as environmental toxins, 1276
 functional groups and, 62f
 in regulation of mammalian reproduction, 1030, 1031f-1032f, 1033-1034
 in sex determination, 1030
 smooth ER synthesis of, 104-105
 as steroids, 75f, 1014, 1015f

- Sex-linked genes, 298f–300f, **299**
 Sex pili, 576, 580f, 581
 Sex reversal, 1020
 Sexual dimorphism, **499f**, 752, 1149–1150, 1151f
 Sexual intercourse, human, 1034, 1081–1082
 Sexual life cycles. *See also* Life cycles
 alternation of fertilization and meiosis in, 256f–258f, 259
 angiosperm, 826, 827f, 828
 asexual reproduction vs., 255f
 chromosomal basis of Mendelian inheritance in, 294f, 295. *See also* Chromosomal basis of inheritance
 evolution from genetic variation produced in, 265f–267f
 genetics of heredity and genetic variation in, 254–255
 graphing DNA changes in meiosis of, 264
 human chromosome sets in, 256f–257f, 258
 inheritance of chromosomes and genes in, 255
 karyotypes of chromosomes in, 256f
 mitosis vs. meiosis in, 262, 263f, 264
 protist, 594
 stages of meiosis in, 259f–262f
 varieties of, 258f, 259
 Sexually transmitted diseases (STDs), 600f, 1038–1039. *See also* AIDS; HIV
 Sexually transmitted infections (STIs), 1038–1039
 Sexual reproduction, **255**. *See also* Sexual life cycles
 in angiosperms. *See* Angiosperm reproduction
 in animals, 674f, 675. *See also* Animal reproduction
 asexual reproduction vs., 255f, 833–834
 in bryophytes, 623, 624f–627f
 flowers and angiosperm, 644f
 in fungi, 658f
 inheritance in, 255
 microevolution from sexual selection in, 499f–500f
 as source of genetic variation, 489
 switch to, 268
 Sexual reproduction, animal, **1020**. *See also* Animal reproduction; Human reproduction
 asexual reproduction vs., 1021, 1022f
 as evolutionary enigma, 1021, 1022f
 fertilization mechanisms in, 1022f–1024f
 reproductive cycles in, 1021f
 variations in patterns of, 1020f
 Sexual response, human, 1034
 Sexual selection, **499f**–500f, 515f, 1151, 1152f–1153f, 1154
 S-genes, 835
 Shade avoidance, plant, 857
 Shaffer, Mark, 1268
 Shannon diversity index (*H*), **1222**, 1223f
 Shapes
 cell, 116–117
 enzyme, 155f, 156, 160f–161f
 insect pollinators and flower, 649f
 molecular, 39f–40f
 morphogenesis and cell, 1056f–1057f
 of organic compounds, 59f
 prokaryotic, 574f
 Shared ancestral characters, **560**, 561f
 Shared derived characters, **560**, 561f
 Shark Bay, 532f
 Sharks, 442f, 719f, 726, 727f, 890f, 979, 1091f
 Shelf fungi, 665f
 Shell drilling adaptation, 542
 Shells, electron, 32f, **34**, 35f, 36
Shewanella oneidensis, 1255f
 Shivering thermogenesis, 887, 888f
 Shoots, 848f
 apical meristems of plant, 621f
 light capture and architecture of, 785, 786f, 787
 photosynthesis and architecture of, 804
 phytochromes and, 871
 primary growth of, 769f–771f
 transport of water and minerals from roots to, via xylem, 792, 793f–795f, 796
 Shoot systems, **759f**
 Short-day plants, **859f**
 Short tandem repeats (STRs), **436**, 437f, **452**, 462
 Short-term memory, **1100**–1101
 Shrews, 1234, 1235f
 Shrimp, 464f, 512f, 513, 708–709
 Siamese cats, 364
 Siberian tiger (*Panthera tigris altaica*), 1288
 Sickle-cell disease, **82f**, **286**, **935**
 abnormal hemoglobin in, 935
 CRISPR-Cas9 system for, 360, 361f
 emergent properties of, 505
 evolution of, 503f
 genetic diagnosis of, 433
 heterozygote advantage in, 501
 inheritance of, 293
 pleiotropy and, 280
 point mutations and, 357f, 488, 502f
 protein primary structure changes and, 82f
 as recessively inherited, 286f, 287
 scientific cooperation and, 22–23
 Sickle-cell trait, 286
 Side-blotted lizards, 1154f
 Side chains, amino acid, 75, 76f–77f
 Sidedness, cellular membrane, 131f
 Sieve plates, **765f**, 799–800
 Sieve-tube elements, **765f**
 Sieve tubes, 799, 800f–801f
 Signaling molecules, 215f, 216. *See also*
 Animal hormones; Neurohormones;
 Neurotransmitters
 Signaling molecules, endocrine system, 1000f–1004f.
See also Animal hormones
 Signal peptides, **354f**
 Signal-recognition particles (SRPs), **354f**
 Signals, animal, **1141f**–1143f
 Signal transduction, **1002**
 in hormone pathways, 1002, 1003f
 membrane proteins and, 130f
 Signal transduction pathways, **216**
 cancer and interference with normal, 389f–390f, 391
 in cell signaling, 212, 216f, 221–222, 233
 coordinate control of, 376
 differential gene expression and induction in, 382f, 383
 evolution of, 213
 linking signal reception to plant responses, 843f–844f, 845
 neurotransmitters and, 1080
 second messengers in, 223f–225f
 in sensory amplification, 1109–1110
 in visual sensory transduction, 1120f
 in yeast cell mating, 214
 Sign language, 1106
 Sign stimulus, **1140f**
 Silencing, gene expression, 427
 Silencing, transcription, 374
 Silent mutations, **357**, 358f
Silent Spring (Carson), 1276
 Silicon-based life, 65
 Silk, 80f, 708, 951
 Silk moth, 1006f, 1007
 Silkworm moths, 1110, 1111f
 Silverfish, 712f
 Silversword plants, 543f, 558, 1183
 Simple columnar epithelium, 877f
 Simple endocrine pathway, 1004, 1005f
 Simple fruits, **831f**
 Simple leaves, 761f
 Simple neuroendocrine pathway, 1005f
 Simple sequence DNA, **452**
 Simple squamous epithelium, 877f
 Single bonds, **36**, 37f
 Single-celled organisms, 5f, 93, 532f–535f, 594.
See also Protists
 Single circulation, **924f**, 925
 Single-lens eyes, **1118**–1119
 Single nucleotide polymorphisms (SNPs), **427f**, 428, 433–434, 441, 461–462, 466
 Single-strand binding proteins, **323f**, 327t
 Single-stranded DNA (ssDNA) viruses, 406t
 Single-stranded RNA (ssRNA) viruses, 405f, 406t
 Sinoatrial (SA) node, **928f**
 Sirenia, 745f
 Sister chromatid cohesion, 236, 259
 Sister chromatids, **236f**, 237, 257f, 260f–263f, 264, 266f
 Sister species, 512f
 Sister taxa, **555**, **556f**
 Situs inversus, 1064f
 Sixth mass extinction, 541f, 542
 Size
 brain, 756, 1091f
 carrying capacity and population, 1197, 1198f–1199f, 1198t, 1200
 changes in population, 1196
 determining population, using mark-recapture method, 1191f
 ecosystem, 1239f
 evolution of axon, 1076f–1077f
 extinction risks in small population, 1266, 1267f–1268f, 1269
 of genomes, 448f, 449
 of global human population, 1207f–1210f, 1211, 1213
 Hardy-Weinberg equilibrium and population, 492t
 of *Homo floresiensis*, 754
 of hormones, 216
 of insects, 951
 latitude and animal, 897
 life history traits and, 1200, 1201f–1202f
 locomotion costs and, 1136
 metabolic rate and animal body, 891f
 of plasmodesmal pores, 802
 prokaryotic cell, 573–574
 of prokaryotic vs. eukaryotic cells, 6f, 98
 protist, 593f
 of skeletons, 1134
 Skeletal muscle, **879f**, **1126**. *See also* Muscle in human breathing, 945f
 locomotion from contraction of, in skeletal systems, 1132f–1135f, 1136
 muscle fibers of, 1130, 1131t
 regulation of contraction of, 1128f–1130f
 sliding-filament model of contraction of, 1126, 1127f, 1128
 structure of, 1125, 1126f
 Skeletal systems
 bones and joints of human, 1134f
 cartilage, 723–726
 energy costs of locomotion by, 1136
 locomotion from interaction of muscles and skeletons in, 1132f, 1135f, 1136
 origins of, 725
 types of, 1132, 1133f–1134f
 Skeletons, carbon, 60f–61f
 Skills, scientific. *See* Scientific Skills Exercises
 Skin
 cancer of, 328, 1284
 coloration, 1016, 1018
 gas exchange and, 924f, 925
 heat exchange and, in animals, 885
 mechanoreceptors in human, 1110f
 pigmentation of human, 281, 282f
 Skinner, B. F., 1146
 Skulls, human vs. chimpanzee, 544f, 558
 Skunks, 508f, 1218f
 Sleep, ACTH secretion during, 1014
 Sleep, brain functions and, 1094f
 Sleeping sickness, 65, 600, 601f, 713, 972
 Sleep movements, plant, 857, 858f
 Sliding-filament model, **1126**, 1127f, 1128
 Slime, hagfish, 723f
 Slime bacteria, 213f
 Slime layer, 575
 Slime molds, 612f–613f
 Slope in Scientific Skills Exercises, 157, 1049
 Slow block to polyspermy, 1045
 Slow-twitch fibers, **1131**
 Slugs, 699–700, 1155, 1156f
 Small interfering RNAs (siRNAs), **380f**
 Small intestine, 695f, **908**
 absorption in, 909f–910f
 adaptations of, 912f
 cells of, 125
 digestion in, 908f, 909
 Small populations, conservation of, 1266, 1267f–1268f, 1269
 Smallpox, 408–409, 968
 Smithells, Richard, 902f
 Smooth ER, 100f–101f, 104, 105f, 109f
 Smooth muscle, **879f**, **1131**–**1132**
 Smuts, 665
 Snails, 508f, 522, 538, 688f, 699, 700f, 702f, 1067f–1068
 Snakes, 498, 499f, 719f, 735, 737f, 738, 925, 968, 1053f, 1111f, 1217, 1218f, 1264
 gene flow in Lake Erie water snake, 496, 497f
 prey selection of, 1155, 1156f

- Snapdragons, 279f
 Snapping shrimp, 512f, 513
 Snook, Rhonda, 1024f
 Snow geese, 1256f–1257f
 Snow pea, 650f
 Snowshoe hares (*Lepus americanus*), 501f, 1205f
 Soapberry bugs, 477f, 478, 1187
 Social behavior, 1159f, 1160
 Social learning, 1147f–1148f, 1153
 Social play, 1159
 Society
 plant biotechnology and, 840
 population age structure and, 1208
 Society, science and, 19f, 23, 24f
 Sociobiology, 1159–1160
Sociobiology: The New Synthesis (book), 1159
 Sockeye salmon (*Oncorhynchus nerka*), 978f
 Sodium, 29t
 Sodium chloride
 elimination of excess, by marine birds, 982f
 human diets and, 901
 kidney processing of, 988f–990f, 991
 osmoregulation of, 992, 993f
 plant responses to excessive, 865
 as table salt, 29f, 38f, 49f
 in treating diarrhea, 139
 Sodium ions, 1070t, 1071f
 Sodium-potassium pump, 137, 1069–1070
 as active transport, 136, 137f
 neuron resting potential and, 1070f–1071f
 ouabain and, 1084
 Software, bioinformatics, 444, 445f–448f
 Soil
 acid precipitation and, 821
 antibiotics from bacteria in, 590
 bacteria in, 584f, 586f, 814f–816f, 817
 bryophyte reduction of nitrogen leaching from, 627f
 determining diversity of bacteria in, 1223f
 fossils in, 529f
 fungi in, 656f
 limiting nutrients in, 1244
 plant resource acquisition from, 787
 plant response to excessive salt in, 142, 865
 species distributions and, 1186
 sustainable agriculture and conservation of, 807f–809f
 texture and composition of, 806f–807f
 Soil conservation, 807f–809f
 Soil horizons, 806f
 Soil worm model organism. *See Caenorhabditis elegans*
 Solar cycle, 1282
 Solar energy
 absorption of, determining primary production with, 1242f
 in energy flow and chemical cycling, 9f, 1240f
 global energy budget and, 1241
 in photosynthesis, 41f, 187f
 primary production in aquatic ecosystems and limitations of, 1242
Solidago canadensis, 812
 Solute potential, 789, 804
 Solute potential equation, 804
 Solutes, 49
 animal osmoregulation of, 981, 982f
 diffusion of, 132, 133f
 diffusion of, across capillary walls, 932, 933f
 effects of, on water potential, 789–790
 ion gradients and transport of, 993f
 kidney gradients of, 989, 990f, 991
 osmoregulation of, 977f–982f
 short-distance transport of, across plant plasma membranes, 788, 789f
 solvents and, 49f, 50
 transport of, from roots to shoots via xylem, 792, 793f–795f, 796
 transport of, from sources to sinks via phloem, 799, 800f–801f
 Solutions, 49f, 50
 Solvents, 49f, 50
 Somatic cells, 236, 255
 Somatosensory cortex, 1097f, 1098
 Somites, 720, 1054f, 1055
 Songs, bird learning of, 1147
 Sonic hedgehog growth factor, 1063–1064
 Soredia, 668, 669f
 Sorghum, 813f
 Sori, 631
 Soufrière Hills volcano, 551
 Sound receptors, 1110, 1112f–1116f
 Sour tastes, 1123f–1124f
 South Africa, restoration projects in, 1254f
 South America, 743–744
 South American vampire bats, 991f, 992
 South Atlantic Subtropical Gyre, 1168f
 Southern flying squirrel (*Glaucomys volans*), 517
 Southern stingray (*Dasyatis americana*), 727f
 South Pacific Subtropical Gyre, 1168f
 Soybeans, 211, 493, 815f–816f, 817, 1015
 Space-filling models, 36, 37f, 39f, 59f, 74f, 79f, 319f
 Spain, 573f
 Spanish flu pandemic, 410
Spartina patens, 1186
 Spatial learning, 1144, 1145f
 Spatial summation, 1079f
 Spawning, 1022–1023
 Speciation, 507
 allopatric, 511f–512f, 513
 allopatric vs. sympatric, 511f, 516
 as conceptual bridge between microevolution and macroevolution, 507, 523
 Darwinian theory of, 473, 474f–476f
 genetics of, 522f, 523
 of humans, 524
 hybrid zones and reproductive isolation in, 516, 517f–519f, 520
 as origin of species in Darwinian evolution, 506f, 507
 orthologous genes and, 566
 reproductive isolation and biological species concept in, 507f–510f
 species selection and differential, 548–549
 sympatric, 513, 514f–515f, 516
 time course of, 520f–521f, 522
 Speciation clock, 522
 Species, 507
 biological concept of, 507f–510f
 classification of, 12f–13f, 470, 554, 555f
 communities of. *See Communities*
 comparing developmental processes of, 463f–464f
 comparing genomes of, 459, 460f–462f
 complete genome sequences for, 448f
 cross-species gene expression in evolution of, 423
 C. Darwin's theory of origin and evolution of, 14f–16f, 473, 474f–476f. *See also Evolution; Speciation*
 discovery of new, 1164f, 1185, 1260f
 distributions of. *See Species distributions*
 diversity of. *See Species diversity*
 edge, 1271
 endangered or threatened, 1261, 1262f, 1272f, 1288
 extinction of mollusc, 702f
 foundation, 1214, 1226
 fusion of, 519f, 520
 genome size, number of genes, gene density, and noncoding DNA for, 448f, 449
 geographic distribution of, 482f, 483
 homologous genes in, 565f, 566
 interactions between. *See Interspecific interactions*
 interactions of, 1214f–1221f, 1237
 introduced, 1223, 1264f, 1287
 keystone, 1226f, 1270
 large-impact, 1225, 1226f
 loss of amphibian, 733
 metagenomics and genome sequencing of groups of, 444
 morphological and ecological concepts of, 507, 508f–509f, 510
 number of named, 1261
 phylogenies as history of, for species, 554f–556f. *See also Phylogenies*
 populations of. *See Populations*
 resurrection of extinct, 1266
 in tree of life, 15f–16f
 tropical deforestation and extinctions of, 651f, 652
 using phylogenetic gene trees to identify, of whale meat, 557f
 Species-area curve, 1232f
 Species distributions
 abiotic factors in, 1178, 1183f–1186f
 in aquatic biomes, 1178
 biotic factors in, 1178, 1183f–1184f
 climate and, 1164, 1170f
 determinants of, 1164f
 dispersal in, 1183, 1184f
 evolution and, 1183, 1189
 natural range expansion, 1183, 1184f
 Species diversity, 1222f
 benefits of, to humans, 1262, 1263f
 biodiversity crisis and, 1260f–1262f
 biogeographical factors affecting, 1231, 1232f–1233f
 bottom-up and top-down controls in, 1226, 1227f
 climate change effects on, 1279
 community stability and, 1223f
 disturbances influencing, 1228, 1229f–1231f
 human impacts on, 1231f
 large-impact species in, 1225, 1226f
 as level of biodiversity, 1261f–1262f
 protection of, 1260
 resurrection of, 1266
 species richness and relative abundance in, 1222f
 sustainable development and, 1284, 1285f, 1286
 threats to, 1260f, 1261, 1263, 1264f–1266f
 trophic structure and, 1223, 1224f–1227f. *See also Trophic structure*
 Species richness, 1222
 biogeographic factors affecting, 1231, 1232f–1233f
 species-area curves of, 1232f
 in species diversity, 1222f. *See also Species diversity*
 Species selection, 548–549
 Species transplants, 1184
 Specific heat, 46, 47f
 Specificity
 cell-signaling, 227, 228f
 enzyme substrate, 155f, 156
 polymerase chain reaction, 421, 422f
 viral, 401
 Specific transcription factors, 374f–375f, 845
 Spectrophotometer, 193f
 Speech
 brain function and, 1098f
 FOXP2 gene and, 461, 462f
 Spemann, Hans, 1060, 1061f–1062f
 Sperm, 1020
 biased usage of, in female fruit flies, 1024f
 chromosomes in human, 236–237
 conception and, 1035f
 in fertilization, 1022f–1024f, 1044f, 1045
 flagellated, in plants, 619
 human spermatogenesis and, 1027, 1028f, 1031f, 1042
 mammalian sex determination and, 298f
 seed plant. *See Pollen grains*
 Spermathecae, 711, 1024f
 Spermatids, 1028f
 Spermatocytes, 1028f
 Spermatogenesis, 1022f, 1028f, 1031f, 1042
 Spermatogonia, 1028f
 Spermicidal foam or jelly, 1038f
Spermophilus parvii, 893
Sphagnum moss, 627f, 628
 S phase, 237f
Sphenodon punctatus, 737f
 Spherical prokaryotes, 574f
 Sphincters, 906f, 907
 precapillary, 932f
 Sphygmomanometer, 931f
 Spiders, 45f, 707, 708f, 951
 Spikemosses, 631, 632f, 633
Spilogale species, 508f
 Spina bifida, 1055
 Spinal cord, 1086f–1089f
 Spines, 762f
 Spines, sea star, 714f
 Spinners, 708
 Spiny-headed worms, 687f
 Spiny mouse, 1216f
 Spiral cleavage, 681, 682f
 Spiral phyllotaxy, 786f
 Spiral prokaryotes, 574f
 Spiral valve, shark, 727
Spirobranchus giganteus, 703f
 Spirochetes, 584f
Spirodela oligorrhiza, 101f

- Spliceosomes, **346f**
 Split-brain effect, 1098
 Sponges
 phylogeny of, 682, 683f, 684, 687f, 690f, 691
 Spongion, 690
 Spongocoel, **690f**
 Spongy mesophyll, **771f**
 Spontaneous abortions, 306, 1039
 Spontaneous change, 148f
 Spontaneous mutations, 360, 388
 Spontaneous processes, **146**
 Sporangia, **621f**, 625, 631, 640f, 641, 662f
 Spores, **620f**, **657**
 in alternation of generations, 258f
 brown algae, 603f, 604
 cell signaling and bacterial, 213f
 fossilized plant, 622f
 fungal, 654, 655f, 657, 658f–659f, 662f–663f
 meiosis and production of, 270n
 of plants, 620f–621f
 seeds vs., 639
 variations of, in vascular plants, 631
 Sporophylls, **631**
 Sporophytes, **620f**, **823**
 in alternation of generations, 258f
 brown algae, 603f, 604
 of bryophytes, 625, 626f
 gametophyte relationships with, in plants, 637f, 638
 in pine tree life cycle, 640f, 641
 of plants, 620f–621f
 of seedless vascular plants, 628f–630f
 Sporopollenin, **619**, 621f, 638
 Sporozoites, 605, 606f
 Spotted ratfish (*Hydrolagus colliei*), **727f**
 Spotted skunks (*Spilogale* species), 508f
 Spruce, 1230f–1231f
 Squamates, 737f, 738
 Squamous epithelium, **877f**
 Squids, 688f, 699, 701f, 702, 1086f
 Squirrel monkeys, 1122f
 Squirrels, 832f
 Arctic ground, 893
 Belding's ground, 1156, 1158, 1159f, 1193t, 1194f, 1195, 1213
 flying, 481f, 517
 Srb, Adrian, 337, 338f
 SRY gene, 298–299
 S-shaped logistic growth curve, 1198f–1199f
 Stability, community, 1223f, 1228
 Stability, equilibrium as, 147, 148f
 Stability, hybrid zone, 519f, 520
 Stability, population, 1205f, 1208
 Stabilizing selection, **498f**
 Stable isotopes, 31
 Staghorn coral, 1234
 Staghorn fern, 819f
 Stahl, Franklin, 322f
 Stalk-eyed flies, 1152f
 Stamens, 270f, 271, **644f**, **823f**
 Staminate flowers, 834
 Standard metabolic rate (SMR), **891**–892
 Stanley, Wendell, 399
Staphylococcus aureus, 214f, 478f, 584f
 Star anise, 650f, 653
 Starches, **70**
 as fuel for catabolism, 182f
 as product of photosynthesis, 206, 207f
 as storage polysaccharides, 70f, 71
 Starfish. *See* Sea stars
 Starling, European, 1264
 Star-nosed moles, 1107f–1108f
 Start codons, 341f, 350
 Start point, transcription, **343f**
 Statins, 938
 Stationary cilia, 1064
 Statistics, 17
 Statocysts, **1112f**
 Statoliths, **861f**, **1112f**
 Stator, ATP synthase, 175f
 Steinbeck, John, 807f
 Stele, **763**, 769f
 Stem cells, **428**, **935**
 animal embryonic and adult, 430, 431f
 animal induced pluripotent, 431, 432f
 generation of differentiated cells from, 431f
 glia as, 1090f
 plant, 766
 potential of, 428
 in replacement of blood components, 935f, 936
 in spermatogenesis, 1042
 Stems, **758**, **761**
 ethylene in triple response of, to mechanical stress, 853f
 gibberellins in elongation of, 851f
 monocot vs. eudicot, 649f
 primary and secondary growth of, 766f–767f
 primary growth of, 769f–771f, 775f
 secondary growth of, 772f–775f
 structure of, 761f
 Stenohaline animals, 978
 Stents, 937f
 Steppes, 1175f
 Sterility
 hybrid, 509f, 522–523
 transgenic plant, 839–840
 Sterilization, human, 1038f, 1039
 Steroid hormones, **75**
 coordinate control of genes by, 375–376
 functional groups and, 62f
 as intracellular chemical signals, 220, 221f
 as lipids, 75f
 smooth ER synthesis of, 104–105
 Steroids, **75**
 adrenal gland and, 1012f, 1013
 brassinosteroids as, 854–855
 as environmental toxins, 1276
 in human endocrine system, 1004f
 as lipid-soluble hormones, 1001f
 receptors for, 1003f
 sex hormones as, 1014, 1015f
 Steward, F. C., 428
 Stickleback fish (*Gasterosteus aculeatus*), 481, 546f, 547, 1140f
 Sticky end, DNA, **420**
 Stigma, **644f**
 Stigma, angiosperm, **823f**
 Stimulus, **882**
 environmental, 1140f–1141f
 homeostatic, 882
 sensory, 1108f–1109f
 in stimulus-response chains, 1141f, 1142
 Stingrays, 726, 727f
 Stink bugs, 712f
 Stipes, **602**, 603f
 Stock, **835**–836
 Stolons, 761f
 Stomach, **907**
 adaptations of, 912f
 bacteria in, 912, 913f
 digestion in, 907f–908f
 dynamics of, 908
 Stomach ulcers, 584f
 Stomata, **189**, **621**, **771f**, **777f**
 of CAM plants, 205, 206f
 of horsetail, 635
 ion gradients and, 993f
 in photosynthesis, 189f
 photosynthesis–water loss compromise, 787
 plant, 622
 regulation of transpiration by opening and closing of, 796, 797f–799f
 sporophyte, 625
 transpiration and, 203
 Stop codons, 341f, 352, 353f
 Storage leaves, 762f
 Storage polysaccharides, 70f, 71
 Storage proteins, 76f
 Storage roots, 760f
 Storms, 1172, 1228
 climate change and, 11
 Stramenopiles, 599f, 602f–604f
 Strangling aerial roots, 760f
 Strasburger, Eduard, 794
 Strata, **470f**, 529f
 Strathdee, Steffanie, 872
 Stratified squamous epithelium, 877f
 Strawberry poison dart frogs, 524
 Streams, 1180f, 1274
Streptococcus, 575f, 584f, 691
Streptococcus pneumoniae, 315f, 579, 957
Streptococcus pyogenes, 404f
 Stress
 adrenal gland response to, 1012f–1013f, 1014
 ethylene in plant responses to, 853f
 immune systems and, 971
 response to, 1003
 Stretch receptors, 1110
 Striated muscle, 879f, 1126. *See also* Skeletal muscle
Striga, 855
 Strigolactones, 846t, 850, **855**
 Strobili, **631**
 Strokes, **937f**, 938–939
 Stroke volume, **927**
 Stroma, **110**, 111f, **189f**, 191f, 192, 200f, 201
 Stromatolites, 532f, **533**
 Structural formulas, 36, 37f, 59f, 74f
 Structural isomers, **61f**
 Structural polysaccharides, 70f–72f
 Structural proteins, 76f
 Structure, function and, 6
 Strychnine, 1220
 Studies. *See* Inquiry Figures
Sturnella magna, 507f
Sturnella neglecta, 507f
 Sturtevant, Alfred H., 305f–306f
 Styles, flower, **644f**, **823f**
 Subatomic particles, 30f, 31
 Suberin, 774
 Subsidence, land, 808f
 Substance P, 1081t
 Substrate feeders, **903f**
 Substrate-level phosphorylation, 168, **169f**
 Substrates, **155f**, 156, 160f–161f
 Succulent Karoo restoration project, 1254f
 Succulent plants, 205, 206f
 Suckling, 1036
 Sucrase, 153, 155
 Sucrose
 as disaccharide, 69f
 enzymatic catalysis and, 153, 155
 molecular mass of, 50
 plant cell uptake of, 142
 as product of photosynthesis, 206, 207f
 transport of, in vascular plants, 799, 800f–801f
 Sudden oak death (SOD), 614f, 867, 1234
 Sugarcane, 206f
 Sugar gliders, 481f
 Sugar-phosphate backbone, DNA, 85f–86f, 317f–320f, 325f–326f
 Sugars. *See also* Carbohydrates
 blood regulation, 10f
 as components of nucleic acids, 84, 85f
 conduction of, in plant cells, 765f
 monosaccharides and disaccharides, 68f–69f, 70
 polysaccharides, 70f–72f
 as products of photosynthesis, 191f, 192, 201, 202f, 206, 207f
 translocation of, from sources to sinks via phloem, 799, 800f–801f
 Sugar sinks, **800**
 Sugar sources, **800**
 Suicide genes, 390
 Sulphydryl group, 63f
 Sulfur, 29t, 64
 Sulfur dioxide emissions, 1266
 Sulston, John, 1058–1059
 Sumner, Francis Bertody, 20
 Sundews, 819f
 Sunflowers, 521f, 894f
 Sunlight
 absorption of, determining primary production with, 1242f
 aquatic biomes and, 1177f–1178f
 cancer and, 394
 DNA damage from, 328
 in energy flow and chemical cycling, 9f, 164–165, 1240f
 as energy for life, 143, 145, 150
 global energy budget and, 1241
 latitudinal variation in intensity of, 1166f
 in photosynthesis, 187f, 206, 207f
 primary production in aquatic ecosystems and limitations of, 1242
 properties of, 192f
 seasonal variations in, 1167f
 species distributions and availability of, 1185, 1186f
 Supercontinent, 538, 539f
 Supergroups, protist, 597f–599f
 Superimposed electron orbitals model, 35f
 Supernatural vs. natural explanations, 18
 Super-resolution microscopy, 95f, 96
 Superweeds, 438

- Suprachiasmatic nucleus (SCN), 893f, 1015, **1094–1095**
- Surface area
calculating cell volume and, 99
maximizing, by animals, 695f
- Surface area-volume relationships, 98f
- Surface tension, 45f, 46
- Surfactants, 943, 944f
- Surroundings, systems and, 145
- Survival
adaptations, natural selection, and, 475f, 476
animal behavior evolution and, 1148, 1149f–1154f
gecko appearance and, 26
life histories and, 1200, 1201f–1202f
- Survivorship curves, **1193**, 1194f
- Suspension feeding, 721f, 727, 903f
- Suspensor cells, 828f
- Sustainability, 1284
- Sustainable agriculture, **808**
in Costa Rica zoned reserves, 1273
soil conservation in, 807f–809f
- Sustainable development, **1284**, 1285f, 1286
- Sutherland, Earl W., 216f, 217, 223
- Sutton, Walter S., 295
- Swallowing reflex, 906f
- Sweden, 1208
- Sweet potatoes, 651, 837
- Sweet tastes, 1123f–1124f
- Swim bladders, **728f**
- Swimming, 1135
- Swine flu, 410, 1234
- Switchgrass, 838
- Symbionts, **587**
- Symbiosis, **587**, 1256f. *See also* Commensalism; Mutualism; Parasitism
fungal, 662–663, 667f–669f
protist, 614f
- sym* genes, 660
- Symmetry
animal body, 679, 680f
body, 1059, 1060f, 1064f
flower, 644f, 649f
- Sympathetic division, peripheral nervous system, 928, 1088f–**1089f**
- Sympatric populations, character displacement in, 1216, 1217f
- Sympatric speciation, **513**, 514f–515f, 516
- Symplast, **787**, 788f, 800f
- Symplastic communication, 801, 802f
- Symplastic domains, 802
- Symplastic route, 788f, 793f
- Synapses, 1067–**1068**
electrical and chemical, 1077, 1078f
generation of postsynaptic potentials and, 1077–1078
in memory and learning, 1099, 1100f–1101f
modulated signaling at, 1080
neurotransmitters and, 1077, 1078f, 1080f, 1081t, 1082
in regulation of muscle contraction, 1128, 1129f, 1130
scaffolding proteins and, 228f, 229
summation of postsynaptic potentials and, 1078, 1079f
- Synapsids, 531f, **741**, 742f
- Synapsis, **262f**
- Synaptic cleft, 1077
- Synaptic signaling, 215f, 216, 1000f, 1001
- Synaptic terminals, 1068f
- Synaptic vesicles, 1077
- Synaptonemal complex, **262f**
- Syndermata, 687f
- Syndromes, 308
- Synthesis stage, phage lytic cycle, 402f
- Synthetases, 349f
- Syphilis, 584f
- Systematics, **554**, 682, 683f, 684. *See also* Cladistics; Molecular systematics; Taxonomy
Systemic acquired resistance, **866**, 867f
- Systemic circuit, 924f–926f
- Systemic inflammation, 956–957
- Systemic lupus erythematosus, 971
- Systemic mycoses, 670
- Systems
thermodynamics and isolated vs. open, 145, 149f–150f
- Systems approach, 425
- Systems biology, **5–6**, **446**, 447f–448f
- Systole, **927f**
- Systolic pressure, **930**, 931f
- Szent-Györgyi, Albert, 900
- Szostak, Jack, 528
- T**
- T2 phage, 316f, 317
- Table salt. *See* Sodium chloride
- Tables in Scientific Skills Exercises, 58, 89, 157, 179, 205, 264, 304, 318, 458, 493, 513, 570, 590, 595, 629, 639, 657, 678, 751, 762, 790, 834, 918, 938, 972, 981, 1014, 1030, 1049, 1082, 1186, 1217, 1247, 1279
- TACK supergroup, 586
- Tactile communication, 1141f
- Tadpoles, 381f, 732f
- Taiga, 1175f
- Tail, muscular post-anal, 720f
- Tail end, 680f
- Tails, histone, 330f, 371f
- Takahe bird, 1254f
- TAL protein, 334
- Tamiflu, 414
- Tamoxifen, 250, 393f
- Tannins, 1220
- Tapeworms, 687f, 696, 697f, 1220
- Tapping, in fruit fly courtship, 1141f
- Taproots, **759f**–760f
- Taproot systems, 759f, 760
- Taq* polymerase, 421, 1263
- Tardigrades, 689f, 980f
- Target cells, hormone, 1000f–1004f
- Tarsiers, 746f
- Tar spot fungus, 669f
- Tastants, **1123f**–1124f
- Taste, 233, 1123f–1124f
- Taste buds, **1124f**
- TATA boxes, 343f, **344**, 373
- Tatum, Edward, 336f–338f
- Tau protein, 1104
- Taxis, **576**
- Taxol, 249
- Taxon, **554**, 555f–556f, 560
- Taxonomy. *See also* Cladistics; Phylogenies; Systematics
early schemes of, 470
grouping of species in, 12f–13f
mammalian, 745f
phylogenies and, 554, 555f–556f
possible plant kingdoms, 619f, 621
ten phyla of extant plants, 622t
three-domain system of, 12f, 13, 568, 569f
tree of life of, 15f–16f
- Tay-Sachs disease, **280**
allele dominance and, 280
fetal testing for, 288, 289f
as lysosomal storage disease, 108
recessive alleles in, 285
- T cells, **958f**
antigen recognition by, 959f–960f
clonal selection of, 962f, 963
cytotoxic, 962, 966f, 967
development of, 960, 961f–963f
diversity of, 960, 961f
DNA of, 976
helper, 963, 964f
immunological memory, 963f
proliferation of, 961–962
regulatory, 971
- Tea, 651, 783
- Teal, John, 1247
- Technology, **23**, 24f
DNA. See Biotechnology; DNA technology
global carrying capacity and, 1211
prokaryotes in research and, 589, 590f–591f
- Tectonic plates, 538f–539f, 540
- Teeth
conodont mineralized dental elements, 724f, 725
diet and adaptations of, 911f, 912
mammalian, 530, 531f, 532, 741
origins of, 725
- Teixobactin, 478, 590
- Telomerase, 329
- Telomeres, **328**, 329f, 452
- Telomeric DNA, 452
- Telophase (mitosis), **237**, 239f, 243f, 252, 263f
- Telophase I, 260f, 263f
- Telophase II, 261f
- Temperate broadleaf forests, **1176f**
- Temperate forests, decomposition in, 1248
- Temperate grasslands, **1175f**
- Temperate phages, **403f**
- Temperature, **46**
aquatic biomes and, 1177, 1178f
climographs of, 1171f
coefficients in Scientific Skills Exercise, 790
correlation of atmospheric carbon dioxide with global, 1278f, 1279, 1282, 1283f
decomposition rates and, 1248f
effects of transpiration on leaf, 798
enzymatic catalysis and, 157, 158f
global, and extinction rates, 541f, 542
heat vs., 46
membrane proteins and, 128f
moderation of, by water, 46, 47f–48f
plant response to stress of, 865
primary production in terrestrial biomes and, 1243f, 1244f, 1245
protein denaturation and, 82f, 83
regulation of body. *See Thermoregulation*
species distributions and, 1164, 1185f
- Templates, viral DNA and RNA, 405f, 406f
- Template strands, DNA, 320, 321f–327f, **340f**
- Tempo, speciation, 520f–521f, 522
- Temporal fenestra, 531f, 741
- Temporal isolation, 508f
- Temporal lobe, 1085, 1097f
- Temporal summation, 1079f
- Tendons, **878f**, 1138
- Tendrils, 762f
- Tentacles, invertebrate, 691f, 701f, 702
- Terminal cells, 828f
- Termination, neurotransmission, 1080f
- Termination codons, 341f
- Termination stage
transcription, 343f, 344
translation, 352, 353f
- Terminators, **342**, 343f
- Termites, 143f, 614f, 655
- Terpenoids, 868f
- Terrestrial adaptations
mycorrhizae as plant, 817
seed plant, 637f–638f, 639
- Terrestrial biomes
animal osmoregulation in, 980–981
biodiversity hot spots in, 1272f
chaparral, 1174f
climate and, 1171f
climate change effects on, 1244f, 1245
decomposition in, 1248f
deserts, 1173f
disturbance in, 1172
food chains in, 1224f
general features of, 1172f
global distribution of, 1171f, 1189
habitat loss in, 1263–1264
locomotion in, 1135f
northern coniferous forests, 1175f
nutrient cycling in, 1250f–1251f
plant adaptations to, 203
primary production in, 1243f–1244f, 1245
savannas, 1174f
temperate broadleaf forests, 1176f
temperate grasslands, 1175f
tropical forests, 1173f
tundra, 1176f, 1256f–1257f
- Territoriality, **1192f**, 1204f
- Tertiary consumers, **1240f**
trophic efficiency of, 1246, 1247f, 1248
- Tertiary structure, protein, **81f**
- Testcrosses, **274**, 275f, 301f–302f
- Testes, 257f, 258, 1004f, 1014, 1015f, **1025f**, 1031f
- Testicles, 1025f
- Testing, genetic. *See* Genetic testing
- Testing, hypothesis, 17, 18f–19f
- Testosterone, 62f, 397, 999f, **1014**, 1015f, **1030**, 1031f
- Tests, foraminiferan, **608**
- Test-tube cloning, 836f
- Tetanus, **1130**
- Tetrahymena*, 346
- Tetraploids, 514
- Tetraploidy, 307

- Tetrapods, **730**
 amniotes, 734f–735f
 amphibians, 731, 732f–733f
 derived characters of, 730
 evolution of, 678
 homologous characteristics of, 480f
 land colonization by, 537
 as lobe-fins, 730
 origin and phylogeny of, 730f–731f
 origin of, 530, 531f–533f
Tetrodotoxin, 813f
Texture, soil, 806f
Thalamus, **1093f**, 1095f, 1097
Thalassoma bifasciatum, 1020
Thalidomide, 65
Thalloid liverworts, 626f
Thaumarchaeota clade, 586
Themes of biology, 3f–16f
Theobroma cacao, 667f, 668
Theories, **21**–**22**, 483–484
Therapeutic cloning, 431
Therapsids, 531f
Thermal energy, **46**, 132, **144**
Thermocline, **1177**, 1178f
Thermodynamics, laws of, 143, 145f, 146, 1239
Thermogenesis, 887f–888f
Thermophiles, 441, 585f, 586
Thermoreceptors, **1111f**
Thermoregulation, **884**
 acclimatization in, 883f, 888
 aquatic animal feedback regulation in, 881f
 circadian rhythms in human, 882, 883f
 in endothermic and ectothermic animals, 884f
 heat loss and gain balance in, 885f–888f
 minimum metabolic rate and, 890–891
 nonliving example of, 881–882f
 penguin form and function for, 873f
 physiological thermostats and fever in, 888, 889f
 variation in animal body temperatures and, 884–885
Thermostatic thermoregulation, 888, 889f
Thermus aquaticus, 421, 441, 1263
Theropods, **736**
Thick filaments, **1125**, 1126f–1127f, 1131–1132
Thigmomorphogenesis, **861**, 862f
Thigmotropism, **862f**
Thin filaments, **1125**, 1126f–1127f, 1131–1132
Thiol compounds, 63f
Thiomargarita namibiensis, 574, 584f
Third-generation sequencing, 416
Thirst, 1110
Thlaspi caerulescens, 809
Thompson seedless grapes, 851f
Thoracic cavity, 942, 945
Thorax, insect, 710f
Threatened species, **1261**, 1262f, 1272f
Three-parent babies, 311
Threonine, 77f, 222
Threshold, **1073**
Thrombin, 936f
Thrombus, **937**, 939
Thrum flower, 835f
Thucydides, 962
Thumbs, opposable, 744
Thunus albacares, 729f
Thylakoid membranes, 189f, 190, 196f–200f, 201
Thylakoids, **110**, **189**
 ATP production and, 211
 in chloroplasts, 110, 111f
 light reactions in, 191f, 192
 as sites of photosynthesis in chloroplasts, 189f, 190
Thylakoid space, 189f
Thymine, 84, 85f, 86, 317f, 318, 337, 340f
Thymine dimers, 328
Thymus, **958**
Thyroid gland, 1004f, 1008, **1009f**, 1010
Thyroid hormone (T_3 and T_4), 1004f, **1008**, 1009f, 1010, 1015f
Thyroid hormones, 179, 220
Thyroid-stimulating hormone (TSH), 1004f, 1008f–1009f, 1010
Thyrotropin-releasing hormone (TRH), 1009f
Thyroxine (T_4), 1001f, 1003, 1008, 1009f, 1010, 1015f
Tiburon Mariposa lily (*Calochortus tiburonensis*), 30f
Ticks, 588f, 707–708, 1220, 1234, 1235f
Tidal volume, **945**
Tides, 1181f
Tiger moths, 717
Tigers, 293, 1288
Tiger swallowtail, 313
Tight junctions, 120f
Tiktaalik fossil, 533f, 730f, 731
Time
 phylogenetic tree branch lengths and, 561, 562f
 required for human cell division, 237
Tinbergen, Niko, 1140, 1145f
Tissue culture, plant, 836f
Tissue-level herbivore defenses, plant, 868f
Tissue plasminogen activator (TPA), 436, 457f
Tissues, **5f**, **674**, **759**, **876**
 animal, 673–674, 876, 877f–879f
 animal body plan and, 673–674, 680–681
 culturing plant, 836f
 of human endocrine system, 1003, 1004f
 immune system rejection of transplanted, 969–970
 as level of biological organization, 5f
 plant, 759, 762, 763f
 proteins specific to, in cell differentiation, 383
 renewal of, as cell division function, 235f
 substitutes for, 897
 water and salt concentrations in, 977f, 978
Tissue-specific proteins, 383
Tissue systems, plant, **762**
 in leaves, 770, 771f
 in primary growth of roots, 768f–769f
 in primary growth of shoots, 769f–771f
 types of, 762, 763f
Tit-for-tat strategy, 1159
Timesipteris, 632f, 633
Toadfish, 1131f
Toads, 516, 517f, 520, 732, 1217
Tobacco mosaic virus (TMV), 399f–400f, 412
Tobacco plant, 342f
Toll-like receptors (TLRs), **955f**, 976
Toll receptors
 in insects, 954
Tollund Man, 627f
Tomatoes, 645f, 849
Tongue, 906f, 1124f
Tonicity, **134f**–**135f**
Tools, hominin use of, 750
Tooth cavities, 213
Top-down control, 1226, **1227f**
Topoisomerases, **323f**, 327t
Topologically associated domains (TADs), 377, 378f
Topsoil, **806**, 807f
Torpor, **892**
Tortoise shell cats, 300f
Totipotent amoebocytes, 691
Totipotent cells, **428**, **1061**
Totipotent plants, **835**–**836**
Touch, plant response to, 861, 862f
Touch receptors, 1110f
Tourism, zoned reserves and, 1273, 1273f
Toxic waste
 bioremediation of, 1253, 1255f
 biotechnology in cleanup of, 418f, 437
 density-dependent population regulation by, 1204f
Toxins
 botulism, 1080
 as defensive adaptations, 1217–1220
 detoxification and, 104–105, 112
 dinoflagellate, 605f
 environmental, 1275, 1276f–1277f
 enzymatic catalysis and, 158–159
 evolution of tolerance to, 30f
 fungal, 669f
 soil, 809, 812
T phages, 400f–402f, 403
Trace elements, **29t**
Trace fossils, 529f
Tracers, radioactive, 31, 32f, 190
Trachea, 906f, **942**, 943f
Tracheal systems, insect, 707, 710f, **941**, 942f
Tracheids, **629**–**630**, **765f**
Trade-offs, 501
Trade-offs, life history, 1201f–1202f
Tragopogon species, 514, 515f
Traits, **270**. *See also* Alleles
 characters and, 270–271
C. Darwin on natural selection and, 14f–16f
dominant vs. recessive, 271f, 272t, 285f
inheritance of, in Darwinian evolution, 475f, 476
inheritance of X-linked genes and recessive, 299f, 300
life history, 1200, 1201f–1202f
noninheritance of acquired, 471f
plant derived, 620f–621f
seedless vascular plant, 628f–631f
Transacetylase, 368f
Transcription, **337**
 effects of ncRNAs on, 380–381
 eukaryotic gene regulation after, 377, 378f, 379
 in gene expression and protein synthesis, 7f–8f, 335–336, 337, 339f
 gene expression as, 371
 molecular components and stages of, 342, 343f
 regulation of, in plant responses, 845
 regulation of bacterial, 366f–369f, 370
 regulation of eukaryotic initiation of, 373f–378f, 379
RNA processing after, 345f–347f
 scale of, 123f
 summary of eukaryotic, 356f
 synthesis of RNA transcript during, 343f–344f
 template strands in, 340f
Transcription factories, 377, 378f
Transcription factors, 343f, **344**
 in cell signaling, 221f, 226f
 in eukaryotic gene regulation, 374f–377f
Transcription initiation complex, 343f, **344**, 373f–375f
Transcription units, **342**, **343f**
Transduction, genetic, **579f**
Transduction, sensory, 1109, 1114, 1115f, 1120f
Transduction stage, cell-signaling, **216**
 multistep pathways and signal amplification in, 221
 overview of, 216f, 217
 in plant signal transduction pathways, 844f, 845
 protein phosphorylation and dephosphorylation in, 222f, 223
 signal transduction pathways and, 221–222
 small molecules and ions as second messengers in, 223f–225f
 in yeast-cell mating, 214
trans face, Golgi apparatus, 106f, 107
trans fats, 61, **74**, 938
Transfer RNA (tRNA), **348**. *See also* RNA (ribonucleic acid)
 structure of, 86f, 348f
 in translation, 347f–350f, 352, 353f
Transformation, cancer and cellular, **249f**
Transformation, energy, 143f–146f, 147, 209f. *See also* Metabolism
Transformation, genetic, **315f**, **579**, 776
Transfusions, blood, 969–970
Transgender individuals, 299
Transgene escape issue, 839–840
Transgenes, **436f**, 776, **837**, 841
Transgenic animals, **436**
Transgenic plants, **837**. *See also* Genetically modified organisms
 biotechnology and genetic engineering of, 837, 838f
 issues about agricultural crops as, 438–439, 838–840
trans isomers, 61f
Transitional ER, 105f
Transition state, 154
Translation, **339**
 basic concept of, 347f
 building polypeptides in, 350f–353f
 completing and targeting functional proteins in, 354f, 355
 in eukaryotic cells, 356f
 in gene expression and protein synthesis, 335–337, 339f
 identifying ribosome binding sites with sequence logos in, 351
 molecular components of, 347f–350f
 post-translational protein modification in plant responses, 845
 regulation of eukaryotic initiation of, 378–379
 ribosomes in, 349, 350f
 scale of, 123f
 synthesizing multiple polypeptides with polyribosomes in, 355f

- transfer RNA in, 347f–350f
 Translation initiation complex, 352f
 Translation initiation factors, 378–379
Translocation, 799
 cancer gene, 388, 389f
 chromosome structure and, 307, 308f, 309f
 plant transport, 799, 800f–801f
 in translation, 352, 353f, 354–355
Transmembrane proteins, 129f–130f, 217f–220f
Transmembrane route, 788f, 793f
Transmission, sensory, 1109f
Transmission electron microscope (TEM), 96
Transmission electron microscopy (TEM), 95f
Transmission rate, disease, 1204f
Transpiration, 792
 effects of, on plant wilting and leaf temperature, 798
 plant adaptations for reducing evaporative water loss by, 798, 799f
 regulation of, by opening and closing stomata, 796, 797f–799f
 in water and mineral transport from roots to shoots via xylem, 792, 793f–795f, 796
 in water cycle, 1250f
Transpirational pull, 794f–795f
Transplants
 immune system rejection of, 969–970
 species, 1184
Transport, plant and animal, 895f. *See also*
 Circulatory systems; Transport in vascular plants
Transport epithelia, 981, 982f, 988f, 989
Transport function, membrane protein, 130f
Transport in vascular plants, 629–630. *See also*
 Vascular plants
 regulation of transpiration rate by stomata in, 796, 797f–799f
 resource acquisition adaptations and, 784f–786f, 787
 short-distance and long-distance mechanisms of, 787, 788f–791f
 sugar transport from sources to sinks via phloem in, 799, 800f–801f
 symplastic communication in, 801, 802f
 of water and minerals from roots to shoots via xylem, 792, 793f–795f, 796
 xylem and phloem in, 765f
Transport proteins, 76f, 126, 132
 in active transport, 136, 137f
 aquaporins, 790–791
 cellular membrane selective permeability and, 132f
 as cotransporters, 138f, 139
 facilitated diffusion and, 135f, 136
 ion pumps and, 138
 plant solute transport and, 788, 789f
 water diffusion and, 790–791
Transport vesicles, 105, 106f, 107, 109f, 139, 140f
Transport work, 150, 152f
Transposable elements, 450f–451f, 452, 459
Transposase, 451f
Transposition process, 450f–451f, 452, 459
Transposons, 380–381, 408, 451f
Transthyretin protein, 80f–81f
Transverse (T) tubules, 1128f–1129f
Trawling
 community disturbances by, 1231f
Tree frogs, 500f
Treehopper, 466
Tree of life
 Darwinian evolution and, 15f–16f, 474f. *See also*
 Evolutionary trees
 phylogenies in investigation of, 553f–554f, 568, 569f–570f
 three-domain taxonomy of, 568, 569f
Tree rings, 773f
Trees
 climate change effects on CO₂ absorption by, 1245
 ecosystem interaction with, 10f, 11
 petrified, 529f
 photosynthesis in, 187f
Tree trunks, 774f
Trematodes, 696f
Trends, evolutionary, 548, 549f
Treponema pallidum, 584f
Triacylglycerols, 72, 73f, 74
Trial-and-error learning, 1146f
Tricarboxylic acid cycle. *See* Citric acid cycle
Trichechus manatus, 572, 1219f
Trichinosis, 705f, 706
Trichomes, 763f, 799f, 868f
Trichomonas vaginalis, 600f
Triglycerides, 72, 73f, 74, 910f
Triiodothyronine (T₃), 1008, 1009f, 1010
Trilobites, 706f
Trimesters, human pregnancy, 1035f–1037f
Trimethylamine oxide (TMAO), 979
Trioses, 68f
Triple response, plant, 853f
Triplet code, 340f. *See also* Genetic code
Triploblastic animals, 680, 681f
Triploid, 268, 307
Trisomic cells, 307
*Trisomy 21, 308f, 309. *See also* Down syndrome*
Trisomy X, 309
Tristan da Cunha, 495
Triticum aestivum, 1204f
Triticum species, 514–515, 524
Trochophore larva, 683f, 684, 685, 694
Trophic efficiency, 1246, 1247f, 1248
Trophic levels, 1224, 1257f
 in ecosystem energy flow and chemical cycling, 1240f, 1241
 energy transfer between, 1246, 1247f, 1248
Trophic structure, 1223
 bottom-up and top-down controls on, and
 biomanipulation of, 1226, 1227f
 energetic hypothesis on restriction of food chain length, 1225f
 food webs of food chains in, 1224f–1225f, 1237
 species with large impacts on, 1225, 1226f
Trophoblasts, 1035, 1052, 1053f
Tropical cone snails, 1067f–1068
Tropical dry forests, 1173f, 1263
Tropical rain forests, 1173f
 climate change and photosynthesis of, 211
 decomposition in, 1248
 deforestation of, as threat to biodiversity, 651f, 652, 1263
 fragmentation of, 1271f
 primary production in, 1244
Tropic hormones, 1008f
Tropic of Cancer, 1166f
Tropic of Capricorn, 1166f
Tropics, 1166f, 1232
Tropidolaemus wagleri, 737f
Tropisms, 847
Tropomyosin, 1128f–1129f
Troponin complex, 1128f
Troponin T, 378f
Trout, 728f, 1265
trp operator, 367f
trp operon, 367f, 368–369
TRP (transient receptor potential) proteins, 1111, 1124
trp repressor, 367f
True-breeding organisms, 271
True bugs, 712f
Truffles, 663f, 670
Trypanosoma, 600, 601f, 713, 972
Trypsin, 158f
Tryptophan, 77f, 366f–367f, 1081
Tsetse flies, 713, 903f
*Tuataras (*Sphenodon punctatus*), 735, 737f*
Tubal ligation, 1038f, 1039
Tubal pregnancies, 1039
Tube cells, 646f, 826
Tube feet, 713, 714f
Tuberculosis, 584f, 589, 592, 957, 1204f
Tubers, 761f
Tubeworms, 914f
Tubulin, 114, 240–241
Tubulinids, 612
Tumbleweeds, 832f
Tumors, 435
Tumors, cancer, 249f, 250
Tumor-suppressor genes, 388, 391f, 394
Tumor viruses, 394–395
Tuna, 729f, 874f, 1265f
Tundra, 1176f, 1238f, 1244, 1256f–1257f
Tunicates, 715, 719f, 721f, 722, 1058f
Turgid cells, 134f, 135, 790, 791f, 797f
Turgor movements, plant, 862f
Turgor pressure, 134f, 135, 789
Turner syndrome, 309
Turnover, 1178f
Turtles, 719f, 735, 736f, 737, 884f, 925, 1066, 1194, 1195f
Tutu, Desmond, 462
Twins, 1036, 1061, 1162
Twin studies, 1144
Tympanic membrane, 1112f–1113f
Typanuchus cupido, 495f, 496, 1267f
Type 1 diabetes, 917
Type 2 diabetes, 372f, 917
Typha angustifolia, 1186
Typhoid fever, 588
Tyrannosaurus rex, 736, 874, 983
Tyrosinase, 337
Tyrosine, 77f, 222, 1009, 1081

U

- Ubiquinone (Q), 175
Ubiquitin, 379
Ubx gene, 545f, 546, 706f
Ulcers, 584f, 912, 913f
Ultimate causation, 1140
Ultrasound sound, 717
Ultrasound fetal testing, 289
Ultrasound imaging, 1039
Ultraviolet (UV) radiation
 cancer and, 394
Chlamydomonas nivalis and, 211
 DNA damage from, 328
 elevation and, affecting species distributions, 1186f
 flowers and, 824f
 in insect vision, 1117–1118
 mutations from, 360
 ozone depletion and, 1283f, 1284
Ulva, 610f
Umami tastes, 233, 1123f–1124f
Undernourishment, 902
Undershoot phase, action potential, 1074f, 1075
Unger, Franz, 270
Ungulates, 481f–482f
Unicellular organisms, 532f–535f
Uniform dispersion, 1192f
Unikonts, 599f, 611f, 612f–613f, 614
Unisexual flowers, 824
United States, age-structure pyramid for, 1209f
Unity
 in biodiversity, 13f–14f, 26
 cellular structures and, 125
 evolution and, 469, 473
 within species, 510
Unlinked genes
 identifying, 304
 mapping, 305f–306f
 recombination of, 302f
Unpaired electrons, 36
Unsaturated fats, 73f, 74, 128f
Unsaturated fatty acids, 73f, 74
Unselfish behavior, 1156f–1157f
Untranslated regions (UTRs), 345f, 378
Upright posture, hominin, 748
Upwellings, 1243
Uracil, 84, 85f, 86, 337, 340f–341f
Uranium
 bioremediation of, 1255f
 half-life of, 32
Uranium-238, 529, 530f
Urban ecology, 1273, 1274f
Urea, 60, 979, 982f, 983, 989, 990f, 991
Ureter, 986f
Urethra, 986f, 1025f
Urey, Harold, 57, 526
Uric acid, 982f–983f
Urinary bladder, 986f
Urine
 concentration of, 989, 990f, 991
 hyperosmotic, 991
 nephron processing of blood filtrate to, 987, 988f, 989
Urochordata (tunicates), 719f, 721f, 722
Urodela, 731, 732f
Ursus arctos, 510f, 1268f, 1269, 1272–1273
Ursus maritimus, 11, 510f
USA300 bacteria, 478f, 589f
Use and disuse principle, Lamarck's, 471
Uterine cycle, 1032f, 1033
Uterus, 100f, 1026, 1027f

- Utricle, 1115f
Utricularia gibba, 448t, 449
 Uyuni Salt Flat, 1185f
- V**
 Vaccination, 968f, 976
 Vaccines, 408–409
 for amphibians, 733
 Vacuolar sap, 777
 Vacuoles, 100f–101f, 108f
 Vagina, 1026, 1027f, 1034
 Vaginal pouch, 1038
 Valence, 36, 59f
 Valence electrons, 35–36
 Valence shells, 35
 Valine, 77f
 Valium, 1081
 Vampire bats, 991f, 992
 van der Waals interactions, 39, 81f
 van Leeuwenhoek, Antoni, 94
 van Niel, C. B., 190
Varanus komodoensis, 1042
 Variable (V) region, light and heavy chain, 958f–961f
 Variables, 20–21
 comparing two, 972
 identifying dependent and independent, 513
 Variation, 255
 Variation, genetic. *See* Genetic variation
 Variegation, 311f
 Vasa recta, 987f
 Vascular bundles, 763, 770f
 Vascular cambium, 766f; 772f–774f, 849
 Vascular cylinder, 763
 Vascular plants, 622. *See also* Seedless vascular plants;
 Seed plants
 origin and traits of, 628f–631f
 phylogeny of, 622t
 resource acquisition for, 784f–786f, 787
 seedless. *See* Seedless vascular plants
 transport in. *See* Transport in vascular plants
 Vascular rays, 773f
 Vascular tissue, 622, 785f
 Vascular tissue system, plant, 758, 763f, 765f
 Vascular transport, 536, 629–630
 Vas deferens, 1025f
 Vasectomy, 1038f, 1039
 Vasocongestion, 1034
 Vasoconstriction, 885, 931
 Vasodilation, 885, 931, 1001, 1026
 Vasopressin. *See* Antidiuretic hormone
 Vectors, zoonotic disease, 1234, 1235f
 Vegetable oil, 49–50, 74
 Vegetal pole, 1048f
 Vegetarian diets, 899
 Vegetation, climate effects of, 1169f
 Vegetative growth, 830
 Vegetative propagation, 835–836, 849
 Vegetative reproduction, 833–834
 Veins, blood, 924f–926f, 929f–932f
 Veins, leaf, 189f, 761, 771f, 849
 Veldts, 1175f
 Velocity
 blood flow, 930f
 Velvetleaf plants, 205
 Velvet worms, 689f
 Venae cavae, 926f, 930f
 Venom, snail, 1067f
 Venomous snakes, 738
 Venter, Craig, 443f
 Ventilation, 941. *See also* Breathing
 of lungs, 944, 945f–946f
 Ventral nerve cords
 earthworm, 704f
 planarian, 696f
 Ventral side, 680f
 Ventral tegmental area (VTA), 1103f
 Ventricles, brain, 1087f
 Ventricles, heart, 924f–927f
 Venules, 924, 929f–930f, 932f
 Venus flower basket glass sponge, 146f
 Venus flytrap (*Dionaea muscipula*), 802, 819f, 862
 Vernalization, 860
 Verreaux's sifaka (*Propithecus verreauxi*), 746f
 Vertebrae, 718
 Vertebrates, 683, 719
 action potential conduction speed in, 1076
 adaptations of digestive systems of, 911f–914f.
 See also Digestive systems
 amniotes and development of terrestrially
 adapted eggs in, 734f–740f. *See also* Amniotes
 anatomical homologies in embryos of, 479f, 480
 brains of, 1091f–1096f, 1099f. *See also* Nervous
 systems
 cardiovascular systems of. *See* Cardiovascular
 systems
 as chordates, 689f, 715, 719f, 722, 723f–725f.
 See also Chordates
 circulatory systems of, 924f, 925. *See also*
 Cardiovascular systems
 derived characters of, 722, 723f
 energy budgets for terrestrial, 892
 evolution of, 678
 evolution of backbones and diversity vs. disparity
 in, 718f, 719
 fossils and early evolution of, 724f–725f
 gamete production and delivery in, 1024
 gas exchange systems of. *See* Gas exchange
 gnathostomes and development of jaws in,
 725f–729f, 730
 hominins and humans, 748f–754f
 innate immunity in, 954f–956f, 957
 kidneys in excretory systems of, 985, 986f–987f,
 991f–993f. *See also* Excretory systems;
 Kidneys
 limb formation in, 1062, 1063f, 1064
 mammals, 741f–747f
 mechanoreceptors for hearing and equilibrium
 in, 1112f–1116f. *See also* Sensory systems
 nervous system of, 1086f–1090f. *See also* Nervous
 systems
 neuroendocrine signaling in, 1007f–1008f
 organogenesis in, 1055f
 origins of bone and teeth in, 725
 phylogeny of, 683f
 small intestine surface area in, 695f
 tetrapods and development of limbs in, 730f–733f
 visual systems of, 1118f–1122f, 1123
 Vertical layering, terrestrial biome, 1172
 Vertical transmission, viral, 412
 Vervet monkeys, 1148f
 Vesicles, 104
 abiotically produced, as protocells, 527, 528f
 in endomembrane system, 104
 in exocytosis and endocytosis, 139, 140f
 in plant cytokinesis, 241, 242f
 self-replicating RNA in, 528
 transport, 105, 106f, 107, 109f
 Vessel elements, 648, 765f
 Vessels, 765f
 Vessels, blood. *See* Blood vessels
 Vessels, lymph, 933f
 Vestibular glands, 1027f
 Vestigial structures, 479
 Viagra, 224, 1001, 1026, 1082
Vibrio cholerae, 224, 584f, 588
 Viewpoints, science and diverse, 24
 Villi, 695f, 909f, 910
 Vinegar, 49–50
 Viral envelopes, 400f, 401, 405f
 Viral integration, 395
 Viral movement proteins, 802f
 Virtual plants, computer-generated, 776
 Virulent phages, 402f
 Viruses, 315, 399
 analyzing sequence-based phylogenetic trees to
 understand evolution of, 411
 antibodies as medical tool for detection of, 969f
 antigenic variation in, 972–973
 cancer-causing, 974f
 in cancer development, 394–395
 cellular RNAi pathway and, 380
 classes of animal, 406t
 climate change and, 412
 discovery of, 399f
 emerging, 409f–412f
 evolution of, 406, 408, 411
 features of replicative cycles of, 401f, 402
 host range of, 401
 immune system recognition of, 952f
 importance of, 400
- infection of bacterial cells by, 315f–316f, 317
 influenza. *See* Influenza viruses
 insect defense against, 954f
 latency of, 973t
 mutations of, 409, 414
 as pathogens, 398f–400f, 401, 408, 409f–413f
 rapid reproduction of, as source of genetic
 variation, 489
 replication of, 398
 replicative cycles of animal, 404, 405f, 406t, 407f
 replicative cycles of phages as, 402f–404f
 structure and function of, 414
 structure of, 399, 400f, 401
 viral movement proteins of plant, 802
- Visceral mass, 699f
 Visible light, 192f
 Visual communication, 1142f
 Visual cortex, 1121f
 Visualizing Figures
 biogeochemical cycles, 1249f
 DNA, 319f
 gastrulation, 1050f
 molecular machinery in cell, 122f–123f
 phylogenetic relationships, 556f
 primary and secondary growth, 767f
 proteins, 79f
 scale of geologic time, 532f–533f
- Visual pigments, 1119f, 1122
 Visual Skills Questions, 6f, 10f, 34f, 36, 45, 53f, 58,
 62, 64–65, 79f, 95f, 98f, 114f, 127f, 130f–133f,
 137f, 139, 140f, 150, 167f, 171, 174f, 177f,
 184, 186, 198f, 216f, 227f–228f, 246f, 252,
 257f–258f, 259, 280f–281f, 306, 320, 329,
 340f–341f, 348f, 355f, 367f, 374f, 377f, 401,
 408, 423, 428, 443f, 451f, 453f, 457f, 474f,
 480f, 482f, 494f, 504, 536f, 539f, 558, 564f,
 572, 576f, 579f, 583f, 596f, 603f, 611f, 613f,
 624f, 638f, 648f, 679, 683f, 722, 734f, 741f,
 746f, 770f, 772f, 774f, 786f, 791f, 793f, 807f,
 815f–816f, 827f, 829f–830f, 853f, 860f, 906f,
 910f, 926f, 946f, 954f–955f, 962f, 967f, 996f,
 1003f, 1015f, 1024f, 1035f, 1037f, 1072f,
 1079f, 1096f–1097f, 1119f, 1126f, 1142f, 1147f,
 1188, 1195f, 1224f, 1240f, 1242f, 1252f, 1271f.
 See also Draw It Questions
 Visual systems, 1117f–1123
 Vital capacity, 945
 Vitamin A, deficiencies of, 838f
 Vitamin D, 1003, 1011f
 Vitamins, 158, 900
 deficiencies of, 902f
 effects of supplementation of, on neural tube
 defects in, 902f
 as lipid-soluble hormones, 1003
 parathyroid hormone and, 1011f
 requirements for, 899f, 900t
 Vitelline layer, 1045
 Vitellogenin, 1003f
 Vitreous humor, 1118f
 Viviparous organisms, 727
 Vocal cords, 942, 943f
 Vocal folds, 942, 943f
 Vocalization, *FOXP2* gene and, 461, 462f
 Vogt, Walther, 1058
 Volcanic springs, 585f
 Volcanism, 636f, 637
 Volcanoes, 57–58, 526f, 527, 540, 551, 1282
 Voles, 1155f
 Voltage-gated ion channels, 220f, 1072f–1077f
 Volume, 99, 1114
 Volume-surface area relationships, 98f
 Voluntary contraception, population growth and,
 1208
 Volutidae family, 538
Volvox, 599f, 610f
 von Frisch, Karl, 1142
 von Humboldt, Alexander, 1232
 Vulva, 1026, 1027f
- W**
 Waggle dance, honeybee, 1142f
 Wagler's pit viper (*Tropidolaemus wagleri*), 737f
 Waists, chromatid, 236
 Walking, 756, 1135
 Wallace, Alfred Russel, 469f, 473, 1232

- Walled spores, 621f
 Wandering albatross (*Diomedea exulans*), 977f
 Warming, global. *See* Climate change
 Warren, Robin, 912
 WAS (Wiskott-Aldrich syndrome), 229
 Washington, Earl, 437f
 Wasps, 672, 712f, 822f, 869f, 1145f
 Waste, toxic. *See* Toxic waste
 Wastes, nitrogenous. *See* Nitrogenous wastes
 Water
 acidic and basic conditions of, and living organisms, 51, 52f, 53
 acidification as threat to quality of, 53f, 54
 albatross drinking of salty, 977f
 biomanipulation and quality of, 1227f
 in blood plasma, 934f
 cellular regulation of, 142
 cohesion of molecules of, 45f–46f
 conduction of, in plant cells, 765f
 covalent bonding of, 37f, 45f
 evolution of life on planets with, 50f
 floating of ice on liquid, 44, 48f
 forms of, 44
 fruit and seed dispersal by, 832f
 gain and loss of, 998
 hydrogen bonds and, 39f
 imbibition of, by seeds, 829
 ions in, 38
 irrigation with, 808
 latitudinal gradients and evapotranspiration of, 1232f
 as limiting factor on human population size, 1211
 maximizing body surface area and uptake of, 695f
 moderation of temperature by, 46, 47f–48f
 molecular shape of, 39f, 40
 molluscs and pollution of, 702–703
 photosynthesis and compromise with loss of, 787
 plant adaptations for reducing evaporative loss of, 798, 799f
 in plant composition, 809
 plant response to submergence in, 864f
 plant transport of, 46f
 properties of, 45f–50f
 regulation of transpiration and plant loss of, 796, 797f–799f
 root architecture and acquisition of, 787
 roots interaction with, 10f, 11
 seed dispersal by, 645f
 as solvent of life, 49f, 50, 55
 species distributions and availability of, 1185
 splitting of, in photosynthesis, 190f
 transport of, across plant plasma membranes, 788, 789f–791f
 transport of, from roots to shoots via xylem, 792, 793f–795f, 796
 uptake of, 898
 Water balance
 effects of osmosis on, 133f–135f
 hormonal regulation of, 994f–996f
 osmoregulation of, 977f–982f
 Water bears, 689f
 Water bodies, climate and, 1168f–1169f
 Water bugs, 1023f
 Water conservation
 kidney adaptations for, 991f–992f
 kidney role in, 989, 990f, 991
 Water cycle, 1250f, 1259
 Water cycling, in ecosystems, 1248f–1252f
 Water fleas (*Daphnia pulex*), 448t, 1021, 1199f, 1200
 Waterland, Robert, 372
 Water lily, 650f, 653
 “Watermelon snow,” 211
 Water potential, 788, 789f–791f
 Water scorpions, 708
 Water snakes, 496, 497f
 Water-soluble hormones, 1001f–1003f
 Water-soluble vitamins, 900t
 Water vascular system, 713, 714f
 Watson, James
 discovery of DNA molecular structure by, 4, 23–24, 314f, 317, 318f–320f
 model of DNA replication by, 320, 321f
 Wavelengths, electromagnetic, 192f–194f, 195
 Wawona Sequoia, 774f
 WD40 domains, 445f, 446
 Weak acids, 51
 Weather
 climate change and, 11
 population fluctuations and, 1205f. *See also* Climate
 Weathering, rock, 629
 Web of life, 570f
 Weddell seals, 949f
 Weeds, transgene escape and, 839
 Weevils, 712f
Welwitschia, 642f
 Wernicke, Karl, 1098
 Wernicke’s area, 1098f
 Westemeier, Ronald, 1267f
 Western garter snakes, 1155, 1156f
 Western gulls, 1151f
 West Indian manatee (*Trichechus manatus*), 572, 1219f
 West Nile virus, 401, 409
 Wetlands, 1179f, 1262
 restoration of, 1254f
 Whales, 88f, 481f–482f, 525f, 526, 557f, 710, 719, 903f, 1111f, 1265
 Wheat (*Triticum aestivum*), 514–515, 524, 595, 651, 1204f
 Whisk ferns, 631, 632f, 633
 White, John, 24f
 White-band disease, 1234
 White blood cells. *See* Leukocytes
 White-crowned sparrows, 1147
 White-footed mice, 1144f
 White matter, 1087f
 White rhinoceros, 1199f, 1266
 White-tailed deer (*Odocoileus virginianus*), 1271
 Whole-genome shotgun approach, DNA sequencing, 443f, 444, 447, 448f, 452
 Whooping cough, 218f
 Whooping crane (*Grus americana*), 1144
 Whorled phyllotaxy, 786
 Widow’s peak pedigree analysis case, 284f, 285
 Wieschaus, Eric, 386
 Wildfires, 1172, 1228, 1229f, 1244f
 Wild mustard, artificial selection and, 475f
 Wild tobacco plants, 869f
 Wild types, 295f
 Wilkins, Maurice, 317–318, 320
 Wilson, E. O., 1159, 1232, 1233f, 1262f, 1263
 Wilting, 790, 798, 804, 852, 863
 Wind
 climate change and, 11
 dispersal of mosses by, 627
 flower pollination by, 824f
 fruit and seed dispersal by, 832f
 global patterns of, 1166f
 seed dispersal by, 645f
 Windpipes, 13f
 Winged fruits and seeds, 832f
 Wings
 bat, as evolutionary adaptation, 15f
 bird, 738f, 739
 evolution of, 679
 flight muscles and, 1136
 insect, 710, 711f–712f
 muscle contraction and insect, 1132
 pterosaur, 736
 seed, 645f
 Wireframe models, 79f
 Wiskott-Aldrich syndrome (WAS), 229
 Witchweed, 855
 WNT4 gene, 299
 Wobble, 349
 Wollemi pine, 643f
 Wolves, 529f, 1205f, 1257f, 1270
 Wood, 118, 651, 783
 Wood ants, 28f
 Wood lice, 709
 Woolly mammoths, 421
 Work, cellular, 150, 151f–153f
 World Trade Center attack, 437
 Worldwide adaptive radiations, 542, 543f
 Worms, 905f, 1133f
- X**
Xanthomonas, 334
 X chromosomes, 256f–257f, 298f–300f, 381, 1030, 1040
 Xenarthra, 745f
 Xeroderma pigmentosum (XP), 328
 Xerophytes, 798, 799f
 X-linked genes, 299f–300f
 X-O sex determination system, 298f
 X-ray crystallography, 83f, 96, 217, 317, 318f
 X-rays
 cancer and, 388
 mutations from, 360
 Xylem, 629, 763, 785
 primary growth and, 769f
 resource acquisition and, 785f
 transport of water and minerals from roots to shoots via, 792, 793f–795f, 796
 vascular plant, 629–630
 in vascular tissue systems, 763
 water-conducting cells of, 765f
 Xylem sap, 792, 793f–795f, 796
 X-Y sex determination system, 298f, 313
- Y**
 Yamanaka, Shinya, 432f
 Yangtze River dolphin, 1262f
 Yarrow (*Achillea lanulosa*), 1189
 Y chromosomes, 256f–257f, 298f, 299, 313, 1030
 Yeast cells, 100f
 Yeast infections, 670
 Yeasts, 655
 alcohol fermentation by, 180f
 asexual reproduction in, 659f
 cell division in, 244f
 cell signaling in, 213f, 214
 expressing cloned eukaryotic genes in, 422–423
 fungi as, 655, 670
 human uses of, 670–671
 model organism. *See* *Saccharomyces cerevisiae*
 Yellowfin tuna (*Thunnus albacares*), 729f
 Yellow jackets, 1218f, 1219
 Yellow-legged frogs, 669, 670f
 Yellowstone National Park, 441, 1270
 extreme thermophiles in, 585f, 586
 forest fire disturbance of, 1228, 1229f
 grizzly bear population in, 1268f, 1269, 1272–1273
 Taq polymerase from bacterium in, 1263
 Y-linked genes, 299
 Yolk, 91, 1048f
 Yolk sac, 735f, 1053f, 1054
 Young, Michael, 883
 Yucca, 824f
- Z**
 Zambia, age-structure pyramid for, 1209f
 Zambia, elephant poaching in, 1265f
Zea mays (corn). *See* Corn; Maize
 Zeatin, 850
 Zebra finches, 1152f
 Zebrafish model organism, 22
 Zebra mussels, 1264
 Zero population growth, 1208, 1211
 Zika virus, 409f
 Zona pellucida, 1046f
 Zonation, aquatic, 1177f–1178f
 Zoned reserves, 1273f
 Zone of cell division, 768f
 Zone of differentiation, 768f
 Zone of elongation, 768f
 Zone of polarizing activity (ZPA), 1062, 1063f
 Zoonotic pathogens, 1234, 1235f
 Zoopagomycetes, 660f, 662f, 663
 Zooplankton, in biomass pyramids, 1247f, 1248
 Zoospores, 603f, 661f
 zur Hausen, Harald, 974
 Z-W sex determination system, 298f
 Zygentoma (silverfish), 712f
Zygnuma, 619f
 Zygomycetes, 660
 Zygosporangium, 662f, 663
 Zygotes, 257f, 258, 1020, 1034, 1035f