Section II

BIOLOGY

CHAPTER FOUR

Biology Strategies

The biology knowledge you need for the DAT encompasses a wide variety of topics in the categories of cell and molecular biology, diversity of life, vertebrate anatomy and physiology, developmental biology, genetics and evolution, and ecology and behavior. Mastering biology on the DAT means not only memorizing biology vocabulary and facts but also learning to integrate your knowledge, make connections, and otherwise approach the multiple-choice questions in the Biology subtest and the entire Survey of Natural Sciences section in the best way possible.

THE SURVEY OF NATURAL SCIENCES

Biology content appears in the Survey of Natural Sciences section, which contains the Biology, General Chemistry, and Organic Chemistry subtests. The Survey of Natural Sciences has a total of 100 questions that must be completed in 90 minutes. Questions 1–40 are always related to biology, questions 41–70 are always related to general chemistry, and questions 71–100 are always related to organic chemistry. The content in each subtest does overlap in some areas (such as chemical bonding, which is tested in both General Chemistry and Organic Chemistry), but the questions always remain in three discrete groups, and you will receive separate scores for each subtest in addition to your cumulative Survey of Natural Sciences score. Therefore, when you first begin studying for the Survey of Natural Sciences, it's generally best to treat the section as three separate tests and master each content area separately, except for those topics that obviously overlap.

Survey of Natural Sciences Pacing

On Test Day you will be able to freely navigate among all 100 questions in the Survey of Natural Sciences section. Time is shared for all three subtests, giving you an average of 54 seconds per problem. Because the Survey of Natural Sciences is one long section, some test takers find themselves overwhelmed by the need to keep track of time, since there are so many questions yet less than one minute per question. Therefore, you should not only study each subtest separately but also consider each separately when managing the entire section.

Among the three subtests, you should complete Biology in the least amount of time since its questions are mostly fact based and require few calculations. Spend 30 seconds or less on each question to finish the Biology subtest within 20 minutes.

General Chemistry, which involves many more calculations and therefore more use of your scratch work, will take the most time. You should average 75 seconds for each General Chemistry question, which means the entire subtest will take you a total of 37.5 minutes.

Finally, Organic Chemistry will be somewhere in the middle, with some questions that involve drawing out reactions or complex figures taking longer and other questions that require just naming or identifying molecules taking less time. With 60 seconds per question, you will be able to complete this section in 30 minutes.

The Kaplan timing guidelines for the Survey of Natural Sciences are summarized below:

Biology: 20 minutes (30 seconds per question)

General Chemistry: 37.5 minutes (75 seconds per question)

Organic Chemistry: 30 minutes (60 seconds per question)

Review Marked Questions: 2.5 minutes

Total: 90 minutes

Following these guidelines will allow you to break down the Survey of Natural Sciences into more reasonable pieces and give you a more realistic sense of how you're progressing through the section than if you were to use the overall average of 54 seconds per question. If you stick to the Kaplan guidelines closely, you'll also have 2.5 minutes left at the end of the section to review any questions that you marked to return to later because they involved lengthy calculations or otherwise would take too long to answer during your first pass through the section. By adhering to this Kaplan pacing strategy, using the Test Timing tips from Chapter 1 and the Test Strategies from Chapter 3, and continually practicing, you undoubtedly will find the timing of the Survey of Natural Sciences much more reasonable than you previously thought.

BIOLOGY QUESTION STRATEGY

Kaplan's Stop-Think-Predict-Match strategy is useful for all sections of the test and is especially helpful for the Survey of Natural Sciences section due to the limited time given per question. Before spending a significant amount of time on any one question, *Stop* to consider what content area is being tested and whether you want to attempt that question right away or mark it for later. Each question within a section is worth the same number of points, so answer the easiest and fastest questions first to ensure you've earned as many points as possible before attempting the most difficult and time-consuming problems. Once you've committed to a question, *Think* about what is being asked by carefully reading and paraphrasing the question stem. Next, recall any pertinent outside information and apply that to the question to *Predict* the answer. Only when you have a strong prediction in mind should you read the answer choices, and even then, your goal should be to find a *Match* to your prediction rather than to analyze each answer choice on its own merits. Not reading the answer choices in advance is especially important for the Biology subtest because it contains many questions with lengthy trap answer choices that initially seem correct. For a more thorough review of Stop-Think-Predict-Match, see Chapter 3, Test Strategies.

STUDYING BIOLOGY CONTENT

In the past, most Biology questions on the DAT were based heavily on assessing test takers' memories of discrete biological facts with a particular focus on the molecular basis of life. However, the test makers are now moving away from that reductionist viewpoint and toward an integrative approach that focuses on biological systems as wholes, including the complex interactions within them. This means that the test rewards both breadth of knowledge and the ability to make connections. Learn both approaches; you'll still need to memorize a wide range of biology facts, but you'll also need to understand how those pieces work together.

To help you learn this wide range of material, it's important to use a wide range of methods while studying. The following chapters contain the biology content you need for Test Day, but you may still see questions on your official test about content that doesn't look familiar at first. That won't be a problem, though, because you'll be able to figure out the answers to those types of questions using critical thinking: bringing different ideas together to determine the correct answers and eliminate impossible choices. You may see a question about a particular enzyme you didn't study, but you can still use information in the question about where it is produced and your knowledge of other molecules with similar names to find the correct answer. For example, if a question asks you about carboxypeptidase formed in the pancreas but you can't remember its function, you can take what you do know to infer that coming from the pancreas means it acts in the small intestine. Since *peptid* refers to peptide bonds, carboxypeptidase must help digest proteins.

To ensure the facts you need come readily to mind, supplement your reading by memorizing flashcards as well as the science study sheets, which contain some of the most important content for Test Day, located at the end of this book. Once you have the basics down, use practice questions to evaluate your knowledge in a test-like setting, remembering to spend plenty of time reviewing the explanations for every question. Although it's unlikely you'll see the exact same questions on Test Day, carefully evaluating exactly why you answered correctly or incorrectly will allow you to apply the concepts to any similar questions you see in the future.

Finally, no matter how you're studying, don't neglect to keep a broad focus on the interactions within and among biological systems. It's important to know that aldosterone is produced by the adrenal cortex and increases salt reabsorption in the nephrons, but it's even more valuable to realize that damage to the adrenal glands (in the exocrine system) can cause low blood pressure (in the circulatory system). By making these connections, not only will you be prepared to answer challenging integrative questions on Test Day, but you'll also ensure you have a solid knowledge of the basics as well. Even if you come from a strong biology background, many of the other test takers do as well, and you might not be very familiar with every topic tested, so it's important to have very thorough knowledge to earn a higher score than your competition.

CHAPTER FIVE

Cellular Biology

The cell is the fundamental unit of all living things. Every function in biology involves a process that occurs within cells or at the interface between cells. Therefore, to understand biology, you need to appreciate the structure and function of different parts of the cell.

CELL THEORY AND STRUCTURE

Cell Theory

The cell was not discovered or studied in detail until the development of the microscope in the 17th century. Since then, much more has been learned, and a unifying theory known as the Cell Theory has been proposed.

The Cell Theory may be summarized as follows:

- All living things are composed of cells.
- The cell is the basic functional unit of life.
- The chemical reactions of life take place inside the cell.
- Cells arise only from pre-existing cells.
- Cells carry genetic information in the form of **DNA**. This genetic material is passed from parent cell to daughter cell.

Cell Structure

The components of the cell are specialized in their structure and function. These components, or **organelles,** include the nucleus, ribosomes, endoplasmic reticulum, Golgi apparatus, vesicles, vacuoles, lysosomes, mitochondria, chloroplasts, and centrioles.

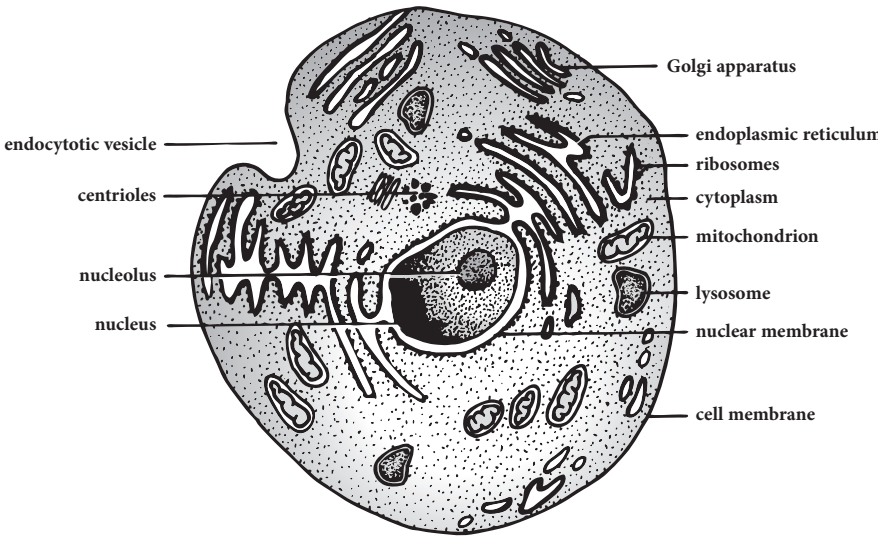


Figure 5.1

There are millions of species of "living things" that can be divided into six kingdoms: **Bacteria, Archaea, Protista, Fungi, Plantae,** and **Animalia.** Within these six kingdoms are two major types of cells: **prokaryotic** and **eukaryotic**. The word prokaryote means "before nucleus," and prokaryotic cells lack a membrane-bound nucleus. Note that scientists formerly divided life into only five kingdoms but recently separated the kingdom of Monera (Prokaryota) into Bacteria and Archaea due to differing evolutionary origins.

Cell membrane

The cell membrane (plasma membrane) encloses the cell and exhibits selective permeability; it regulates the passage of materials into and out of the cell. According to the generally accepted **fluid mosaic model**, the cell membrane consists of a phospholipid bilayer with proteins embedded throughout. The lipids and many of the proteins can move freely within the membrane.

The phospholipid bilayer has a specific structure that forms spontaneously. Phospholipid molecules are arranged such that the long, nonpolar, hydrophobic, "fatty" chains of carbon and hydrogen face each other, with the phosphorus-containing, polar, hydrophilic heads facing outward. The hydrophilic heads face the watery regions inside and outside the cell, while the hydrophobic tails face each other in a water-free region.

As a result of its lipid bilayer structure, a plasma membrane is readily permeable to both small, nonpolar, hydrophobic molecules, such as oxygen, and small polar molecules, such as water. Small charged particles are usually able to cross the membrane through protein channels. However, charged ions and larger charged molecules cross the membrane with the assistance of **carrier proteins**.

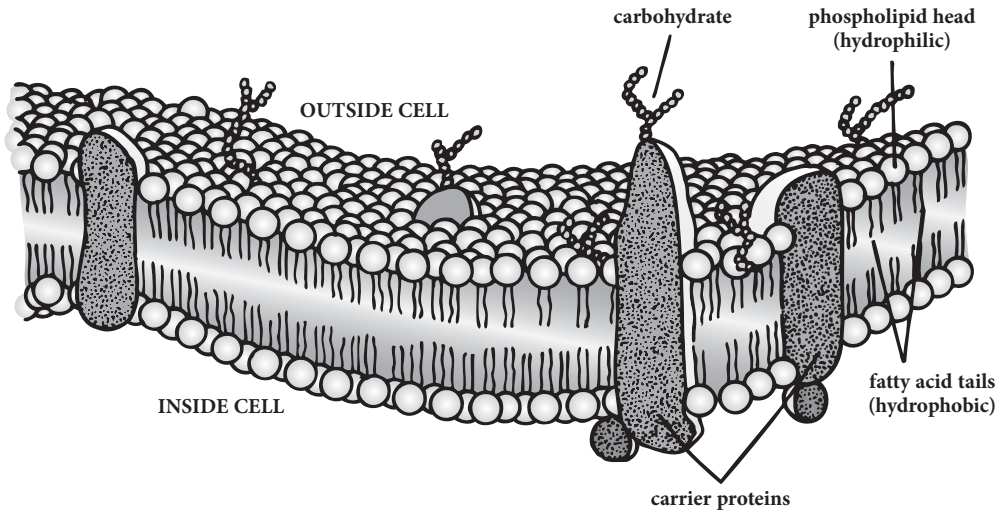


Figure 5.2

Nucleus

The nucleus controls the activities of the cell, including cell division. It is surrounded by a nuclear membrane. The nucleus contains DNA, which is complexed with structural proteins called **histones** to form **chromosomes**. DNA winds around histones to make it more compact, and these histones are also involved in regulation of gene transcription. The **nucleolus** is a dense structure in the nucleus where **ribosomal RNA** (rRNA) synthesis occurs (ribosomal RNA is necessary for protein synthesis at the ribosome).

Ribosome

Ribosomes are the sites of protein production and are synthesized by the nucleolus. Free ribosomes are found in the cytoplasm, whereas bound ribosomes line the outer membrane of the endoplasmic reticulum.

Endoplasmic reticulum

The endoplasmic reticulum (ER) is a network of membrane-enclosed spaces involved in the transport of materials throughout the cell, particularly those materials destined to be secreted by the cell. There are two kinds of endoplasmic reticuli, rough ER and smooth ER. **Smooth ER** does not contain ribosomes and so is not involved with protein synthesis but instead is involved with metabolism and the production of lipids. **Rough ER** contains ribosomes (which gives it a "rough" appearance under microscopy) and plays an important role in the production of proteins.

Golgi apparatus

The Golgi apparatus receives vesicles and their contents from the smooth ER and then modifies them (via processes such as glycosylation), repackages them into vesicles, and distributes them to the cell surface for exocytosis.

Mitochondria

Mitochondria are the sites of aerobic respiration within the cell and hence the suppliers of energy, especially in the form of adenosine triphosphate (ATP). Each mitochondrion is composed of an outer and inner phospholipid bilayer.

Cytoplasm

Most of the cell's metabolic activity occurs in the cytoplasm, which includes the **cytosol** (the cellular fluid contained within the cell membrane) and all the organelles of the cell. Transport within the cytoplasm occurs by **cyclosis** (streaming movement within the cell).

Vacuoles/Vesicles

Vacuoles and vesicles are membrane-bound sacs involved in the transport and storage of materials that are ingested, secreted, processed, or digested by the cell. Vacuoles are larger than vesicles and are more likely to be found in plant than in animal cells.

Centrioles

Centrioles are composed of microtubules and are involved in spindle organization during cell division. They are not bound by a membrane. Animal cells usually have a pair of centrioles oriented at right angles to each other that lie in a region called the centrosome. The centrosome organizes microtubules and helps regulate the progression of the cell cycle. Plant cells do not contain centrioles.

Lysosomes

Lysosomes are membrane-bound vesicles that contain **hydrolytic enzymes** involved in intracellular digestion. Lysosomes break down material ingested by the cell. An injured or dying cell may self-destruct by rupturing the lysosome membrane and releasing its hydrolytic enzymes; this process is called **autolysis**.

Cytoskeleton

The cytoskeleton supports the cell, maintains its shape, and aids in cell motility. It is composed of microtubules, microfilaments, and intermediate filaments.

Microtubules are hollow rods made up of polymerized **tubulin** that radiate throughout the cell and provide it with support. Microtubules provide a framework for organelle movement within the cell. Centrioles, which direct the separation of chromosomes during cell division, are composed of microtubules. **Cilia** and **flagella** are specialized arrangements of microtubules that extend from certain cells and are involved in cell motility and cytoplasmic movement.

Microfilaments are solid rods of **actin,** which are important in cell movement as well as support. Muscle contraction, for example, is based on the interaction of actin with myosin. Microfilaments move materials across the plasma membrane, for instance, in the contraction phase of cell division and in amoeboid movement.

CELLULAR TRANSPORT

Substances can move into and out of cells in various ways. Some methods occur passively, without energy, whereas others are active and require energy expenditure (via hydrolysis of ATP).

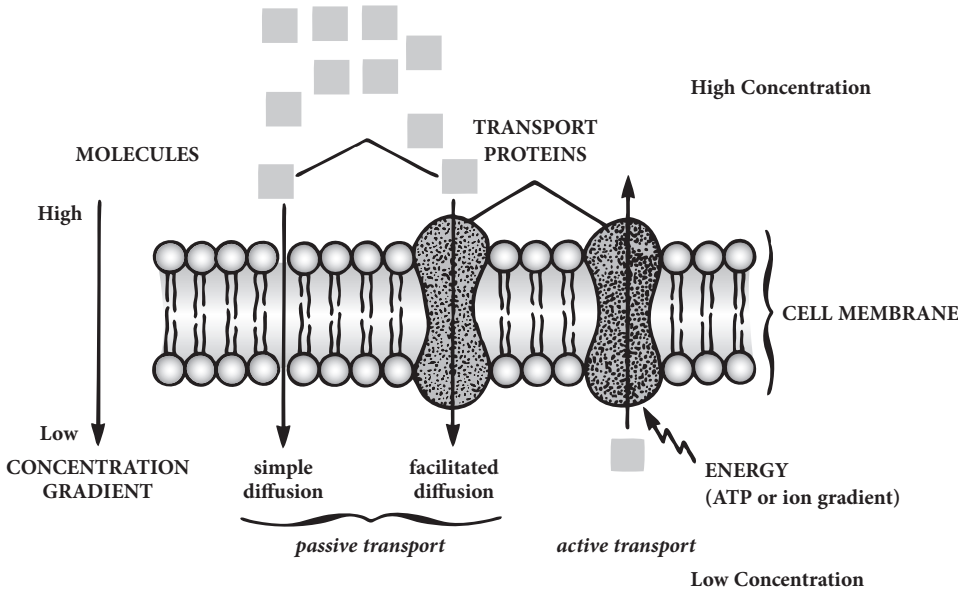


Figure 5.3

Simple Diffusion

Simple diffusion is the net movement of dissolved particles down their concentration gradients—from a region of higher concentration to a region of lower concentration. This is a passive process that requires no external source of energy.

Osmosis

Osmosis is the simple diffusion of water from a region of lower solute concentration to a region of higher solute concentration. When the cytoplasm of a cell has a lower solute concentration than the extracellular medium, the medium is said to be **hypertonic** to the cell, and water will flow out of the cell into the surrounding medium. This process, also called **plasmolysis**, will cause the cell to shrivel.

If the extracellular environment is less concentrated than the cytoplasm of the cell, the extracellular medium is said to be **hypotonic** and water will flow into the cell, causing it to swell and **lyse** (burst). For example, red blood cells will burst if placed in distilled water. Freshwater protozoa have contractile vacuoles to pump out excess water and prevent bursting.

If the extracellular environment has the same concentration of solutes as the cell cytoplasm, the cell is said to be **isotonic** to the environment, and water will move back and forth in equal amounts across the cell membrane.

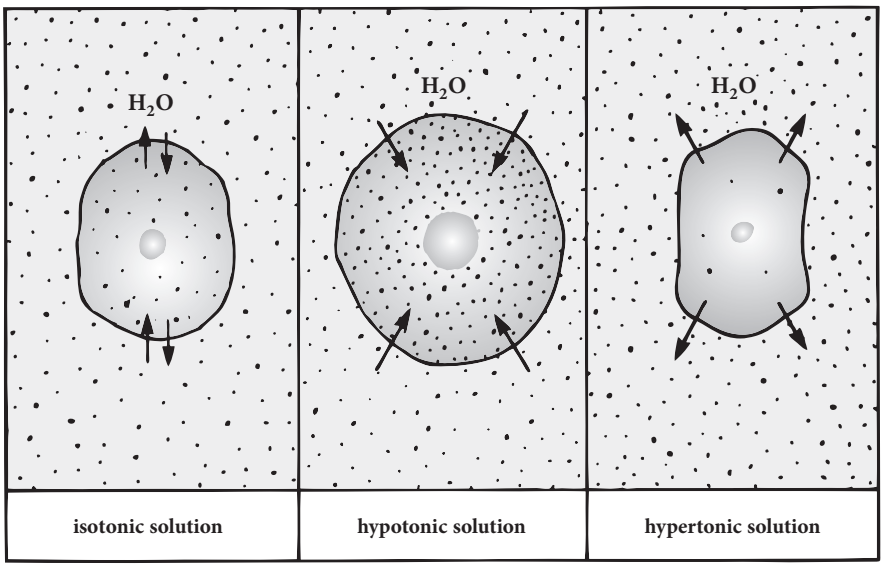


Figure 5.4

Facilitated Diffusion

Facilitated diffusion (passive transport) is the net movement of dissolved particles down their concentration gradient through special channels or carrier proteins in the cell membrane. This process, like simple diffusion, does not require energy.

Active Transport

Active transport is the net movement of dissolved particles against their concentration gradients with the help of transport proteins. Unlike diffusion, active transport requires energy. These carrier molecules or transport proteins aid in the regulation of the cell's internal content of ions and large molecules. The passage of specific ions and molecules is facilitated by these carrier molecules, which include the following:

- **Symporters**: move two or more ions or molecules in the same direction across the membrane
- **Antiporters**: exchange one or more ions (or molecules) for another ion or molecule across the membrane
- **Pumps**: energy-dependent carriers (require ATP); e.g., sodium-potassium pump

Endocytosis

Endocytosis is a process in which the cell membrane invaginates, forming a vesicle that contains extracellular medium (see Figure 5.5). This allows the cell to bring large volumes of extracellular material inside the cell. **Pinocytosis** is the ingestion of fluids or small particles, and **phagocytosis** is the engulfing of large particles. Particles may bind to receptors on the cell membrane before being engulfed.

Exocytosis

In exocytosis, a vesicle within the cell fuses with the cell membrane and releases a large volume of contents to the outside. Fusion of the vesicle with the cell membrane can play an important role in cell growth and intercellular signaling (see Figure 5.5). For example, neurotransmitters, which act as signals to neighboring cells, are often released from neurons in this manner. Note that in both endocytosis and exocytosis, material never actually passes through the cell membrane.

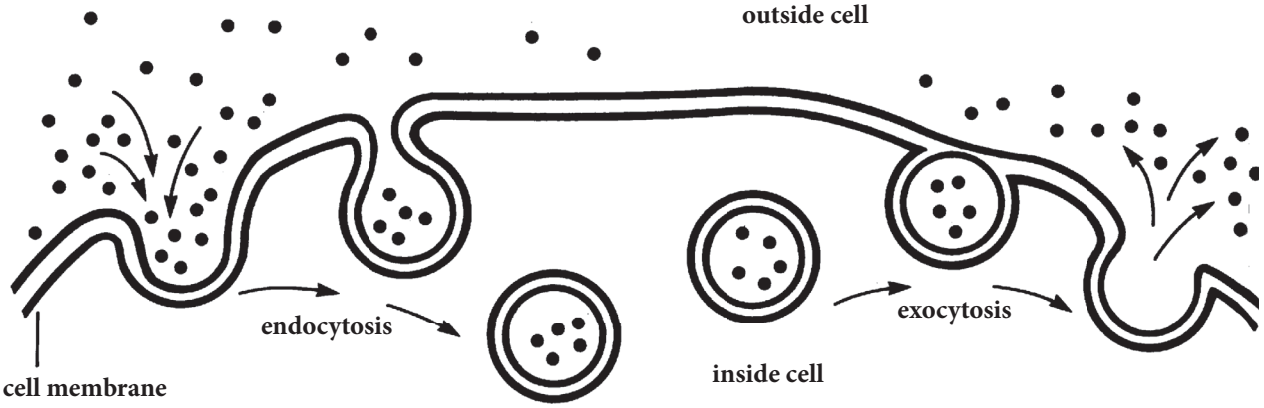


Figure 5.5

Intracellular Circulation

Materials move about within a cell in a number of ways. Some examples include the following:

- **Brownian movement**: Kinetic energy spreads small suspended particles throughout the cytoplasm of the cell.
- **Cyclosis or streaming**: The circular motion of cytoplasm around the cell transports molecules.
- **Endoplasmic reticulum**: The ER forms a network of channels throughout the cytoplasm and provides a direct continuous passageway from the plasma membrane to the nuclear membrane.

Extracellular Circulation

A number of systems deal with the movement of materials on a larger scale through the body of an organism. Examples include:

- **Diffusion**: If cells are in direct or close contact with the external environment, diffusion can serve as a sufficient means of transport for food and oxygen from the environment to the cells. In larger, more complex animals, diffusion is important for the transport of materials between cells and the interstitial fluid that bathes the cells.
- **Circulatory system**: Complex animals, whose cells are too far from the external environment to transport materials by diffusion, require a circulatory system. It generally includes vessels to transport fluid and a pump to drive the circulation. See Chapter 13, Circulatory and Respiratory Systems, for more information.

CELL DIVISION

Cell division is the process by which a cell doubles its organelles and cytoplasm, replicates its DNA, and then divides in two. For **unicellular organisms**, cell division is a means of reproduction, whereas for **multicellular organisms**, it is a method of growth, development, and replacement of worn-out cells. Cell division can follow two different courses, mitosis or meiosis, but each is preceded by interphase. The entire series of events leading to cellular replication constitutes the cell cycle.

Interphase

Interphase is a period of growth and chromosome replication. A cell normally spends at least 90 percent of its life in interphase. During this period, the cell performs its normal cellular functions, and each chromosome is replicated so that during division a complete copy of the genome can be distributed to both daughter cells. After replication, the chromosomes consist of two identical **sister chromatids** held together at a central region called the **centromere**. During interphase the individual chromosomes are not visible; the DNA is instead uncoiled and called **chromatin**.

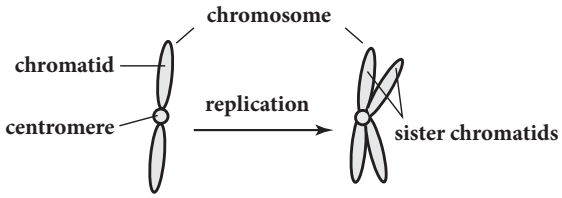


Figure 5.6

Interphase consists of the following three parts:

1. **G1**: This phase initiates interphase. It is described as the active growth phase and can vary in length. The cell increases in size and synthesizes proteins. The length of the G1 phase determines the length of the entire cell cycle.
2. **S**: This is the period of DNA synthesis.
3. **G2**: The cell prepares to divide in G2. It grows and synthesizes proteins.

The last phase of the cell cycle is the M phase. During M phase mitosis or meiosis occurs, generally resulting in either two identical or four non-identical daughter cells.

Mitosis

Mitosis is the division and distribution of the cell's DNA to its two daughter cells such that each cell receives a complete copy of the original genome. This type of cell division takes place in somatic cells (as opposed to gametes). Nuclear division (**karyokinesis**) is followed by cell division (**cytokinesis**).

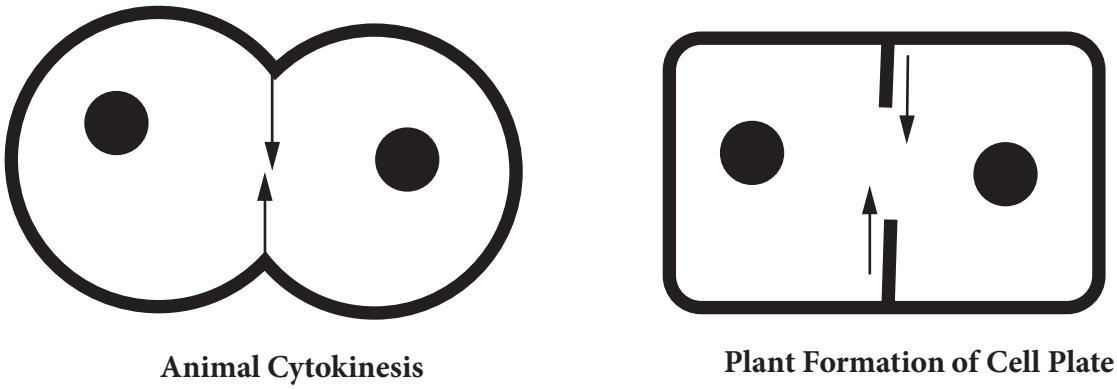


Figure 5.7

Prophase

During prophase, the chromosomes condense and the centriole pairs (in animals) separate and move toward the opposite poles of the cell. The spindle apparatus forms between them and the nuclear membrane dissolves, allowing the spindle fibers to interact with the chromosomes.

Metaphase

The centriole pairs are now at opposite poles of the cell. The fibers of the spindle apparatus attach to each chromatid at its corresponding **kinetochore**, a protein location on the centromere. The spindle fibers align the chromosomes at the center of the cell (equator), forming the **metaphase plate**.

Anaphase

The centromeres split so that each chromatid has its own distinct centromere, thus allowing sister chromatids to separate. The sister chromatids are pulled toward the opposite poles of the cell by the shortening of the spindle fibers. Spindle fibers are composed of microtubules.

Telophase

The spindle apparatus disappears. A nuclear membrane forms around each set of newly formed chromosomes. Thus, each nucleus contains the same number of chromosomes (the **diploid** number, 2*N*) as the original or parent nucleus. The chromosomes uncoil, resuming their interphase form.

Cytokinesis

Near the end of telophase the cytoplasm divides into two daughter cells, each with a complete nucleus and its own set of organelles. In animal cells, a **cleavage furrow** forms, and the cell membrane indents along the equator of the cell, eventually pinching through the cell and separating the two nuclei. In plant cells a cell plate forms between the two nuclei, effectively splitting the plant cell in half and allowing the cell to divide.

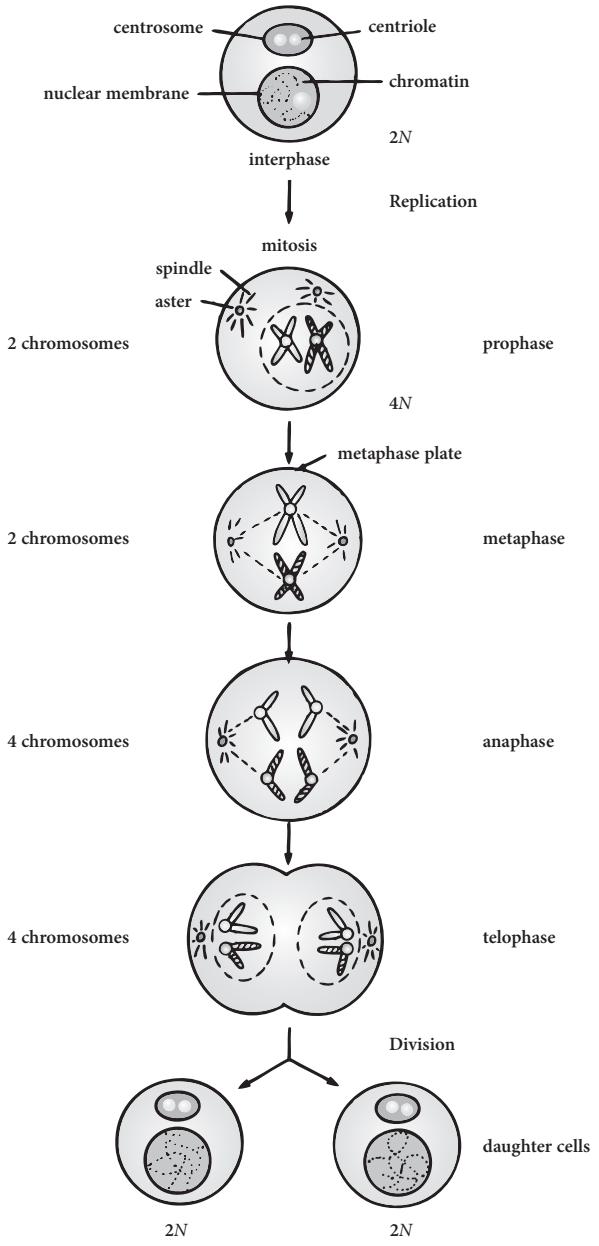

centrosome
centriole
nuclear membrane
chromatin
2N
interphase
Replication
mitosis
spindle
aster
2 chromosomes
prophase
4N
metaphase plate
2 chromosomes
metaphase
4 chromosomes
anaphase
4 chromosomes
telophase
Division
daughter cells
2N
2N

Figure 5.8

Meiosis

Sexual reproduction differs from asexual reproduction in that there are two parents involved. Sexual reproduction occurs via the fusion of two gametes—specialized sex cells produced by each parent. **Meiosis** is the process by which these sex cells are produced. Meiosis is similar to mitosis in that a cell duplicates its chromosomes before undergoing the process. However, whereas mitosis preserves the diploid number of the cell, meiosis produces **haploid** (1*N*) cells, halving the number of chromosomes. Meiosis involves two divisions of **primary sex cells**, resulting in four haploid cells called **gametes**.

Interphase

As in mitosis, the parent cell's chromosomes are replicated during interphase, resulting in the 2*N* number of sister chromatids.

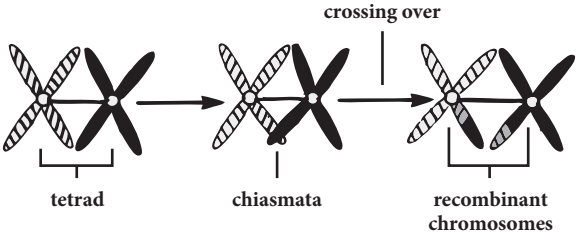


Figure 5.9

First meiotic division

The first division produces two intermediate daughter cells with *N* chromosomes and sister chromatids.

Prophase I: The chromatin condenses into chromosomes, the spindle apparatus forms, and the nucleoli and nuclear membrane disappear. Homologous chromosomes (chromosomes that code for the same traits, one inherited from each parent) come together and intertwine in a process called **synapsis**. Since at this stage each chromosome consists of two sister chromatids, each synaptic pair of homologous chromosomes contains four chromatids and is therefore often called a **tetrad**. Sometimes chromatids of homologous chromosomes break at corresponding points and exchange equivalent pieces of DNA; this process is called **crossing over**. The points of contact between these homologous chromosomes where crossing over can occur are called chiasmata. Note that crossing over occurs between homologous chromosomes and not between sister chromatids of the same chromosomes (the latter are identical, so **crossing over** would not produce any genetic variation). The chromatids involved are left with an altered but complete set of genes. Recombination among chromosomes results in increased genetic diversity within a species. Note that the two pairs of sister chromatids are no longer identical after recombination has occurred.

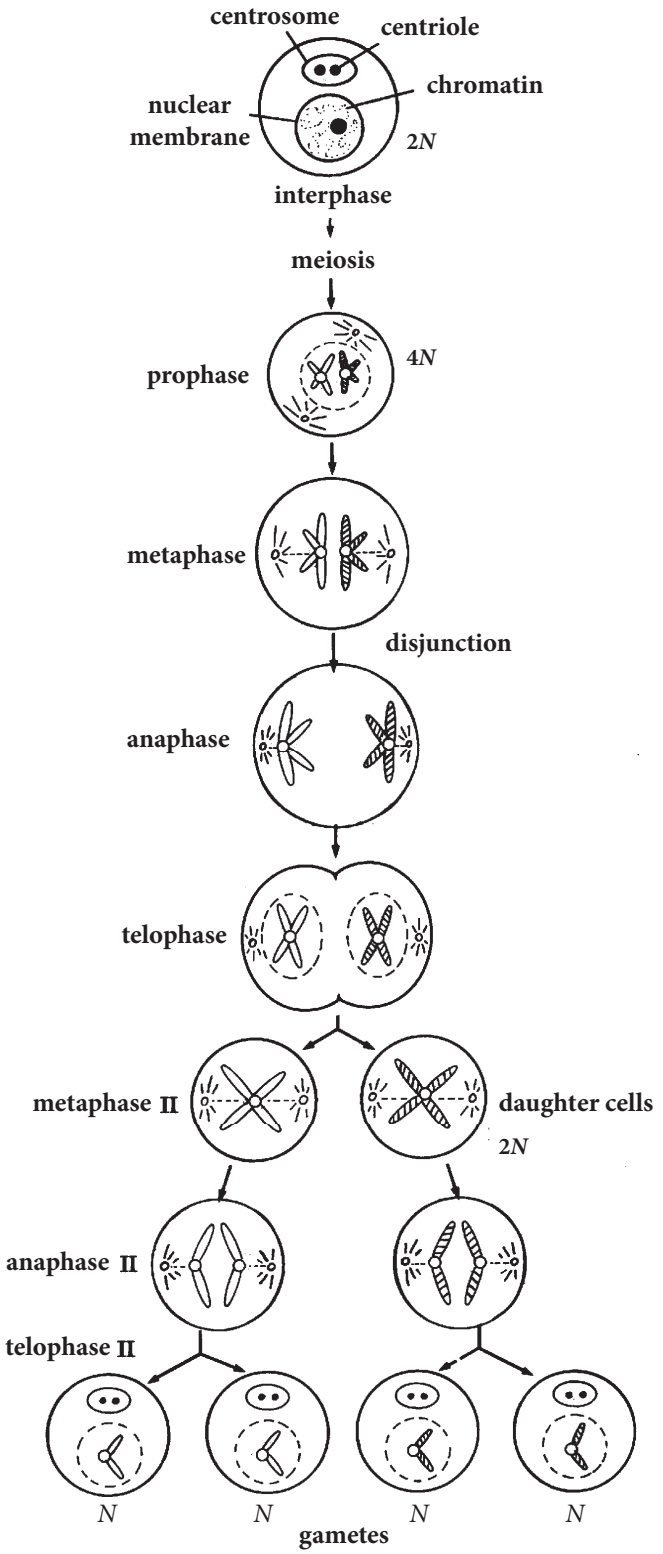

centrosome
centriole
chromatin
nuclear membrane
2N
interphase
meiosis
prophase
4N
metaphase
disjunction
anaphase
telophase
metaphase II
daughter cells
2N
anaphase II
telophase II
N
N
N
N
gametes

Figure 5.10

Metaphase I: Homologous pairs (tetrads) align at the equatorial plane and each pair attaches to a separate spindle fiber at the kinetochore.

Anaphase I: The homologous pairs separate and are pulled to opposite poles of the cell. This process is called **disjunction** and it accounts for a fundamental Mendelian law. During disjunction, each chromosome of paternal origin separates (or disjoins) from its homologue of maternal origin, and either chromosome can end up in either daughter cell. Thus, the distribution of homologous chromosomes to the two intermediate daughter cells is random with respect to parental origin. Each daughter cell will have a unique pool of genes from a random mixture of maternal and paternal origin.

Nondisjunction occurs when cells do not separate appropriately during meiosis. This results in the daughter cells having an incorrect number of chromosomes and is discussed in greater detail in Chapter 15.

Telophase I: A nuclear membrane forms around each new nucleus. At this point, each chromosome still consists of sister chromatids joined at the centromere.

Second meiotic division

This second division is very similar to mitosis, except that meiosis II is not preceded by chromosomal replication. The chromosomes align at the equator, separate and move to opposite poles, and are surrounded by a re-formed nuclear membrane. The new cells have the haploid number of chromosomes. Note that, in women, only one of these daughter cells becomes a functional gamete; the other two or three cells are destroyed by the body.

REVIEW PROBLEMS

1. All of the following are components of the Cell Theory EXCEPT the idea that

A. all living things are composed of cells.
B. all living things contain mitochondria.
C. cooperation among cells allows for complex functioning in living things.
D. all cells arise from preexisting cells.
E. cells carry genetic information in the form of DNA.

2. A eukaryotic cell contains organelles specialized for various activities. Name the organelles involved and the role they play in the following activities.

A. Ingestion
B. Digestion
C. Transport of proteins

3. Which of the following activities occurs in the Golgi apparatus?

A. Synthesis of proteins
B. Breakdown of lipids and carbohydrates
C. Catalysis of various oxidative reactions
D. Modification and packaging of proteins
E. Aerobic respiration

4. Draw the fluid mosaic model of the cell membrane. How does this model account for the passage of materials across the membrane?

5. Prokaryotes and eukaryotes differ in a number of ways. Compare them in terms of the following characteristics.

A. Organization of genetic material
B. Site of cellular respiration
C. Presence of membrane-bound organelles

6. A researcher treats a solution containing animal cells with ouabain, a substance that interferes with the Na^+/K^+ pump embedded in the cell membrane and causes the cell to lyse. Which of the following statements best explains ouabain's mechanism of action?

A. Treatment with ouabain results in high levels of extracellular Ca_2^+.
B. Treatment with ouabain results in high levels of extracellular K^+ and Na^+.
C. Treatment with ouabain increases intracellular concentrations of Na^+.
D. Treatment with ouabain decreases intracellular concentrations of Na^+.
E. Treatment with ouabain results in high levels of extracellular Na^+ only.

7. Prokaryotic cells and eukaryotic animal cells both have

A. DNA.
B. ribosomes.
C. cell walls.
D. chloroplasts.
E. A and B

8. What is the significance of the lysosomal membrane?

9. What roles do microtubules and microfilaments play in cell division?

10. If the haploid number of an organism is 13, what is its diploid number?

11. Fill in the blanks with the name of the appropriate stage of mitosis.

A. During _____, the chromosomes separate and move to opposite poles of the cell.
B. The nuclear membrane begins to dissolve during _____.
C. The centromeres of the replicated chromosomes have completely split by _____.
D. During _____, nucleoli disappear.
E. Chromosomes condense, shorten, and coil during _____.
F. Centromeres line up at the equatorial plate during _____.
G. During _____, a cleavage furrow is formed.

12. How do metaphase and anaphase of mitosis differ from metaphase I and anaphase I of meiosis?

SOLUTIONS TO REVIEW PROBLEMS

1. B Discussed in cell theory section of this chapter.

2. A Cellular ingestion is a function of the cell membrane and vesicles. The cell membrane invaginates around a food particle and pinches off, enclosing the material in a vesicle that can travel freely in the cytoplasm. This is known as endocytosis.

B The organelles involved in digestion are lysosomes, vesicles, and mitochondria. A lysosome is a membrane-bound sac containing hydrolytic enzymes. It fuses with a vesicle, allowing its enzymes to chemically degrade the ingested material. The products of lysosomal digestion are released into the cytoplasm, where they can be used by the cell. Glucose is metabolized in mitochondria via aerobic respiration.

C The endoplasmic reticulum forms a long, interconnecting series of passageways through which proteins are transported. Smooth ER secretes proteins into cytoplasmic vesicles that are transported to the Golgi apparatus. Microtubules are involved in the transport of proteins in some specialized cells, such as neurons.

3. D Discussed in cell biology section of this chapter.

4. According to the fluid mosaic model in Figure 5.2, the individual molecules of the lipid bilayer are in constant motion within the plane of the membrane. This fluidity allows ions and small molecules to diffuse directly across the cell membrane. However, large molecules cannot cross the membrane without the aid of special carrier protein molecules, which are embedded within the phospholipid bilayer. Some substances cannot cross the membrane at all. This selective permeability allows the cell membrane to tightly control the passage of materials into and out of the cell.

5. A In prokaryotes, the genetic material is composed of a single circular molecule of DNA localized in a region of the cell called the nucleoid. Eukaryotes have highly coiled linear strands of DNA organized into chromosomes within a membrane-bound nucleus.

B In prokaryotes, cellular respiration occurs directly at the cell membrane, whereas in eukaryotes, cellular respiration occurs across the mitochondrial membrane and within the mitochondrion itself.

C Prokaryotes do not contain any membrane-bound organelles, whereas eukaryotes contain a number of membrane-bound organelles, such as the nucleus, lysosomes, vesicles, ER, and mitochondria.

6. C This question requires an understanding of osmosis and the action of the Na^+/K^+ pump, also known as Na^+/K^+ adenosine triphosphatase (ATPase). When a cell is placed in a hypertonic solution (a solution having a higher solute concentration than the cell), fluid will diffuse out of the cell into the solution, resulting in cell shrinkage. When a cell is placed in a hypotonic solution (a solution having a lower solute concentration than the cell), fluid will diffuse from the solution into the cell, causing the cell to expand and possibly lyse. Na^+/K^+ ATPase moves three sodium ions out for every two potassium ions it lets into the cell. Therefore, inhibition of Na^+/K^+ ATPase by ouabain will cause a net increase in the Na^+ concentration inside the cell, and water will diffuse down its concentration gradient and into the cell, causing the cell to swell and then lyse.

7. **E** Discussed in cell biology section of this chapter.

8. The lysosomal membrane serves an important function. It protects the cell from the hydrolytic actions of the enzymes it contains. If the membrane were to burst, these enzymes would digest cellular components and ultimately kill the cell.

9. Microtubules and microfilaments play important roles in cell division. Microtubules form the mitotic spindle, which is responsible for separating sister chromatids. During prophase, a radial array of microtubules forms around the centrioles. The microtubules "push" the centrioles to opposite poles of the cell, forming the bipolar spindle apparatus. When the chromosomes align at the metaphase plate, these spindle fibers attach to the centromeres. During anaphase, the fibers shorten and pull on the centromeres, separating the sister chromatids and moving them toward opposite poles of the cell.

After anaphase, microfilaments (actin filaments) and myosin filaments under the cell membrane contract, leading to the indentation of the membrane at the metaphase plate and the subsequent division of the parent cell into two daughter cells.

10. Haploid gametes are produced by meiosis, a process in which the chromosome number of the parent cell is reduced by one half. Thus, if the haploid number (N) of a particular organism is 13, then the diploid number ($2N$) must be 26.

11. **A** anaphase
B prophase
C anaphase
D prophase
E prophase
F metaphase
G telophase

12. In metaphase of mitosis, replicated chromosomes line up in single file; during anaphase, sister chromatids separate and move to opposite poles of the cell. In metaphase I of meiosis, homologous pairs of replicated chromosomes line up; during anaphase I, the homologous chromosomes separate, but sister chromatids remain attached to each other.

CHAPTER SIX

DNA and RNA

Genes are composed of **DNA** (deoxyribonucleic acid), which contains information coded in the sequence of its base pairs. This information can be transcribed into **RNA** (ribonucleic acid), which is then translated into a sequence of amino acids called a **protein**. Therefore, the DNA sequence is essentially a blueprint for protein synthesis. These proteins regulate all life functions. DNA is also able to **self-replicate**, an essential step in cell division and therefore for cell (and organism) reproduction.

DEOXYRIBONUCLEIC ACID

Deoxyribonucleic acid (DNA) is the basis for heredity. Its ability to self-replicate makes sure that the coded DNA sequence will be passed on to future generations. This concept, along with the sequences of events described above, is the **central dogma** of molecular genetics. DNA is **mutable** and can be altered under certain conditions. These changes alter the proteins produced and therefore the organism's characteristics. Changes in DNA are usually stable and are passed down from generation to generation. This provides the basis for evolution.

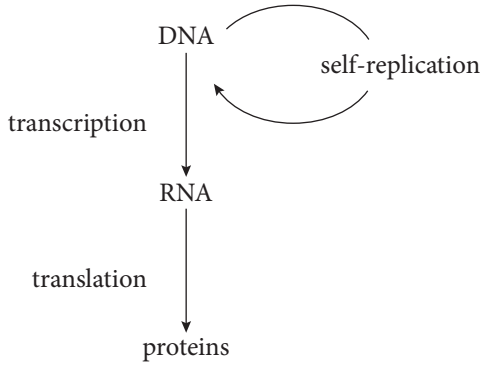


Figure 6.1

DNA Structure

The basic unit of DNA is the **nucleotide**. A nucleotide is composed of deoxyribose (a sugar) bonded to both a phosphate group and a nitrogenous base. There are two types of bases: **purines** and **pyrimidines**. Purines in DNA include **adenine** (A) and **guanine** (G); pyrimidines are **cytosine** (C) and **thymine** (T). Purines are larger in structure than pyrimidines because they possess a two-ring nitrogenous base, whereas pyrimidines have a one-ring nitrogenous base. The phosphate and sugar form a chain with the bases arranged as side groups off the chain.

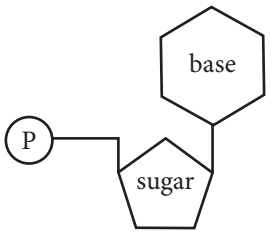


Figure 6.2

The directionality of DNA is designated by a 3′ (read as "three prime") and a 5′ (read as "five prime") end. This naming convention is based on which carbon of the sugar molecule of the DNA strand is the terminus of the helix. If the 5′ carbon is at the end of the DNA strand, then that end is referred to as the 5′ end. Similarly, if the 3′ carbon is at the end of the DNA strand, then that end is referred to as the 3′ end.

DNA is most commonly found in humans as double-stranded helices of complementary strands with the sugar-phosphate chains on the outside of the helix and the nitrogenous bases on the inside. These strands are held together by hydrogen bonds between the bases oriented toward the center. Purines pair with pyrimidines in the following pattern: T forms two hydrogen bonds with A, and G forms three hydrogen bonds with C. This pairing holds the two strands of the double helix together and links the polynucleotide chains. When arranged this way, one DNA strand has its 5′ end pointing up, and the other strand has its 3′ end pointing up, resulting in an **antiparallel** arrangement. This structure was discovered by James Watson and Francis Crick with the help of Rosalind Franklin and others and is therefore known as the **Watson-Crick DNA model**.

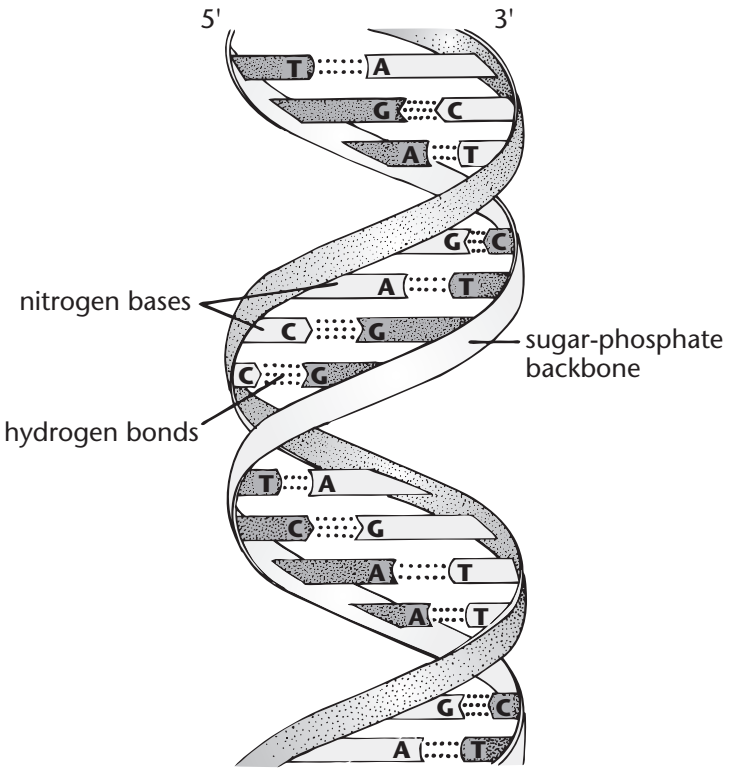


Figure 6.3

DNA Function

DNA replication

In order to replicate, the double-stranded DNA helix must unwind and separate into two single strands. This involves uncoiling the strands by **topoisomerase** and breaking the hydrogen bonds between the nitrogenous bases of each nucleotide by **DNA helicase**. The opening in the DNA molecule created by DNA helicase is known as the **replication fork**.

With their hydrogen bonds broken, each single strand can act as a template for complementary base-pairing. This allows for the synthesis of two new daughter strands. Each new daughter helix contains an intact strand from the parent helix and a newly synthesized strand; this type of replication is called **semiconservative**. The daughter strands of DNA formed from the parent strands are identical to the parent strands.

Creation of these daughter strands is a result of the action of **DNA polymerase**. DNA polymerase reads the parent DNA strand and creates a complementary, antiparallel daughter strand. DNA polymerase always reads the parent strand in the 3′ → 5′ direction, creating a new daughter strand in the 5′ → 3′ direction. One daughter strand is the **leading strand**, and the other is the **lagging strand**. The leading strand is continually synthesized by DNA polymerase, which attaches nucleotides to the exposed 3′ end of the parent strand and follows the replication fork to the 5′ end. However, the other

daughter strand, the lagging strand, is synthesized discontinuously because the 5′ end of the parent strand is the one exposed. Therefore, DNA polymerase, which can only read in the 3′ → 5′ direction, must continually reattach to the 3′ ends of the parent strand since these ends are continually exposed as new section of helices unwinds. The short fragments that result from this discontinuous synthesis are known as **Okazaki fragments**; as the lagging daughter strand is being formed, DNA ligase joins these fragments together.

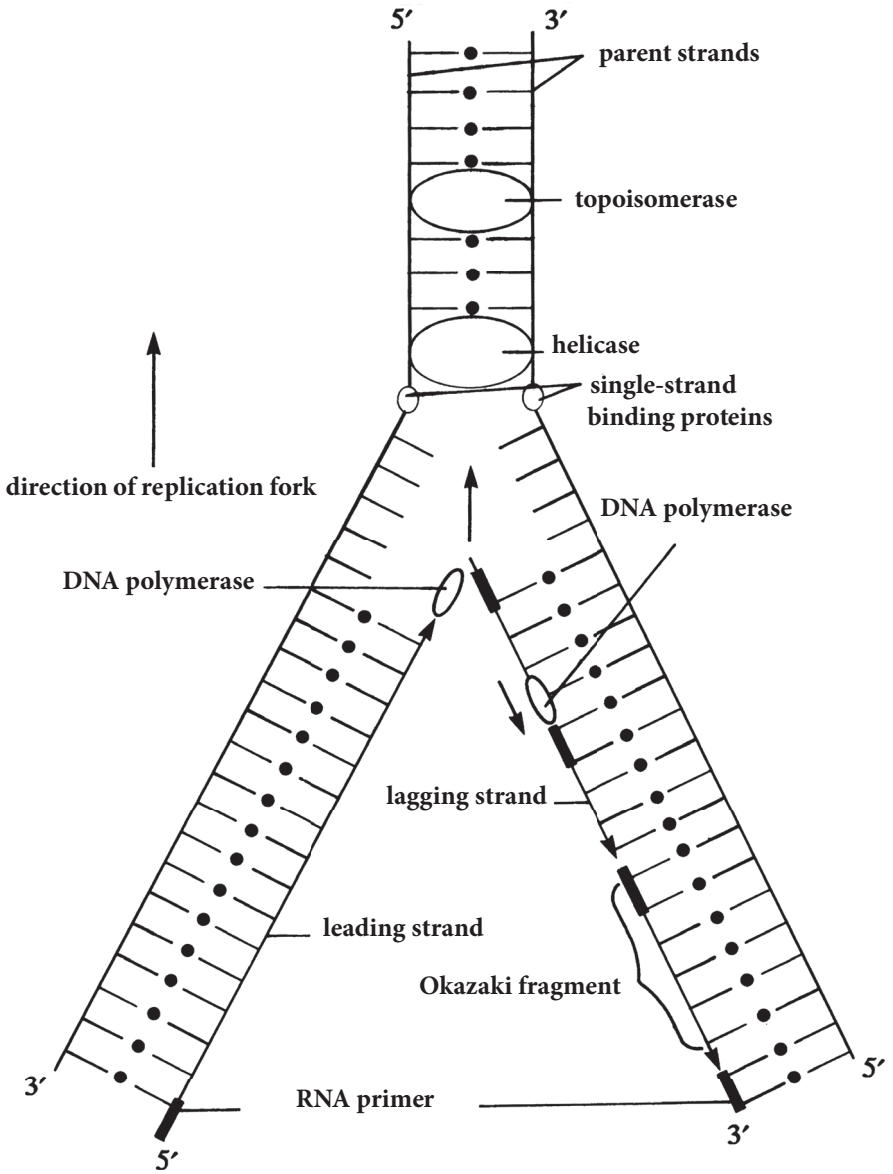


Figure 6.4

The genetic code

DNA is made up of four different nucleosides: **adenine** (A), **thymine** (T), **cytosine** (C), and **guanine** (G). In RNA, the nucleosides are identical except for thymine, which is replaced with **uracil** (U). DNA is transcribed into mRNA and arranged into **triplets** (sets of three). These triplets (also known as **codons**) are then translated from mRNA into amino acids. There are 20 amino acids that can be formed from all possible combinations of the four nucleosides. A sequence of three consecutive bases codes for a particular amino acid; e.g., the codon GGC specifies glycine, and the codon GUG specifies valine. The genetic code is universal for almost all organisms.

Given that 64 different codons are possible based on the triplet code and four possible nucleotides, and only 20 amino acids need to be coded, the code must contain synonyms. This means that most amino acids have more than one codon coding for them. This is referred to as the degeneracy or **redundancy** of the genetic code.

Second Base

First Base (5′)	U	C	A	G	**Third Base (3′)**
U	UUU, UUC: Phe UUA, UUG: Leu	UCU, UCC, UCA, UCG: Ser	UAU, UAC: Tyr UAA, UAG: *Stop*	UGU, UGC: Cys UGA: *Stop* UGG: Trp	U C A G
C	CUU, CUC, CUA, CUG: Leu	CCU, CCC, CCA, CCG: Pro	CAU, CAC: His CAA, CAG: Gln	CGU, CGC, CGA, CGG: Arg	U C A G
A	AUU, AUC, AUA: Ile AUG: *Start* or Met	ACU, ACC, ACA, ACG: Thr	AAU, AAC: Asn AAA, AAG: Lys	AGU, AGC: Ser AGA, AGG: Arg	U C A G
G	GUU, GUC, GUA, GUG: Val	GCU, GCC, GCA, GCG: Ala	GAU, GAC: Asp GAA, GAG: Glu	GGU, GGC, GGA, GGG: Gly	U C A G

Figure 6.5

RIBONUCLEIC ACID

RNA Structure

Ribonucleic acid (RNA) is a polynucleotide that is very structurally similar to DNA but with three major exceptions:

- Its sugar is ribose (instead of deoxyribose).
- It contains uracil instead of thymine.
- It is usually single-stranded.

RNA can be found in both the nucleus and the cytoplasm of the cell. There are several types of RNA, all of which are involved in protein synthesis. The three major types are mRNA, tRNA, and rRNA.

Messenger RNA

Messenger RNA (mRNA) carries the complement of a DNA sequence (except that thymine is substituted with **uracil**). It transports this complement from the nucleus to the ribosomes for protein synthesis. mRNA is made from ribonucleotides complementary to the template strand of DNA. This means that mRNA has the complementary code to the original DNA. For example, because the DNA code for the amino acid valine is AAC, the mRNA sequence is the complementary UUG: A pairs with U, and C pairs with G. mRNA is monocistronic, meaning that one mRNA strand codes for one polypeptide.

Transfer RNA

Transfer RNA (tRNA) is a small RNA molecule found in the cytoplasm. It assists in the translation of mRNA's nucleotide code into a sequence of amino acids. It does this by bringing the amino acids coded for in the mRNA sequence to the ribosomes during protein synthesis. tRNA recognizes both the mRNA codon and its corresponding amino acid. This dual function is reflected in its three-dimensional structure. One end contains a three-nucleotide sequence, the **anticodon**, which is complementary to one of the mRNA codons. The other end is the site of attachment of the corresponding amino acid. Each amino acid has its own aminoacyl-tRNA synthetase, which has an active site that binds to both the amino acid and its corresponding tRNA, catalzying their attachment to form an aminoacyl-tRNA complex. There is at least one type of tRNA for each amino acid (there are approximately 40 known types of tRNA).

Ribosomal RNA

Ribosomal RNA (rRNA) is a structural component of ribosomes and is the most abundant of all RNA types. The mRNA sequence passes through two subunits of the rRNA structure and is translated into amino acids at this time. rRNA is synthesized in the nucleolus.

Transcription

Transcription is the process through which information coded in the base sequence of DNA is used to direct the synthesis of a strand of mRNA, when then leaves the nucleus through nuclear pores. Each human chromosome is a long strand of DNA that is used to make approximately 1,000 different sequences of RNA; therefore, RNA molecules are much shorter than DNA molecules since only a segment of each original DNA strand is used as a template. The first step of transcription occurs when RNA polymerase binds to the DNA at a **promoter region**, a short DNA sequence found upstream from the site where transcription of a specific RNA is going to take place. In humans, this is most commonly a TATA box.

Transcription factors then help **RNA polymerase** bind to the DNA molecule and initiate transcription. In a process very similar to DNA replication, the RNA polymerase surrounds the DNA molecule after it has been opened by the actions of DNA helicase and topoisomerase. The RNA polymerase then recruits and adds complementary RNA nucleotides based on the DNA sequence. As with DNA polymerase, RNA polymerase reads DNA in the 3′ → 5′ direction and creates a new daughter strand of RNA in the 5′ → 3′ direction. The RNA sequence is complementary to the original DNA sequence except that A binds with uracil (U) rather than T. RNA also uses a slightly different sugar backbone than that used in DNA: ribose (with an oxygen on C–2) instead of deoxyribose (without an oxygen on C–2).

After transcription is complete, mRNA undergoes post-transcriptional processing. RNA that has not yet been processed is known as hetero-nuclear RNA (hnRNA), or pre-RNA, and contains extra nucleotides that are not necessary to create the corresponding protein. These extra sequences are called **introns**; in contrast, **exons** are the nucleotides necessary to make the protein. The introns are **spliced** out (removed) by the spliceosome, leaving only the exons behind. Additionally, a **guanine cap** and a series of adenines known as a **poly-A tail** are added to the ends of the new molecule to provide protection from enzyme degradation once the RNA leaves the nucleus.

Translation

Translation is the process through which mRNA codons are translated into a sequence of amino acids. Translation occurs in the cytoplasm and involves tRNA, ribosomes, mRNA, amino acids, enzymes, and other proteins and can be divided into four distinct stages: initiation, elongation, translocation, and termination (see Figure 6.6).

Initiation begins when the ribosome binds to the mRNA near its 5′ end. The ribosome scans the mRNA until it binds to a **start codon** (AUG). The initiator aminoacyl-tRNA complex, methionine-tRNA (with the anticodon 3′–UAC–5′), base pairs with the start codon.

In **elongation**, hydrogen bonds form between the mRNA codon in the A site of the ribosome and its complementary anticodon on the incoming aminoacyl-tRNA complex. A peptide bond is formed between the amino acid attached to the tRNA in the A site and the amino acid attached to the tRNA in the P site of the ribosome. After the peptide bond formation, a ribosome carries uncharged tRNA in the P site and peptidyl-tRNA in the A site.

The cycle is completed by **translocation**, in which the ribosome advances three nucleotides along the mRNA in the 5′ to 3′ direction. In a concurrent action, the uncharged tRNA from the P site is expelled and the peptidyl-tRNA from the A site moves into the P site. The ribosome then has an empty A site ready for the entry of the aminoacyl-tRNA corresponding to the next codon.

Polypeptide synthesis undergoes **termination** when one of three special mRNA termination codons, or **stop codons** (UAA, UAG, or UGA), arrives in the A site. These codons signal the ribosome to terminate translation; they do not code for amino acids. Frequently, numerous ribosomes simultaneously translate a single mRNA molecule, forming a structure known as a **polyribosome**.

After the release of the protein from the ribosome, the protein immediately assumes its characteristic three-dimensional native conformation. This conformation is determined by the primary sequence of amino acids. Additional secondary and tertiary structural folding occurs based on the primary sequence. Furthermore, the polypeptide chains can form intramolecular and intermolecular cross-bridges with disulfide bonds. The result is a functional protein or complex of multiple proteins.

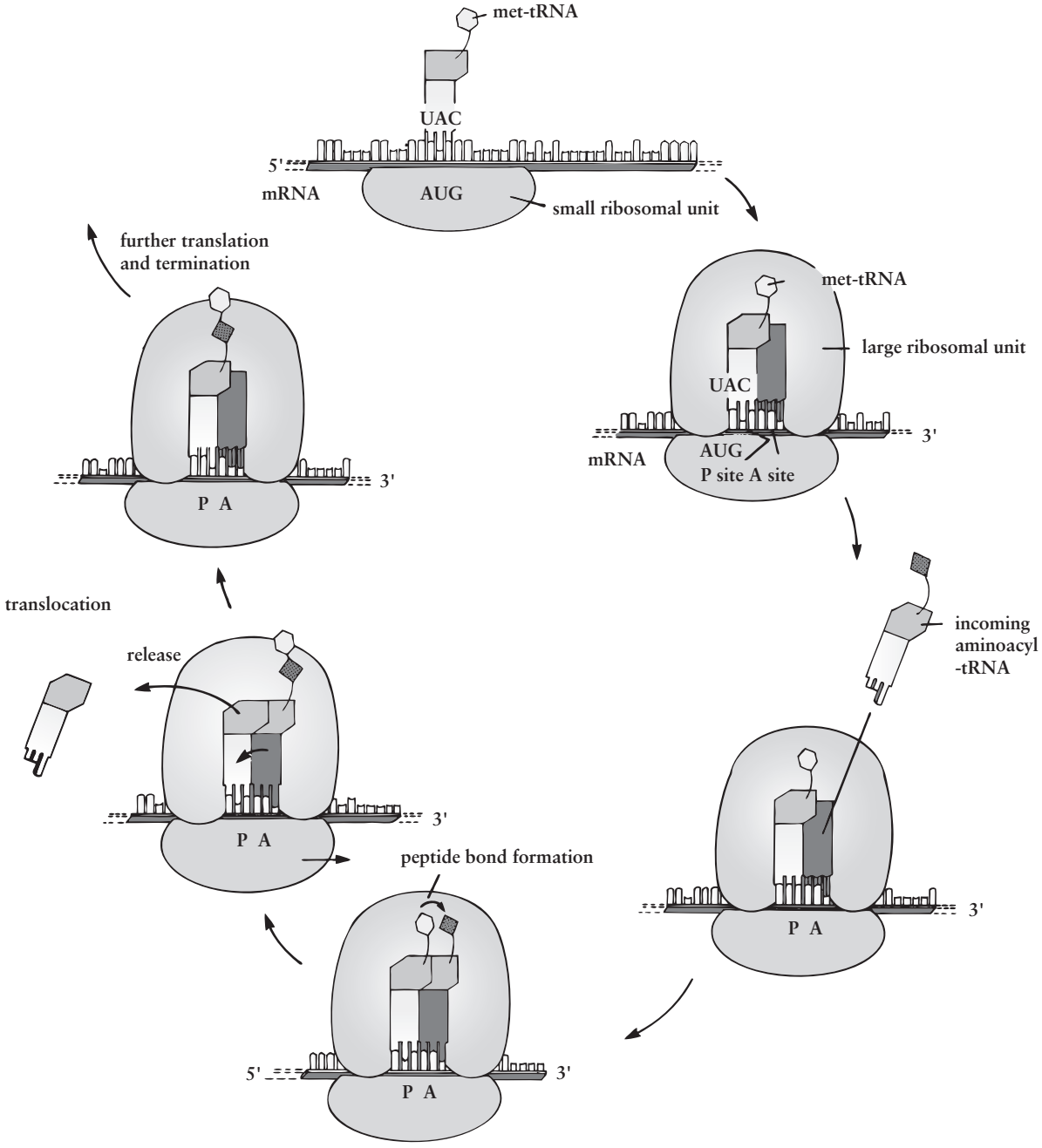

met-tRNA
UAC
5'
mRNA
AUG
small ribosomal unit
met-tRNA
large ribosomal unit
UAC
3'
mRNA
AUG
P site A site
incoming
aminoacyl
-tRNA
3'
P A
peptide bond formation
5'
3'
P A
translocation
release
3'
P A
further translation
and termination
3'
P A

Figure 6.6

Ribosomes, where translation takes place, are composed of two subunits, one small and one large, each consisting of proteins and rRNA. These bind together only during protein synthesis. As previously discussed, ribosomes also have three binding sites for tRNA: the A, P, and E sites. The **A site** (aminoacyl-tRNA complex binding site) binds to the next incoming tRNA complex. The tRNA complex is then transferred to the **P site** (peptidyl-tRNA binding site), where the tRNA contributes its amino acid to the growing polypeptide chain. Finally, having already given up its amino acid, the tRNA is released at the **E site** (exit site).

Humans and bacteria have different types of subunits that make up their ribosomes. This is a difference that drug manufacturers capitalize on when designing antibiotics. Many antibiotics target only the ribosomal structures specific to bacteria, thereby harming bacterial cells while leaving human cells unharmed.

REVIEW PROBLEMS

1. What is the central dogma of molecular genetics?

2. What of the following is NOT true about pyrimidines and purines?

A. Pyrimidines have a two-ring nitrogenous base.
B. Purines have a two-ring nitrogenous base.
C. Purines always bind to pyrimidines when a DNA helix is formed.
D. Purines and pyrimidines make up the "rungs" of the DNA ladder.
E. Purines and pyrimidines bind together using hydrogen bonds.

3. What is the difference between the 3′ and the 5′ ends of a DNA molecule?

4. Which model of DNA replication describes one parental strand and one new strand of DNA making up each new helix?

A. Semiconservative
B. Conservative
C. Dispersive
D. Redundancy
E. Degeneracy

5. Describe the process of DNA replication, including the roles of topoisomerase and DNA helicase and the definitions of Okazaki fragments and the replication fork.

6. What is the redundancy of the genetic code?

7. What are the three major differences between RNA and DNA?

8. Distinguish between transcription and translation and describe the process that takes place within the ribosome during translation.

SOLUTIONS TO REVIEW PROBLEMS

1. The central dogma of molecular genetics states that genetic information goes from DNA to RNA to protein.

2. A Purines are larger molecules than pyrimidines and have a two-ring nitrogenous base, whereas pyrimidines only have a one-ring nitrogenous base. It is true that purines and pyrimidines bind to each other via hydrogen bonds when the DNA helix is formed and that they are on the inside of the helix ("rungs" of the DNA ladder) rather than the outside of the structure.

3. The 3′ end of DNA is where the carbon on the sugar molecule at the farthest end of the DNA molecule is the 3′ carbon within the ring structure. Similarly, the 5′ end is where the carbon on the sugar molecule at the DNA terminus is the 5′ carbon.

4. A Semiconservative replication produces two copies of DNA that each contain one parent strand and one new strand. In conservative replication there is one DNA copy with both parent strands and one with two new strands. In dispersive replication there are two copies of DNA that both have pairs of parent and new genetic material interspersed throughout the helix. Redundancy and degeneracy describe the multiple codons that code for the same amino acid in the genetic code.

5. DNA helicase "unzips" the DNA helix, exposing the two parent DNA strands. This opening is called the replication fork. DNA polymerase moves in a 3′ $\longrightarrow$ 5′ direction along both parent DNA strands, recruiting complementary nucleotides and creating the daughter strands. The leading strand is made continuously, whereas the lagging strand is made discontinuously because DNA polymerase only moves in a 3′ $\longrightarrow$ 5′ direction. This means that on the lagging strand DNA pieces are made in short sequences rather than one long strand. The short pieces of new DNA on the lagging strand are called Okazaki fragments. Topoisomerase prevents DNA from overcoiling during replication.

6. The genetic code is redundant because more than one codon (sequence of three base pairs) codes for many amino acids. Because there are four possible nucleotides for a codon consisting of a combination of three nucleotides, 64 possible combinations of nucleotides exist to make each codon. However, since only 20 amino acids are coded for, most amino acids can be coded for by more than one sequence of nucleotides. This is referred to as the redundancy of the genetic code.

7. Three major differences between RNA and DNA are that RNA (1) contains ribose instead of deoxyribose as its sugar, (2) contains uracil instead of thymine, and (3) is usually single-stranded.

8. Transcription is the process by which DNA is turned into RNA, whereas in translation RNA is turned into protein. In translation the ribosome locates a start codon near the 5′ end of the mRNA. The ribosome then reads the mRNA sequence, codon by codon, and recruits the corresponding amino acid (attached to a tRNA) encoded by the mRNA. After each codon is read, the mRNA molecule translocates within the ribosome to make room for the next codon. Once a stop codon is reached, termination occurs, and the ribosome falls off the mRNA sequence. At this point the primary structure of the protein is complete, and it assumes its three-dimensional conformation based on its primary sequence.

CHAPTER SEVEN

Metabolism

Humans use energy obtained from the digestion of food to maintain their internal environment and power the basic activities of life. The following terms are used to describe the acquisition, the conversion, and some of the uses of energy by a living organism:

- **Metabolism**: The sum of all chemical reactions that occur in the body. Metabolism can be divided into **catabolic reactions**, which break down large chemicals and release energy, and **anabolic reactions**, which build up large chemicals and require energy.
- **Ingestion**: The acquisition and consumption of food and other raw materials.
- **Digestion**: The process of converting food into a usable soluble form so it can pass through membranes in the digestive tract and enter the body.
- **Absorption**: The passage of nutrient molecules through the lining of the digestive tract into the body proper. Absorbed molecules pass through cells lining the digestive tract by diffusion or active transport.
- **Transport**: The circulation of essential compounds required to nourish the tissues and the removal of waste products from the tissues.
- **Assimilation**: The building up of new tissues from digested food materials.
- **Respiration**: The consumption of oxygen by the body. Cells use oxygen to convert glucose into ATP, a ready source of energy for cellular activities.
- **Excretion**: The removal of waste products (such as carbon dioxide, water, and urea) produced during metabolic processes like respiration and assimilation.
- **Synthesis**: The creation of complex molecules from simple ones (anabolism).
- **Regulation**: The control of physiological activities. The body's metabolism functions to maintain its internal environment in a changing external environment. The steady state of the internal environment is known as **homeostasis** and includes regulation by hormones and the nervous system. **Irritability** is the ability to respond to a stimulus and is part of regulation.
- **Growth**: An increase in size caused by cell division and synthesis of new materials.
- **Reproduction**: The generation of additional individuals of a species.

RESPIRATION

Respiration involves the conversion of the chemical energy in molecular bonds into the usable energy needed to drive the processes of living cells. All living cells need energy for growth, maintenance of homeostasis, defense mechanisms, repair, and reproduction. The cells of the human body and those of other organisms obtain this energy from aerobic respiration (respiration in the presence of oxygen). This process includes the intake of oxygen from the environment, the transport of oxygen in the blood, and the ultimate oxidation of fuel molecules in the cell. **External respiration** refers to the entrance of air into the lungs and the gas exchange between the alveoli and the blood (see Chapter 13, Circulatory and Respiratory Systems). **Internal respiration** includes the exchange of gas between the blood and the cells and the intracellular processes of respiration.

Carbohydrates and fats are the favored **fuel** molecules in living cells. As hydrogen is removed, bond energy is made available. The C-H bond is energy rich; in fact, compared with many other bonds, it is capable of releasing a relatively large amount of energy per mole. In contrast, carbon dioxide contains little usable energy. It is the stable, energy-exhausted end product of respiration.

During respiration, high-energy hydrogen atoms are removed from organic molecules. This is called **dehydrogenation** and is an oxidation reaction. The subsequent acceptance of hydrogen by a hydrogen acceptor (oxygen in the final step) is the reduction component of the redox reaction. Energy released by this reduction is used to form a high-energy phosphate bond in ATP. Although the initial oxidation step requires energy input, the net result of the redox reaction is energy production. If all of this energy was released in a single step, little could be harnessed. Instead, the reductions occur in a series of small steps called the **electron transport chain.**

GLUCOSE CATABOLISM

The degradative oxidation of glucose occurs in two stages: **glycolysis** and **cellular respiration.**

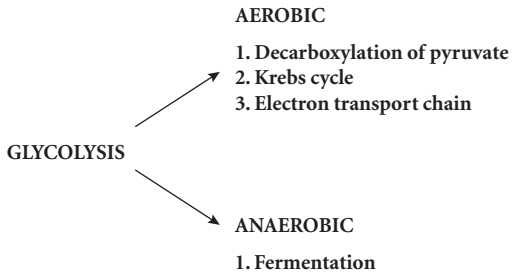


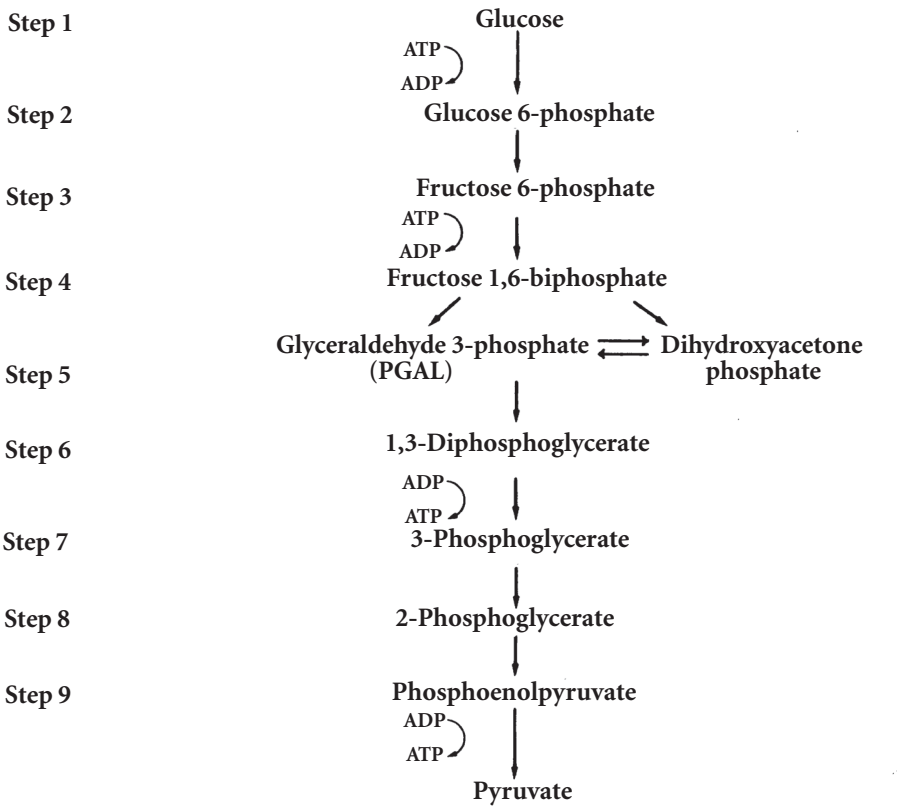
Figure 7.1

Glycolysis

The first stage of glucose catabolism is glycolysis. Glycolysis is a series of reactions that leads to the oxidative breakdown of glucose into two molecules of **pyruvate** (the ionized form of pyruvic acid), the production of ATP, and the reduction of NAD^+ into NADH. All of these reactions occur in the **cytoplasm** and are mediated by specific enzymes.

The process of glycolysis is defined as the sequence of reactions that converts glucose into pyruvate with the concomitant production of ATP. Glycolysis begins when glucose reacts with hexokinase to form glucose 6-phosphate. When this compound interacts with the enzyme phosphoglucose isomerase, the compound fructose 6-phosphate is formed. Fructose 6-phosphate interacts with the enzyme phosphofructokinase to form the compound fructose 1,6-biphosphate. The enzyme aldolase converets 1,6-biphosphate into glyceraldehyde 3-phosphate. After a number of enzymatic reactions, the compound phosphoenolpyruvate is formed. The enzyme pyruvate kinase converts phosphoenolpyruvate into pyruvate, and the glycolytic pathway is complete.

Glycolytic pathway



***Note: Steps 5–9 occur twice per molecule of glucose**

Figure 7.2

Note that at step 4, fructose 1,6-biphosphate is split into two three-carbon molecules: **dihydroxyacetone phosphate** and **glyceraldehyde 3-phosphate (PGAL).** Dihydroxyacetone phosphate is isomerized into PGAL so that it can be used in subsequent reactions. Thus, two molecules of PGAL are formed per molecule of glucose, and all of the subsequent steps occur twice for each glucose molecule.

From one molecule of glucose (a six-carbon molecule), two molecules of pyruvate (a three-carbon molecule) are obtained. During this sequence of reactions, two ATP are used (in steps 1 and 3) and four ATP are generated (two in step 6 and two in step 9). Thus, there is a net production of two ATP per glucose molecule. This type of phosphorylation is called **substrate level phosphorylation** because ATP synthesis is directly coupled with the degradation of glucose without the participation of an intermediate molecule such as NAD^+. One NADH is produced per PGAL for a total of two NADH per glucose.

The net reaction for glycolysis is:

$$\text{Glucose} + 2\ \text{ADP} + 2\ P_i + 2\ NAD^+ \longrightarrow 2\ \text{Pyruvate} + 2\ \text{ATP} + 2\ \text{NADH} + 2\ H^+ + 2\ H_2O$$

At this stage much of the initial energy stored in the glucose molecule has not been released and is still present in the chemical bonds of pyruvate. Depending on the capabilities of the organism, pyruvate degradation can proceed in one of two directions. Under **anaerobic** conditions (in the absence of oxygen), pyruvate is reduced during the process of fermentation. Under aerobic conditions (in the presence of oxygen), pyruvate is further oxidized during cellular respiration in the mitochondria.

Fermentation

NAD^+ must be regenerated for glycolysis to continue in the absence of O_2. This is accomplished by reducing pyruvate into ethanol or lactic acid. Fermentation refers to all of the reactions involved in this process (i.e., glycolysis and the additional steps leading to the formation of ethanol or lactic acid). Fermentation produces only two ATP per glucose molecule.

Alcohol fermentation occurs in yeast and some bacteria. The pyruvate produced in glycolysis is converted to ethanol. In this way, NAD^+ is regenerated, and glycolysis can continue.

Lactic acid fermentation occurs in certain fungi and bacteria and in human muscle cells during strenuous activity. When the oxygen supply to muscle cells lags behind the rate of glucose catabolism, the pyruvate generated is reduced to lactic acid. As in alcohol fermentation, the NAD^+ used in step 5 of glycolysis is regenerated when pyruvate is reduced.

Cellular Respiration

Cellular respiration is the most efficient catabolic pathway used by organisms to harvest the energy stored in glucose. Whereas glycolysis yields only **2 ATP** per molecule of glucose, cellular respiration can yield **36–38 ATP**. Cellular respiration is an **aerobic** process; **oxygen** acts as the final acceptor of electrons that are passed from carrier to carrier during the final stage of glucose oxidation. The metabolic reactions of cell respiration occur in the eukaryotic mitochondrion and are catalyzed by reaction-specific enzymes.

Cellular respiration can be divided into three stages: pyruvate decarboxylation, the citric acid cycle, and the electron transport chain.

Pyruvate decarboxylation

The pyruvate formed during glycolysis is transported from the cytoplasm into the mitochondrial matrix where it is decarboxylated (i.e., it loses a CO_2), and the acetyl group that remains is transferred to coenzyme A to form acetyl-CoA. In the process, NAD^+ is reduced to NADH.

Citric acid cycle

The citric acid cycle is also known as the **Krebs cycle**. The cycle begins when the two-carbon acetyl group from acetyl-CoA combines with oxaloacetate, a four-carbon molecule, to form the six-carbon citrate. Through a series of reactions, two CO_2 are released, and oxaloacetate is regenerated for use in another turn of the cycle.

For each turn of the citric acid cycle one ATP is produced by substrate-level phosphorylation via a GTP intermediate. In addition, electrons are transferred to NAD^+ and FAD, generating NADH and $FADH_2$, respectively. These coenzymes then transport the electrons to the electron transport chain, where more ATP is produced via oxidative phosphorylation (see below). Studying the cycle, we can do some bookkeeping; keep in mind that for each molecule of glucose, two pyruvate are decarboxylated and channeled into the citric acid cycle. Therefore, two of each type of molecular product at this stage of the cycle are created for each glucose molecule.

$$\begin{aligned} 2 \times 3\ \text{NADH} &\rightarrow 6\ \text{NADH} \\ 2 \times 1\ FADH_2 &\rightarrow 2\ FADH_2 \\ 2 \times 1\ \text{GTP (ATP)} &\rightarrow 2\ \text{ATP} \end{aligned}$$

The net reaction of the citric acid cycle per glucose molecule is:

$$2\ \text{acetyl-CoA} + 6\ NAD^+ + 2\ FAD + 2\ GDP + 2\ P_i + 4\ H_2O \longrightarrow 4\ CO_2 + 6\ NADH + 2\ FADH_2 + 2\ GTP + 4\ H^+ + 2\text{CoA}$$

Electron transport chain

The electron transport chain (ETC) is a complex carrier mechanism located on the inside of the **inner mitochondrial membrane.** During oxidative phosphorylation, ATP is produced when high-energy potential electrons are transferred from NADH and $FADH_2$ to oxygen by a series of carrier molecules located in the inner mitochondrial membrane. As the electrons are transferred from carrier to carrier, free energy is released, which is then used to form ATP. Most molecules of the ETC are **cytochromes**, electron carriers that resemble hemoglobin in the structure of their active site. The functional unit contains a central iron atom that is capable of undergoing a reversible redox reaction (i.e., it can be alternatively reduced and oxidized). Sequential redox reactions continue to occur as the electrons are transferred from one carrier to the next; each carrier is reduced as it accepts an electron and is then oxidized when it passes it on to the next carrier. The last carrier of the ETC passes its electron to the final electron acceptor, O_2. In addition to the electrons, O_2 picks up a pair of hydrogen ions from the surrounding medium, forming water.

$$2\ H^+ + 2\ e^- + \frac{1}{2}\ O_2 \longrightarrow H_2O$$

Total Energy Production

To calculate the net amount of ATP produced per molecule of glucose, we need to tally the number of ATP produced by substrate-level phosphorylation and the number of ATP produced by oxidative phosphorylation.

Substrate-level phosphorylation

Degradation of one glucose molecule yields a net of two ATP from glycolysis and one ATP for each turn of the citric acid cycle. Thus, a total of four ATP are produced by substrate-level phosphorylation.

Oxidative phosphorylation

Oxidative phosphorylation is the process that produces more than 90 percent of the ATP used by the cells in our body. The major steps involved in this process occur within the ETC or respiratory chain of the mitochondria. The steps at the end of the electron transport chain, where ATP is generated, are as follows. Along the ETC, the respiratory enzymes continually pump hydrogen ions from the matrix of the mitochondria to the intermembrane space, which creates a large concentration gradient. At the end of the ETC, hydrogen ions pass through channels in the respiratory enzymes along the concentration gradient. As the hydrogen ions pass through these enzymes, the energy released is used to convert ADP to ATP. Now, specifically looking at the process of oxidative phosphorylation, two pyruvate decarboxylations yield one NADH each for a total of two NADH. Each turn of the citric acid cycle yields three NADH and one $FADH_2$, for a total of six NADH and two $FADH_2$ per glucose molecule. Each $FADH_2$ generates two ATP, as previously discussed. Each NADH generates three ATP except for the two NADH that were reduced during glycolysis. These NADH cannot cross the inner mitochondrial membrane and must transfer their electrons to an intermediate carrier molecule, which delivers the electrons to the second carrier protein complex, Q. Therefore, because one ATP is used in this transfer, these NADH generate only two ATP per glucose. So the two NADH of glycolysis yield four ATP, the other eight NADH yield 24 ATP, and the two $FADH_2$ produce four ATP, for a total of 32 ATP produced by oxidative phosphorylation.

The total amount of ATP produced during eukaryotic glucose catabolism is therefore four via substrate-level phosphorylation plus 32 via oxidative phosphorylation, for a total of 36 ATP. (For prokaryotes, the yield is 38 ATP because the two NADH of glycolysis don't have any mitochondrial membranes to cross and therefore don't lose energy.)

Eukaryotic ATP Production per Glucose Molecule

Glycolysis	
2 ATP invested (steps 1 and 3)	– 2 ATP
4 ATP generated (steps 6 and 9)	+ 4 ATP (substrate)
2 NADH × 2 ATP/NADH (step 5)	+ 4 ATP (oxidative)
Pyruvate decarboxylation	
2 NADH × 3 ATP/NADH	+ 6 ATP (oxidative)
Citric acid cycle	
6 NADH × 3 ATP/NADH	+ 18 ATP (oxidative)
2 $FADH_2$ × 2 ATP/$FADH_2$	+ 4 ATP (oxidative)
2 GTP × 1 ATP/GTP	+ 2 ATP (substrate)
Total	+ 36 ATP

ALTERNATE ENERGY SOURCES

When glucose supplies run low, the body uses other energy sources. These sources are used by the body in the following preferential order: other carbohydrates, fats, and proteins. These substances are first converted to either glucose or glucose intermediates, which can then be degraded in the glycolytic pathway and the citric acid cycle.

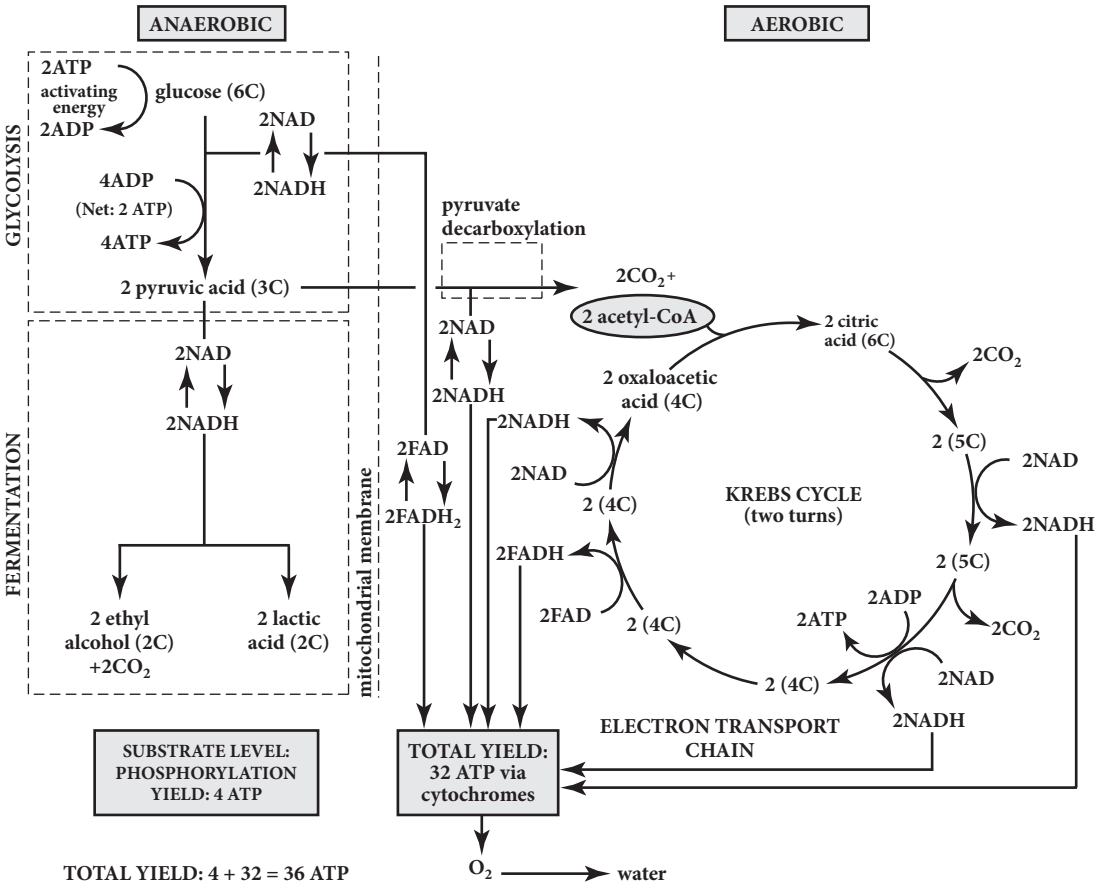


Figure 7.3

Carbohydrates

Disaccharides are hydrolyzed into monosaccharides, most of which can be converted into glucose or glycolytic intermediates. Glycogen stored in the liver can be converted, when needed, into a glycolytic intermediate.

Fats

Fat molecules are stored in adipose tissue in the form of triglycerides. When needed, they are hydrolyzed by **lipases** to **fatty acids** and **glycerol** and are carried by the blood to other tissues for oxidation. Glycerol can be converted into PGAL, a glycolytic intermediate. A fatty acid must first be "activated" in the cytoplasm; this process requires two ATP. Once activated, the fatty acid is

transported into the mitochondrion and taken through a series of beta-oxidation cycles that convert it into two-carbon fragments, which are then converted into acetyl-CoA. Acetyl-CoA then enters the citric acid cycle. With each round of β-oxidation of a saturated fatty acid, one NADH and one $FADH_2$ are generated.

Of all the high-energy compounds used in cellular respiration, fats yield the greatest number of ATP per gram. This makes them extremely efficient energy storage molecules. Thus, while the amount of glycogen stored in humans is enough to meet short-term energy needs for about a day, the stored fat reserves can meet the long-term energy needs for about a month.

Proteins

The body degrades proteins only when not enough carbohydrate or fat is available. Most amino acids undergo a **transamination reaction** in which they lose an amino group to form an α-keto acid. The carbon atoms of most amino acids are converted into acetyl-CoA, pyruvate, or one of the intermediates of the citric acid cycle. These intermediates enter their respective metabolic pathways, allowing cells to produce fatty acids, glucose, or energy in the form of ATP.

Oxidative deamination removes an ammonia molecule directly from the amino acid. **Ammonia** is a toxic substance in vertebrates. Fish can excrete ammonia, whereas insects and birds convert it to uric acid, and mammals convert it to urea for excretion.

ENZYMES

Enzymes are organic catalysts. A catalyst is any substance that affects the rate of a chemical reaction without itself being changed. Enzymes are crucial to living things because all living systems must have continuously controlled chemical activity. Enzymes regulate metabolism by speeding up certain chemical reactions. They affect the reaction rate by decreasing the activation energy.

Enzymes are proteins, and thus, thousands of different enzymes can conceivably be formed. Many enzymes are conjugated proteins (proteins that consist of amino acids attached to other groups via covalent bonds) and have a nonprotein **coenzyme**. In these cases, both components must be present for the enzyme to function.

Enzymes are very selective; they may catalyze only one reaction or one specific class of closely related reactions. The molecule upon which an enzyme acts is called the **substrate**. There is an area on each enzyme to which the substrate binds called the **active site**. The following characteristics are true for all enzymes:

- Enzymes do NOT alter the equilibrium constant.
- Enzymes are NOT consumed in the reaction. This means that they will appear in both the reactants and the products.
- Enzymes are pH- and temperature-sensitive, with optimal activity at specific pH ranges and temperatures.

Most enzyme-catalyzed reactions are reversible. The product synthesized by an enzyme can be decomposed by the same enzyme. An enzyme that synthesizes maltose from glucose can also

hydrolyze maltose back to glucose. The two models that follow describe the binding of the enzyme to the substrate.

Lock and Key Theory

This theory holds that the spatial structure of an enzyme's active site is exactly complementary to the spatial structure of its substrate. The two fit together like a lock and key. In other words, receptors are large proteins that contain a recognition site (lock) that is directly linked to transduction systems. When a drug or endogenous substance (key) binds to the receptor, a sequence of events is started. Although this theory has been largely discounted, it is still frequently used as a teaching tool when explaining drug interactions with receptors and enzymes.

Induced Fit Theory

This more widely accepted theory describes the active site as having flexibility of shape. When the appropriate substrate comes in contact with the active site, the conformation of the active site changes to fit the substrate.

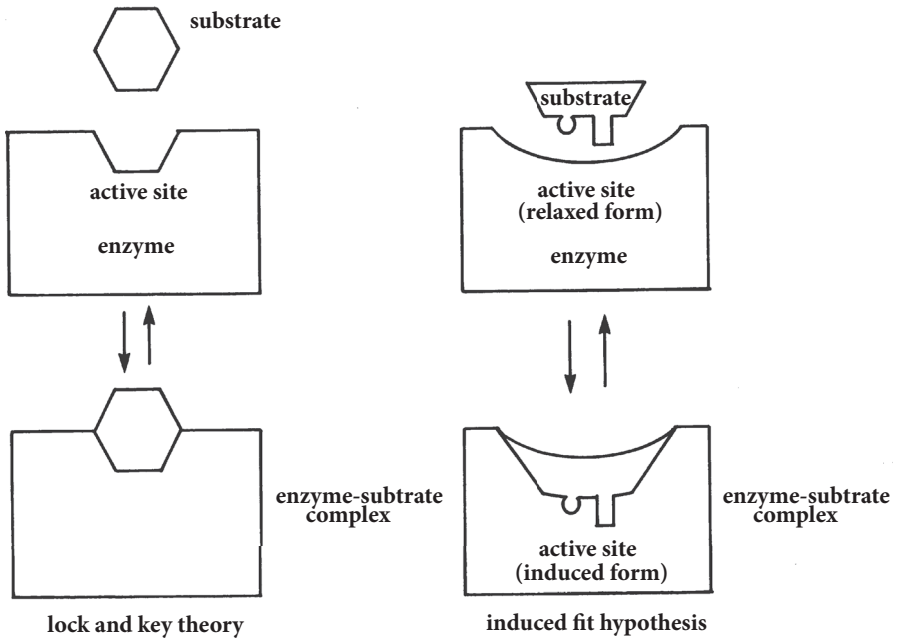


Figure 7.4

Enzyme Specificity

Enzyme action and the reaction rate depend on several environmental factors including temperature, pH, and the concentration of enzyme and substrate.

In general, as the temperature increases, the rate of enzyme action increases until an optimum temperature is reached (usually around 40°C). Beyond optimal temperature, heat alters the shape of the active site of the enzyme molecule and deactivates it, leading to a rapid drop in rate of action.

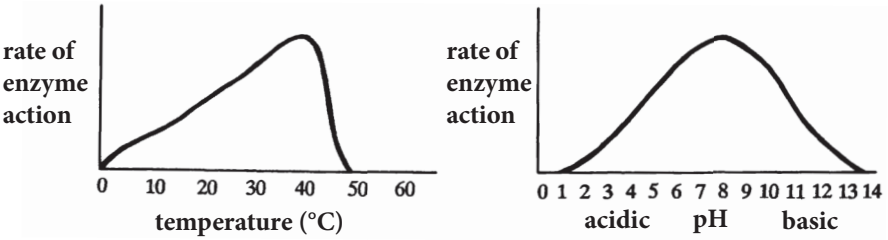


Figure 7.5

For each enzyme there is an optimal pH; above and below that, enzymatic activity declines. Maximal activity of many human enzymes occurs around pH 7.2, which is the pH of most body fluids. Exceptions include **pepsin**, which works best in the highly acidic conditions of the stomach (pH = 2), and pancreatic enzymes, which work optimally in the alkaline conditions of the small intestine (pH = 8.5). In most cases the optimal pH matches the conditions under which the enzyme operates.

The concentrations of substrate and enzyme greatly affect the reaction rate. When the concentrations of both enzyme and substrate are low, many of the active sites on the enzyme are unoccupied, and the reaction rate is low. Increasing the substrate concentration will increase the reaction rate until all of the active sites are occupied. After this point, further increase in substrate concentration will not increase the reaction rate, and the reaction is said to have reached the maximum velocity, V_{max}.

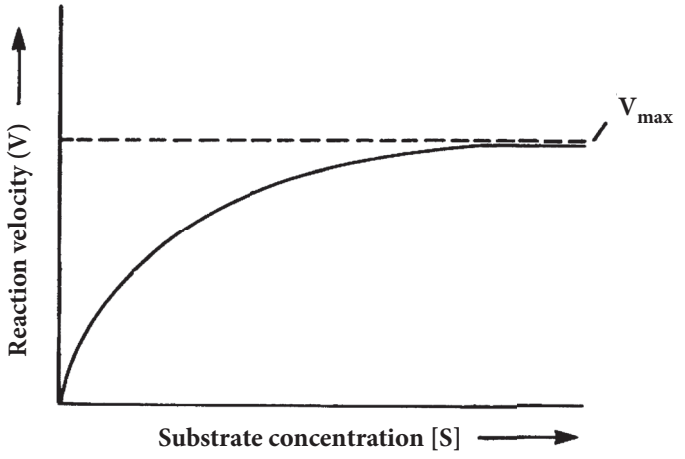


Figure 7.6

Competitive Inhibition

The active site of an enzyme is specific for a particular substrate or class of substrates. However, it is possible for molecules that are similar to the substrate to bind to the active site of the enzyme. If a similar molecule is present in a concentration comparable to the concentration of the substrate, it will compete with the substrate for binding sites on the enzyme and interfere with enzyme activity. This is known as competitive inhibition because the enzyme is inhibited by the inactive substrate, or competitor. If sufficient quantities of the substrate are introduced, however, the substrate can outcompete the competitor and will still be able to reach the V_{max}; however, this will require much higher concentrations of substrate than would be necessary without the competitor.

Noncompetitive Inhibition

A noncompetitive inhibitor is a substance that forms strong covalent bonds with an enzyme, making it unable to bind with its substrate, and consequently a noncompetitive inhibitor cannot be displaced by the addition of excess substrate. Therefore, noncompetitive inhibition is irreversible. Because this inhibition is noncompetitive, addition of excess substrate will not influence the rate of the reaction, and the reaction will never reach V_{max}. A noncompetitive inhibitor may be bound at, near, or far from the active site. When the inhibition takes place at a site other then the active site, this is called **allosteric inhibition**. (**Allosteric** means "other site" or "other structure.") The interaction of an inhibitor at an allosteric site changes the structure of the enzyme so that the active site is also changed.

Examples of enzyme activity

Every reaction in the body is regulated by enzymes. Some of the basic reaction types are listed below.

Hydrolysis reactions function to digest large molecules into smaller components. **Lactase** hydrolyzes lactose to the monosaccharides glucose and galactose. **Proteases** degrade proteins to amino acids, and **lipases** break down lipids to fatty acids and glycerol.

In multicellular organisms, digestion can begin outside of the cells in the gut. Other hydrolytic reactions occur within cells.

Synthesis reactions (including dehydrations) can be catalyzed by the same enzymes as hydrolysis reactions, but the directions of the reactions are reversed.

These reactions occur in different parts of the cell. For example, protein synthesis occurs in the ribosomes and involves dehydration reactions between amino acids.

Synthesis is required for growth, repair, regulation, protection, and production of food reserves such as fat and glycogen by the cell. The survival of an organism depends on its ability to ingest substances that it needs but cannot synthesize. Once ingested, these substances are converted into useful products.

Certain vitamin cofactors and essential amino acids cannot be synthesized by humans. If they are not available in the diet, deficiency diseases will occur.

Many enzymes require the incorporation of a nonprotein molecule to become active. These molecules, called **cofactors**, can be metal cations such as Zn^{2+} or Fe^{2+} or small organic groups called coenzymes. Most coenzymes cannot be synthesized by the body and are obtained from the diet as vitamin derivatives. Cofactors that bind to the enzyme by strong covalent bonds are called **prosthetic groups**.

REVIEW PROBLEMS

1. What is the net reaction for glycolysis? For the citric acid cycle?

2. In glucose catabolism

A. oxygen must be the final electron acceptor.
B. oxygen is necessary for any ATP synthesis.
C. inorganic phosphate is produced.
D. ATP is generated.
E. all of the above occur.

3. Fatty acids enter the degradative pathway in the form of

A. glycerol.
B. glucose.
C. acetyl-CoA.
D. brown adipose tissue.
E. pyruvate.

4. How do ATP, NADH, and $FADH_2$ store energy?

5. How is NAD^+ regenerated and why is this important?

6. Describe the production of ATP via oxidative phosphorylation.

7. Which of the following is LEAST likely to occur during oxygen debt?

A. Buildup of lactic acid
B. Buildup of pyruvate
C. Decrease in pH
D. Fatigue
E. Decrease in pO_2

8. Describe the kinetic effects of increasing substrate concentration while enzyme concentration remains constant.

9. What determines enzyme specificity?

SOLUTIONS TO REVIEW PROBLEMS

1. The net reaction for glycolysis is:

$$\text{Glucose} + 2\text{ATP} + 4\text{ADP} + 2\text{P}_i + 2\text{NAD}^+ \rightarrow$$
$$2\text{ Pyruvate} + 2\text{ADP} + 4\text{ATP} + 2\text{NADH} + 2\text{H}^+ + 2\text{H}_2\text{O}$$

The net reaction for the citric acid cycle is:

$$2\text{ Acetyl-CoA} + 6\text{NAD}^+ + 2\text{FAD} + 2\text{GDP} + 2\text{P}_i + 4\text{H}_2\text{O} \rightarrow$$
$$4\text{CO}_2 + 6\text{NADH} + 2\text{FADH}_2 + 2\text{GTP} + 4\text{H}^+ + 2\text{CoA}$$

2. D Although oxygen is necessary as the final electron receptor for aerobic catabolism (respiration), anaerobic catabolism (fermentation) can occur in the absence of oxygen to still consume ADP and inorganic phosphate as reactants to create ATP.

3. C Discussed in alternate energy sources section of this chapter.

4. Energy is stored in ATP as high-energy bonds created by the covalent bonding of three phosphates to adenosine. The hydrolysis of ATP to ADP releases inorganic phosphate (P_i) and 7 kcal of energy. Hydrolysis of ADP to AMP releases an additional 7 kcal. Alternatively, ATP hydrolysis to AMP + PP_i releases 7 kcal.

NADH and $FADH_2$ are reducing agents that carry chemical energy in the form of high-potential electrons, which can be transferred as hydride ions. In cellular respiration, these hydride ions are transferred to the electron transport chain, where energy release is coupled with ATP synthesis during a series of redox reactions.

5. Step 5 of glycolysis involves the reduction of NAD^+ to NADH. Because NAD^+ is necessary for glycolysis to continue, it must be regenerated in one of two ways. In the presence of oxygen, oxidative phosphorylation and the ETC can be used to oxidize NADH to NAD^+. Alternatively, alcohol or lactic acid fermentation can be used to regenerate NAD^+ under anaerobic conditions.

6. In the electron transport chain, the release of hydrogen ions is coupled with the transfer of electrons. H^+ ions accumulate in the mitochondrial matrix and are shuttled across the inner mitochondrial membrane, creating a proton gradient. To cross the inner membrane, the hydrogen ions must pass through ATP synthetases, which catalyze the phosphorylation of ADP into ATP.

7. B Discussed in fermentation section of this chapter.

8. When substrate concentration is low, the reaction proceeds slowly. Initial increases in substrate concentration greatly increase the reaction rate because of the binding of substrate to available active sites. Eventually, a point is reached at which all of the active sites are occupied, and the addition of more substrate will not hasten the reaction appreciably. Eventually, at very high levels of substrate, the reaction rate approaches a maximum, V_{max}.

9. Enzyme specificity is determined by the unique three-dimensional spatial structure of the active site. According to the induced fit hypothesis, an enzyme's active site is capable of undergoing a conformational change when the appropriate substrate comes into contact with it, such that the substrate is held in place to form an enzyme-substrate complex.

CHAPTER EIGHT

Genetics

Genetics is the study of how traits are inherited from one generation to the next. The basic unit of heredity is the **gene**. Genes are composed of DNA and are located on **chromosomes**. When a gene exists in more than one form, the alternative forms are called **alleles**. The genetic makeup of an individual is the individual's **genotype**; the physical manifestation of the genetic makeup is the individual's **phenotype**. Some phenotypes correspond to a single genotype, whereas other phenotypes correspond to several different genotypes. Knowledge of genetics will help clarify the concepts of evolution by the process of natural selection.

MENDELIAN GENETICS

In the 1860s Gregor Mendel developed the basic principles of genetics through his experiments with the garden pea. Mendel studied the inheritance of individual pea traits by performing **genetic crosses**. He took true-breeding individuals (which, if self-crossed, produce progeny only with the parental phenotype) with different traits, mated them, and statistically analyzed the inheritance of the traits in the progeny.

Mendel's First Law: Law of Segregation

Mendel postulated four principles of inheritance:

1. Genes exist in alternative forms (now referred to as alleles). A gene controls a specific trait in an organism.
2. An organism has two alleles for each inherited trait, one inherited from each parent.
3. The two alleles **segregate** during meiosis, resulting in gametes that carry only one allele for any given inherited trait.
4. If two alleles in an individual organism are different, only one will be fully expressed, and the other will be silent. The expressed allele is said to be **dominant**, the silent allele, **recessive**. In genetics problems dominant alleles are typically assigned capital letters, and recessive alleles are assigned lowercase letters. Organisms that contain two copies of the same allele are **homozygous** for that trait; organisms that carry two different alleles are **heterozygous**. The dominant allele is expressed in the phenotype. This is known as **Mendel's Law of Dominance**. For example, for the following genotypes Yy and YY will both be yellow:

Genes	Genotype	Phenotype
YY	Homozygous	Yellow
Yy	Heterozygous	Yellow
yy	Homozygous	Green

Monohybrid cross

The principles of Mendelian inheritance can be illustrated in a cross between two true-breeding pea plants, one with purple flowers and the other with white flowers. Because only one trait is being studied in this particular mating, it is referred to as a **monohybrid cross**. The individuals being crossed are the **parental** or **P generation**; the progeny generations are the **filial** or **F generations**, with each generation numbered sequentially (e.g., F1, F2, etc.).

The purple flower parent has the genotype PP (i.e., it has two P alleles) and is homozygous dominant. The white flower parent has the genotype pp and is homozygous recessive. When these individuals are crossed, they produce F1 plants that are 100 percent heterozygous (genotype = Pp). Because purple is dominant to white, all the F1 progeny have the purple flower phenotype.

Punnett square

One way of predicting the genotypes expected from a cross is by drawing a **Punnett square diagram**. The parental genotypes are arranged around a grid. Because the genotype of each progeny will be the sum of the alleles donated by the parental gametes, their genotypes can be determined by looking at the intersections on the grid. A Punnett square indicates all the potential progeny genotypes, and the relative frequencies of the different genotypes and phenotypes can be easily calculated.

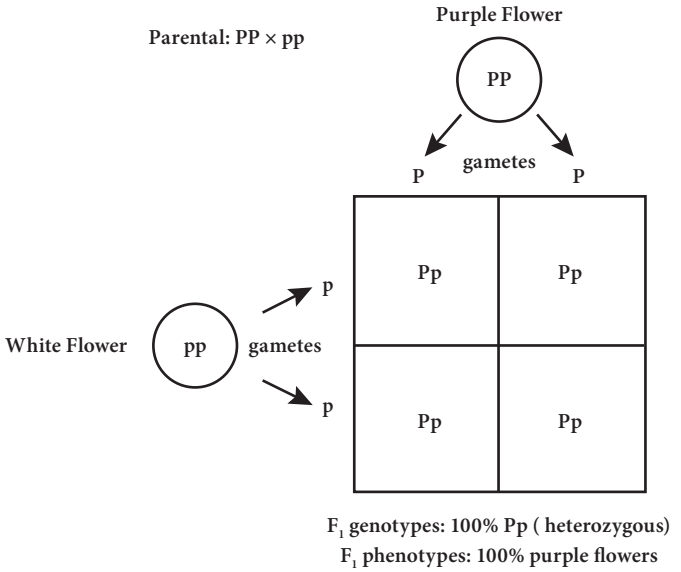


Figure 8.1

When the F1 generation from our monohybrid cross is self-crossed (i.e., Pp × Pp), the F2 progeny are more genotypically and phenotypically diverse than their parents. Because the F1 plants are heterozygous, they will donate a P allele to half of their descendants and a p allele to the other half. One-fourth (25 percent) of the F2 plants will have the genotype PP, 50 percent will have the genotype Pp, and 25 percent will have the genotype pp. Because the homozygous dominant and heterozygous genotypes both produce the dominant phenotype purple flowers, 75 percent of the F2 plants will have purple flowers, and 25 percent will have white flowers.

This is a standard pattern of Mendelian inheritance. Its hallmarks are the disappearance of the silent (recessive) phenotype in the F1 generation and its subsequent reappearance in 25 percent of the individuals in the F2 generation. If we were to take a closer look at the physical characteristics of the plants themselves, we would find that the 1:2:1 genotypic ratio produces a 3:1 phenotypic ratio.

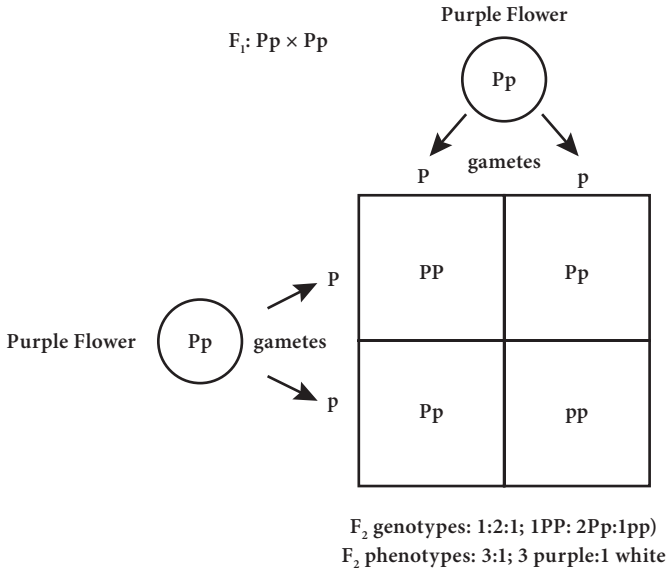


Figure 8.2

Testcross

Mendel also developed the **testcross,** a diagnostic tool used to determine the genotype of an organism. Only with a recessive phenotype can genotype be predicted with 100 percent accuracy. If the dominant phenotype is expressed, the genotype can be either homozygous dominant or heterozygous. Thus, homozygous recessive organisms always breed true. This fact can be used to determine the unknown genotype of an organism with a dominant phenotype, such as when an organism with a dominant phenotype of unknown genotype (Ax) is crossed with a phenotypically recessive organism (genotype aa). Since the recessive parent is homozygous, it can donate only the recessive allele, a, to the progeny. If the dominant parent's genotype is AA, all of its gametes will carry an A, and all of the progeny will have genotype Aa. If the dominant parent's genotype is Aa, half of the progeny will be Aa and express the dominant phenotype, and half will be aa and express the recessive phenotype. In a testcross, the appearance of the recessive phenotype in the progeny indicates that the phenotypically dominant parent is genotypically heterozygous.

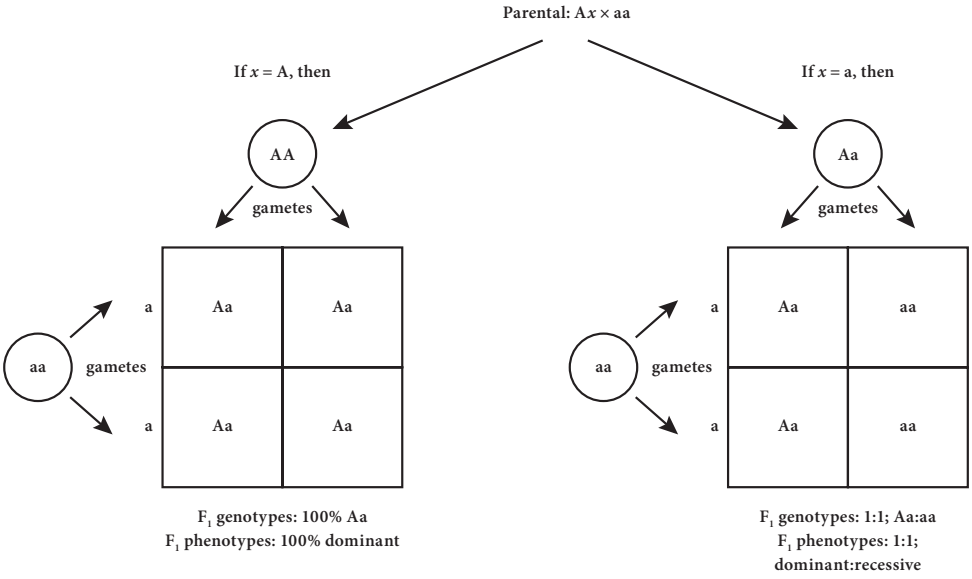


Figure 8.3

Mendel's Second Law: Law of Independent Assortment

The segregation principle provides a satisfactory explanation for the inheritance of a single allele and also can be extended to a dihybrid cross, in which the parents differ in two traits, as long as the genes are on separate chromosomes and assort independently during meiosis. Mendel postulated that the inheritance of one such trait is completely independent of any other. In this way, a plant with purple flowers is no more likely to be a dwarf than a plant with white flowers (see the example below). This is known as **Mendel's Law of Independent Assortment**.

Note that according to modern, non-Mendelian genetics, genes on the same chromosome will not follow this rule and instead will stay together unless **crossing over** occurs (see Chapter 5, Cellular Biology). Nevertheless, crossing over exchanges information between chromosomes and may break the linkage of certain patterns. For example, red hair is usually linked with freckles, but some blondes and brunettes have freckles as well. Generally, the closer the genes are on the chromosome, the more likely they are to be inherited together.

Dihybrid cross

In the following example, a purple-flowered tall pea plant is crossed with a white-flowered dwarf pea plant; both plants are doubly homozygous (tall is dominant to dwarf, T = tall allele, t = dwarf allele; purple is dominant to white, P = purple allele, p = white allele). The purple parent's genotype is TTPP, and it thus produces only TP gametes; the white parent's genotype is ttpp and produces only tp gametes. The F1 progeny will all have the genotype TtPp and will be phenotypically dominant for both traits.

When the F1 generation is self-crossed (TtPp × TtPp), it produces four different phenotypes: tall purple, tall white, dwarf purple, and dwarf white, in the ratio 9:3:3:1, respectively. This is the typical pattern for Mendelian inheritance in a dihybrid cross between heterozygotes with independently assorting traits.

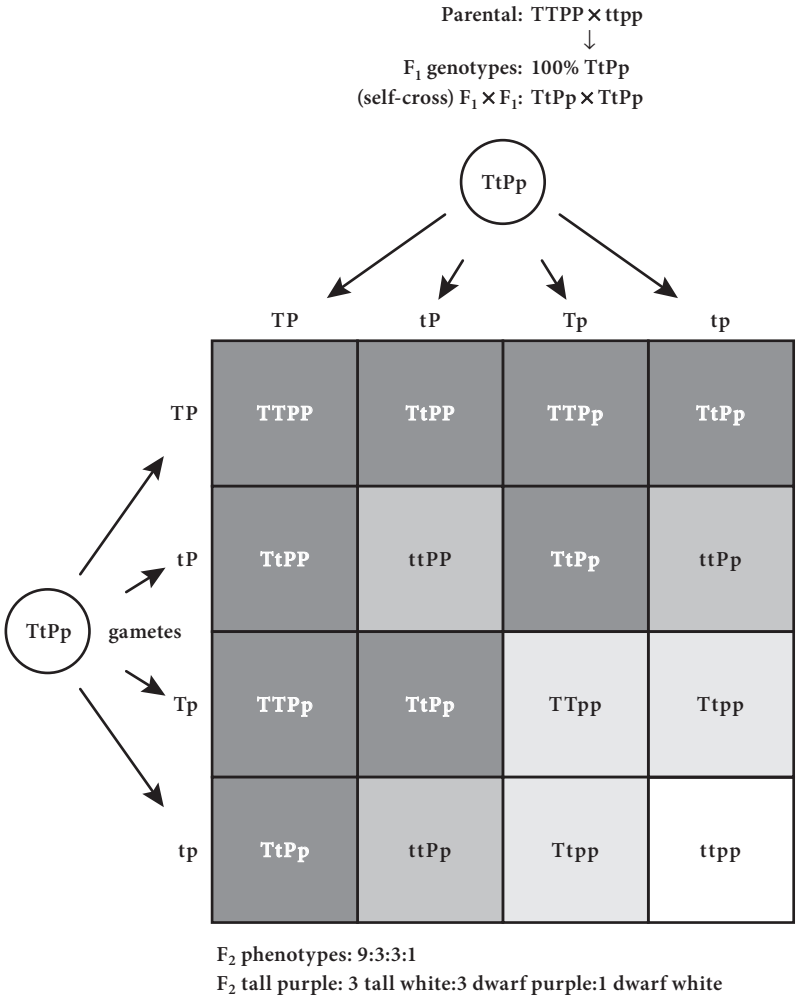


Figure 8.4

Drosophila melanogaster

Modern work with the fruit fly (*Drosophila melanogaster*) helped to provide explanations for Mendelian genetic patterns. The fruit fly possesses several advantages for genetic research:

- It reproduces often (short life cycle).
- It reproduces in large numbers (large sample size).
- Its chromosomes (especially in the salivary gland) are large and easily recognizable in size and shape.
- Its chromosomes are few (4 pairs, $2N = 8$).
- Mutations occur relatively frequently.

Through genetic and mutational analyses of *D. melanogaster*, scientists have elucidated the patterns of embryological development, discovering how genes expressed early in development can affect the adult organism.

NON-MENDELIAN INHERITANCE PATTERNS

In most practical applications, inheritance patterns are often more complicated than Mendel would have hoped. One major source of complications is in the relationship between **phenotype** and **genotype**. In theory, 100 percent of individuals with the recessive phenotype have a homozygous recessive genotype, and 100 percent of individuals with the dominant phenotype have either homozygous or heterozygous genotypes. Such clean concordance between genotype and phenotype is not always the case.

Incomplete Dominance

Some progeny phenotypes are apparently **blends** of the parental phenotypes. The classic example is flower color in snapdragons: homozygous dominant red snapdragons, when crossed with homozygous recessive white snapdragons, produce 100 percent pink progeny in the F1 generation. When F1 progeny are self-crossed, they produce red, pink, and white progeny in the ratio of 1:2:1, respectively. The pink color is the result of the combined effects of the red and white genes in heterozygotes. An allele is incompletely dominant if the phenotype of the heterozygote is an intermediate of the phenotypes of the homozygotes.

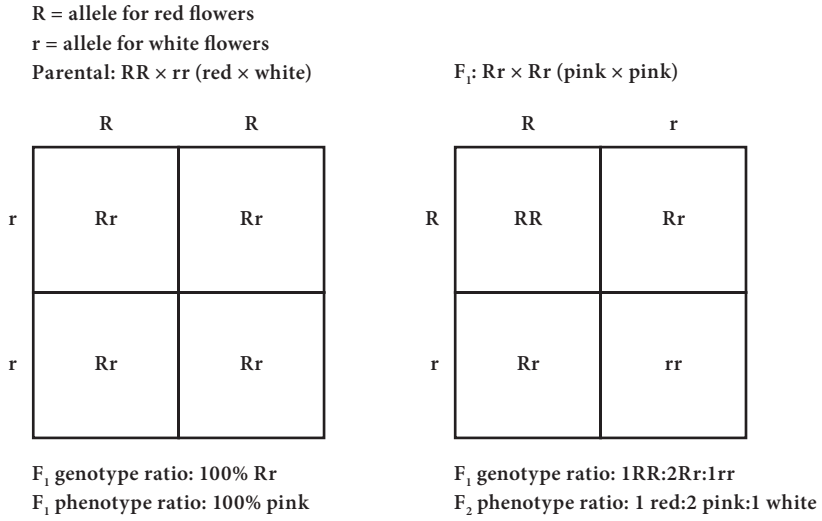


Figure 8.5

Codominance

Codominance occurs when **multiple** alleles exist for a given gene and more than one of them is **dominant**. Each dominant allele is fully dominant when combined with a recessive allele, but when two dominant alleles are present, the phenotype is the result of the expression of both dominant alleles simultaneously.

The classic example of codominance and multiple alleles is the inheritance of **ABO blood groups** in humans. Blood type is determined by three different alleles: I^A, I^B, and i. Only two alleles are present in any single individual, but the population contains all three alleles. I^A and I^B are both dominant to i. Individuals who are homozygous I^A or heterozygous I^Ai have blood type A; individuals who are homozygous I^B or heterozygous I^Bi have blood type B; and individuals who are homozygous ii have blood type O. However, I^A and I^B are codominant; individuals who are heterozygous I^AI^B have a distinct blood type, AB, which combines characteristics of both the A and B blood groups.

Codominance differs from incomplete dominance because in incomplete dominance the phenotype expressed is a blend of both genotypes. In codominance, however, both alleles in the genotype are expressed at the same time without a blending of phenotype.

Sex Determination

The two members of each of the chromosome pairs are identical in shape except for one pair: the sex chromosomes. Different species vary in their systems of sex determination. In sexually differentiated species most chromosomes exist as pairs of homologues called **autosomes**, but sex is determined by a pair of sex chromosomes. All humans have 22 pairs of autosomes; additionally, women have a pair of homologous X chromosomes, and men have a pair of heterologous chromosomes, an X and a Y chromosome. The sex chromosomes pair during meiosis and segregate during the first meiotic division. Since females can produce only gametes containing the X chromosome, the gender of a zygote is determined by the genetic contribution of the male gamete. If the sperm carries a Y chromosome, the zygote will be male; if it carries an X chromosome, the zygote will be female. For every mating, there is a 50 percent chance that the zygote will be male and a 50 percent chance that it will be female.

Genes located on the X or Y chromosome are called **sex-linked**. In humans, most sex-linked genes are located on the X chromosome, although some Y-linked traits have been found (e.g., hair on the outer ear).

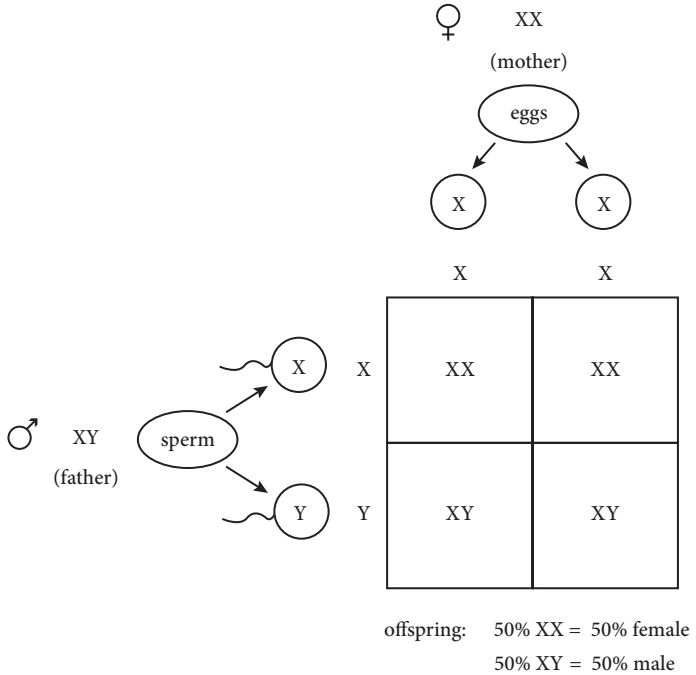


Figure 8.6

Sex Linkage

In humans, women have two X chromosomes and men have only one. As a result, recessive genes carried on the X chromosome will produce the recessive phenotypes whenever they occur in men because no dominant allele is present to mask them. The recessive phenotype will thus be much more frequently found in men. Examples of sex-linked recessives in humans are the genes for **hemophilia** and **color-blindness**.

The pattern of inheritance for a sex-linked recessive trait is somewhat complicated. Because men pass the X chromosome only to their daughters and the gene is carried only on the X chromosome, affected men cannot pass the trait to their male offspring. Affected men will, however, pass the gene to all of their daughters. Nevertheless, unless the daughter also receives the gene from her mother, she will be a phenotypically normal carrier of the trait. Because all of the daughter's male children will receive their only X chromosome from her, half of her sons will receive the recessive sex-linked allele. Thus, sex-linked recessives generally affect only men; they cannot be passed from father to son, but they can be passed from grandfather to grandson via a daughter who is a carrier, thereby skipping a generation.

Environmental Factors

The environment can often affect the expression of a gene. Interaction between the environment and the genotype produces the phenotype. For example, *Drosophila* with a given set of genes have crooked wings at low temperatures but straight wings at higher temperatures.

Temperature also influences the hair color of the Himalayan hare. The same genes for color result in white hair on the warmer parts of the body and black hair on colder parts. If the naturally warm portions are cooled (e.g., by the application of ice), the hair will grow in black.

Cytoplasmic Inheritance

Heredity systems exist outside the nucleus. For example, DNA is found in mitochondria and other cytoplasmic bodies. These cytoplasmic genes may interact with nuclear genes and are important in determining the characteristics of their organelles. Drug resistance in many microorganisms is regulated by cytoplasmic DNA, known as plasmids, that contain one or more genes. Plasmids can be passed from one bacterial cell to another via transformation (described below).

GENETIC PROBLEMS

Although genetic replication is very accurate, chromosome number and structure can be altered by abnormal cell division during meiosis or by mutagenic agents. This can result in the appearance of abnormal characteristics of the offspring in question.

Nondisjunction

Nondisjunction is either the failure of homologous chromosomes to separate properly during meiosis I or the failure of sister chromatids to separate properly during meiosis II. The resulting **zygote** might either have three copies of that chromosome, called **trisomy** (somatic cells will have $2N + 1$ chromosomes), or a single copy of that chromosome, called **monosomy** (somatic cells will have $2N - 1$ chromosomes). A classic case of trisomy is the birth defect **Down syndrome**, which is caused

by trisomy of chromosome 21. Most monosomies and trisomies are lethal, causing the embryo to spontaneously abort early in the pregnancy.

Nondisjunction of the sex chromosomes may also occur, resulting in individuals with extra or missing copies of the X or Y chromosomes.

Chromosomal Breakage

Chromosomal breakage may occur spontaneously or be induced by environmental factors, such as mutagenic agents and X-rays. The chromosome that loses a fragment is said to have a deficiency.

Mutations

Mutations are changes in the genetic information coded in the DNA of a cell. Mutations that occur in **somatic** cells can lead to tumors in the individual. Mutations that occur in the sex cells (**gametes**) will be passed down to the offspring. Most mutations occur in regions of DNA that do not code for proteins and are silent (not expressed in the phenotype). Mutations that do change the sequence of amino acids in proteins are most often recessive and deleterious.

Mutagenic agents

Mutagenic agents induce mutations. These include cosmic rays, X-rays, ultraviolet rays, and radioactivity as well as chemical compounds such as colchicine, which inhibits spindle formation, or mustard gas, which alkylates guanine in DNA. Mutagenic agents are sometimes also **carcinogenic** (cancer-causing).

Mutation types

In a gene mutation, nitrogen bases are **added**, **deleted**, or **substituted**, thus altering the amino acid sequence. Inappropriate amino acids may be inserted into polypeptide chains, and a mutated protein may be produced. Therefore, a mutation is a genetic "error" with the "wrong" base or a missing base in the DNA at any particular position.

In a **point mutation** a nucleic acid is replaced by another nucleic acid. The number of nucleic acids substituted may vary, but generally point mutations involve between one and three nucleotides. There are three possible effects on the **codon**, the sequence of three nucleotides that determines the identity of the amino acid. First, the new codon may code for the same amino acid (a **silent mutation**), and no change in the resulting protein is seen. Second, the new codon may code for a different amino acid (a **missense mutation**). This may or may not lead to a problem with the resulting protein, depending on the role of that amino acid in determining the protein structure. Finally, the new codon may be a stop codon (a **nonsense mutation**). Nonsense mutations are often lethal or severely inhibit the functioning of the protein, which can lead to many different problems depending on the role of that protein in organism function. The length of the genome does not change with any of these mutations, but the primary structure of the proteins formed from an RNA sequence with a nonsense mutation could be much shorter due to the premature stop.

In a **frameshift mutation** nucleic acids are deleted or inserted into the genome sequence. This frequently is lethal. The insertion or deletion of nucleic acids throws off the entire sequence of codons from that point on because the genome is "read" in groups of three nucleic acids. Since nucleic acids are inserted or deleted, the length of the genome changes.

Examples of genetic disorders

- **Phenylketonuria** (PKU) is a molecular disease caused by the inability to produce the proper enzyme for the metabolism of phenylalanine. A degradation product (phenylpyruvic acid) accumulates as a result. The administration of any product that contains phenylalanine, such as aspartame, to an individual with any of the hyperphenylaninemia conditions could be detrimental to his or her general health. Therefore, these individuals are unable to consume products containing aspartame. Hyperphenylaninemia may result from an impaired conversion of phenylalanine to tyrosine. The most common and clinically important impairment is phenylketonuria, which is characterized by an increased concentration of phenylalanine in blood, increased concentration of phenylalanine and its by-products (such as phenylpyruvate, phenylacetate, and phenyllactate) in urine, and mental retardation. Phenylketonuria is caused by a deficiency of phenylalanine hydrolase.
- **Sickle-cell anemia** is a disease in which red blood cells become crescent-shaped because they contain defective hemoglobin. The sickle-cell hemoglobin carries less oxygen. This disease is caused by a substitution of valine (coded by GUA or GUG) for glutamic acid (coded by GAA or GAG) because of a single base-pair substitution in the gene coding for hemoglobin. While the decreased ability to carry oxygen can have negative effects on patients, these individuals do have less severe symptoms of malaria should they become infected, indicating a possible evolutionary advantage in regions where malaria infection is common.

BACTERIAL GENETICS

Bacterial Genome

The bacterial genome consists of a single circular chromosome located in the **nucleoid** region of the cell. Many bacteria also contain smaller circular rings of DNA called **plasmids**, which contain accessory genes. **Episomes** are plasmids that are capable of integration into the bacterial genome.

Replication

Replication of the bacterial chromosome begins at a unique origin of replication and proceeds in both directions simultaneously. DNA is synthesized in the 5′ to 3′ direction.

Genetic Variance

Bacterial cells reproduce by **binary fission** and proliferate very rapidly under favorable conditions. Although binary fission is an **asexual** process, bacteria have three mechanisms for increasing the genetic variance of a population: **transformation**, **conjugation**, and **transduction**.

Transformation

Transformation is the process by which a foreign chromosome fragment (**plasmid**) is incorporated into the bacterial chromosome via recombination, creating new inheritable genetic combinations.

Conjugation

Conjugation can be described as **sexual mating** in bacteria; it is the transfer of genetic material between two bacteria that are temporarily joined. A cytoplasmic conjugation bridge is formed between the two

cells, and genetic material is transferred from the donor male (+) type to the recipient female (–) type. Only bacteria containing plasmids called sex factors are capable of conjugating. The best studied sex factor is the **F factor** in *E. coli*. Bacteria possessing this plasmid are termed F^+ cells; those without it are called F^- cells. During conjugation between an F^+ and an F^- cell, the F^+ cell replicates its F factor and donates the copy to the recipient, converting it to an F^+ cell. Genes that code for other characteristics, such as **antibody resistance**, may be found on the plasmids and transferred into recipient cells along with these factors.

Sometimes the sex factor becomes integrated into the bacterial genome. During conjugation, the entire bacterial chromosome replicates and begins to move from the donor cell into the recipient cell. The conjugation bridge usually breaks before the entire chromosome is transferred, but the bacterial genes that enter the recipient cell can easily recombine with the genes already present to form novel genetic combinations. These bacteria are called **Hfr** cells, meaning that they have a **high frequency of recombination**.

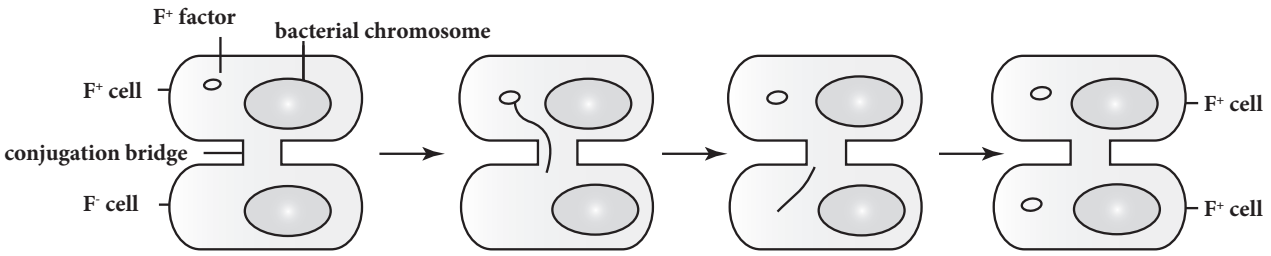


Figure 8.7

Transduction

A **bacteriophage** is a virus that infects its host bacterium by attaching to the bacterium, boring a hole through the bacterial cell wall, and injecting its viral DNA while its protein coat remains attached to the cell wall. Transduction occurs when fragments of the bacterial chromosome become packaged into the viral progeny produced during such a viral infection. These virions may infect other bacteria and introduce new genetic arrangements through recombination with the new host cell's DNA. The closer two genes are to one another on a chromosome, the more likely they will be to transduce together; this fact allows geneticists to map genes to a high degree of precision.

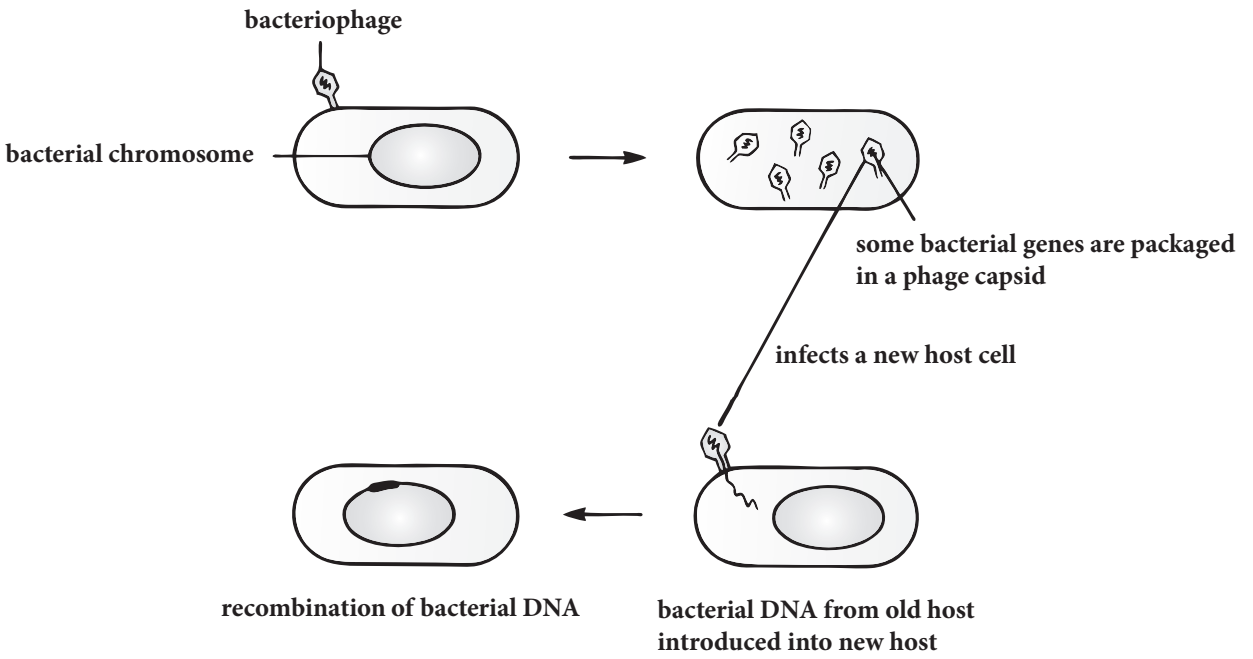


Figure 8.8

Recombination

Recombination occurs when linked genes are separated. It occurs by breakage and rearrangement of adjacent regions of DNA when organisms carrying different genes or alleles for the same traits are crossed.

Gene Regulation

The regulation of **transcription,** one of the steps of gene expression, enables prokaryotes to control their metabolism. Regulation of transcription is based on the accessibility of **RNA polymerase** to the genes being transcribed and is directed by an **operon**, which consists of **structural** genes, an **operator** region, and a **promoter** region on the DNA before the protein coding genes. Structural genes contain sequences of DNA that code for proteins. The operator is the sequence of nontranscribable DNA that is the **repressor** binding site. The promoter is the noncoding sequence of DNA that serves as the initial binding site for RNA polymerase. There is also a **regulator** gene, which codes for the synthesis of a repressor molecule that binds to the operator and blocks RNA polymerase from transcribing the structural genes.

RNA polymerase must also move past the operator to transcribe the structural genes. Regulatory systems function by preventing or permitting the RNA polymerase to pass on to the structural genes. Regulation may be via **inducible systems** or **repressible systems**. Inducible systems are those that require the presence of a substance, called an **inducer**, for transcription to occur. Repressible systems are in a constant state of transcription unless a **corepressor** is present to inhibit transcription.

Inducible systems

In an inducible system the repressor binds to the operator, forming a barrier that prevents RNA polymerase from transcribing the structural genes. For transcription to occur, an inducer must bind to the repressor, forming an **inducer-repressor complex**. This complex cannot bind to the operator, thus removing it as a barrier and permitting transcription. The proteins synthesized are thus said to be inducible. The structural genes typically code for an enzyme, and the inducer is usually the substrate, or a derivative of the substrate, upon which the enzyme normally acts. When the substrate (inducer) is present, enzymes are synthesized; when it is absent, enzyme synthesis is negligible. In this manner, enzymes are transcribed only when they are actually needed.

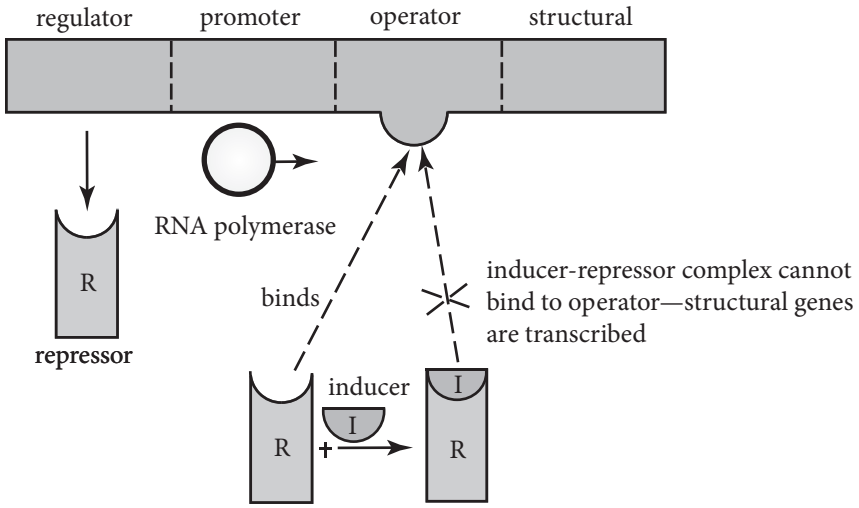


Figure 8.9

Repressible systems

In a repressible system the repressor is inactive until it combines with the corepressor. The repressor can bind to the operator and prevent transcription only when it has formed a repressor-corepressor complex. Corepressors are often the **end products** of the biosynthetic pathways they control. The proteins produced (usually enzymes) are said to be repressible because they are normally being synthesized; transcription and translation occur until the corepressor is synthesized. Operons containing mutations, such as deletions, or whose regulator genes code for defective repressors are incapable of being turned off; their enzymes, which are always being synthesized, are referred to as **constitutive**.

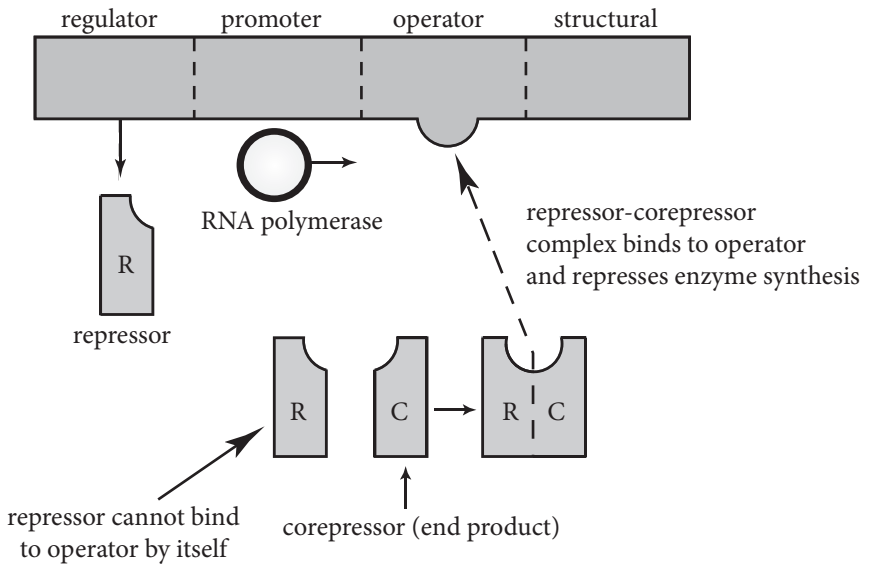

regulator
promoter
operator
structural
RNA polymerase
repressor-corepressor
complex binds to operator
and represses enzyme synthesis
R
repressor
R
C
R
C
repressor cannot bind
to operator by itself
corepressor (end product)

Figure 8.10

REVIEW PROBLEMS

1. A woman with blood genotype I^Ai and a man with blood genotype I^Bi have two children, both type AB. What is the probability that a third child will be blood type AB?

A. 25%
B. 33%
C. 50%
D. 66%
E. 75%

2. In humans, the allele for black hair (B) is dominant to the allele to brown hair (b), and the allele for curly hair (C) is dominant to the allele for straight hair (c). When a person of unknown genotype is crossed against a straight- and brown-haired individual, the phenotypic ratio is:

25% curly black hair
25% straight black hair
25% curly brown hair
25% straight brown hair

What is the genotype of the unknown parent?

A. BBCC
B. BbCC
C. bbCc
D. BbCc
E. BBCc

3. Assuming classical Mendelian inheritance, how can one differentiate between a homozygous dominant individual and one who is heterozygous for the dominant trait?

A. By crossing the individuals in question with one another
B. By crossing each individual with a known homozygous recessive individual and examining the offspring
C. By crossing each individual with a known heterozygote and examining the offspring
D. By crossing each individual with a known homozygous dominant individual and examining the offspring
E. Both B and C

4. If a male hemophiliac (X^hY) is crossed with a female carrier of both color blindness and hemophilia (X^cX^h), what is the probability that a female child will be phenotypically normal?

A. 0%
B. 25%
C. 50%
D. 75%
E. Same as for a male child

5. Explain the concept of Mendel's law of segregation.

6. Why are lethal dominant alleles much less common than lethal recessive alleles?

7. Many point mutations do not have any effect on the gene product. What are two possible explanations for this observation?

SOLUTIONS TO REVIEW PROBLEMS

1. A This is a cross between two heterozygotes for a trait that has codominant alleles. The inheritance pattern for human blood groups is not a simple dominant/recessive pattern because the A and B alleles are both phenotypically expressed when the genotype is I^AI^B.

This is a cross between a woman heterozygous for blood type A and a man heterozygous for blood type B: $I^Ai \times I^Bi$.

F1 genotypes:	25% I^AI^B	phenotypes:	25% type AB
	25% I^Bi		25% type B
	25% I^Ai		25% type A
	25% ii		25% type O

The birth of each child is an independent event. Hence, the fact the first two children this couple had were type AB has no influence whatsoever on the probability that a third child will be AB. So there is a 25 percent chance that any child, not just the third, will be type AB.

2. D In this dihybrid problem, a doubly recessive individual is crossed with an individual of unknown genotype—this is known as a testcross. The straight- and brown-haired individual has the genotype bbcc and can thus produce only bc gametes. Looking at the F1 offspring, there is a 1:1:1:1 phenotypic ratio. The fact that both the recessive and dominant traits are present in the offspring means that the unknown parental genotype must contain both recessive alleles (b and c). The unknown parental genotype must therefore be BbCc. If you want to double-check the answer, you can work out the Punnett square for the cross BbCc × bbcc: BbCc can produce four different types of gametes, BC, Bc, bC, and bc, whereas bbcc can produce only bc gametes, as previously mentioned.

So the unknown parental genotype is BbCc, choice (D).

3. E To differentiate between a homozygous dominant and a heterozygous dominant for a trait that exhibits classic dominant/recessive Mendelian inheritance, one must perform a cross that results in offspring that reveal the unknown parental genotype; this is known as a testcross. If we cross the homozygous dominant with a homozygous recessive, we will get 100 percent phenotypically dominant offspring; if we cross the heterozygous dominant with the homozygous recessive, we will get 50 percent phenotypically dominant and 50 percent phenotypically recessive offspring. Thus, using a homozygous recessive as a testcrosser will allow us to distinguish between the two. We can also use a known heterozygote as the testcrosser because when this is crossed with the homozygous dominant, 100 percent phenotypically dominant offspring are produced, and when it is crossed with the heterozygote, the phenotypic ratio of the offspring is 3:1 dominant:recessive. Hence, the correct answer is (E), because both (B) and (C) are viable options. Crossing the individuals in question with one another or with a homozygous dominant individual, as in (A) and (D), will result in 100 percent phenotypically dominant offspring and hence will not be helpful.

4. C In this problem, we are told that the female in this cross is a carrier of two sex-linked traits: color blindness and hemophilia. We are also told that the genes for these traits are not found on the same X chromosome, as indicated by her genotype, X^cX^h. So of the female offspring, half, or 50 percent, will be phenotypically normal.

5. The chromosomal basis for Mendel's Law of Segregation is as follows: For any given trait, all individuals have two alleles located on separate but homologous chromosomes, one inherited from each parent. During meiosis, or gamete formation, these homologous chromosomes pair and line up along the equatorial plate. As meiosis proceeds, the spindle fibers attached to the homologues move them toward opposite poles of the cell. Because the alleles are on different chromosomes, they segregate and wind up in different gametes. The paired condition of the alleles is restored with the fusion of egg and sperm during fertilization.

6. Lethal dominant alleles are much less common than lethal recessive alleles because a lethal dominant allele kills both heterozygotes and homozygotes, preventing the transmission of the allele to offspring (unless the gene is late-acting). Dominant lethals usually appear in an individual as a result of spontaneous mutations and die with that individual. Thus, the frequency with which dominant lethals appear in the gene pool always remains very low. Lethal recessive alleles only kill homozygotes; however, heterozygotes are phenotypically normal and will not die as a result of their single copy of the lethal recessive. Hence, heterozygotes are able to pass on the lethal allele to offspring and thus maintain the frequency of the allele in the gene pool.

7. A point mutation causes the substitution of one base pair for another. Sometimes, as in the case of sickle-cell anemia, it may have a very profound effect on the gene product (hemoglobin) because it changes the message carried by the gene. In some cases, however, a mutated gene codes for the same product. This can be explained by the redundancy of the genetic code: most amino acids have more than one triplet coding for them. The substitution of the third cytosine in the triplet CCC (proline) by any of the remaining bases (G, A, or U) will not change the amino acid sequence because the codons CCG, CCA, and CCU code for proline as well. In eukaryotes, a point mutation may occur in an intron (noncoding region) and thus will not affect the gene product because noncoding regions are excised after transcription.

CHAPTER NINE

Evolution

The change in the genetic makeup of a population with time is termed **evolution**. Evolution is explained by the constant propagation of new variations in the genes of a species, some of which impart an adaptive advantage. All living things (past and present) are descendents from a single common ancestor. Each of these organisms arose as a direct result of some genetic alteration in the species that lived before them, and this process is called evolution. Most evolutionary changes occur slowly over a long period of time.

THEORIES OF EVOLUTION

Lamarckian Evolution

This discredited theory proposed by Jean-Baptiste Lamarck held that new organs or changes in existing ones arose because of the needs of the organism. The amount of change was thought to be based on the **use or disuse** of the organ. The theory of use and disuse was based upon a fallacious understanding of genetics. Any useful characteristic acquired in one generation was thought to be transmitted to the next. An example of an **acquired characteristic** was the long necks of giraffes. Supposedly, early giraffes permanently stretched their necks to reach for leaves on higher branches of trees. The offspring were believed to inherit the valuable trait of longer necks as a result of this excessive use.

Modern genetics has disproved theories of acquired characteristics. In reality, only changes in the DNA of the sex cells can be inherited. In contrast, changes acquired during an individual's life are changes in somatic cells. August Weismann showed that these changes are not inherited in an experiment in which he cut off the tails of mice for 20 generations (somatic change) only to find that the 21st generation was born with tails.

Darwin's Theory of Natural Selection

In Charles Darwin's theory, pressures in the environment select for the organism most **fit** to survive and reproduce. In the evolutionary sense, **fitness** is the ability to survive and reproduce. Darwin essentially concluded that a member of a particular species that is equipped with beneficial traits, allowing it to cope effectively with the immediate environment, will produce more offspring than individuals with less favorable genetic traits. The genes of parents that are

more fit are therefore passed down to more offspring and become increasingly prevalent in the gene pool. Darwin subsequently chose the words **natural selection** to describe his theory because nature selects the best set of parents for the next generation. Darwin outlined a number of basic agents leading to evolutionary change.

Overpopulation

More offspring are produced than can survive. Thus, the food, air, light, and space are insufficient to support the entire population.

Variations

Offspring naturally show differences (variations) in their characteristics compared to those of their parents. Darwin did not know the source of these differences. Hugo de Vries later suggested mutations as the cause of variations. Some mutations are beneficial, although most are harmful.

Competition

The developing population must compete for the necessities of life. Many young must die, and the number of adults in the population generally remains constant from generation to generation.

Natural selection

Some organisms in a species have variations that give them an advantage over other members of the species. In the struggle for existence, these organisms may have adaptations that are advantageous for survival. For example, a giraffe with a variation of a longer neck would be able to get more food from higher branches of a tree and therefore would be more fit. This principle is encapsulated in the phrase "survival of the fittest."

Inheritance of the variations

The individuals that survive (those with the favorable variations) live to adulthood to reproduce and thus **transmit** these favorable variations or adaptations to their offspring. These favored genes gradually dominate the gene pool.

Evolution of new species

Over many generations of natural selection, the favorable changes (adaptations) are perpetuated in the species. The accumulation of these favorable changes eventually results in such significant changes in the gene pool that we can say a new species has evolved. These physical changes in the gene pool were perpetuated or selected for by environmental conditions.

For example, the rapid evolution of DDT-resistant insects illustrates the theory of natural selection and speciation. A change in the environment such as the introduction of DDT (an insecticide) constitutes a favorable change for the DDT-resistant mutant flies. These mutants existed before the environmental change. Now, conditions select for survival of DDT-resistant mutants.

COMPONENTS OF EVOLUTION

Speciation

Speciation is the evolution of new species, which are groups of individuals that can interbreed freely with each other but not with members of other species. Gene flow is impossible between different species.

Different selective pressures act upon the gene pools of each group, causing them to evolve independently. Genetic variation, changes in the environment, migration to new environments, adaptation to new environments, natural selection, genetic drift, and isolation are all factors that can lead to speciation.

Before speciation, small, local populations called **demes** often form within a species. For example, all the beavers along a specific portion of a river form a deme. There may be many demes belonging to a specific species. Members of a deme resemble one another more closely than they resemble members of other demes. They are closely related genetically since mating between members of the same deme occurs more frequently. They are also influenced by similar environmental factors and thus are subject to the same selection processes.

If these demes become **isolated**, speciation may occur. When groups are isolated from each other, there is no gene flow among them. Any difference arising from mutations or new combinations of genes will be maintained in the isolated population. Over time, these genetic differences may become significant enough to make mating impossible. If the gene pools within a species become sufficiently different so that two individuals cannot mate and produce fertile offspring, two different species have developed and one or more new species have formed. Genetic and eventually reproductive isolation often results from the geographic isolation of a population.

Evolutionary History

Biologists seek to understand the evolutionary relationships among species alive today. This evolutionary history is termed **phylogeny**. Evolutionary history may be visualized as a branching tree on which the common ancestor is found at the trunk and the modern species are found at the tips of the branches.

Convergent evolution

Groups among the branches often develop in similar ways when exposed to similar environments. When two species from different ancestors develop similar traits, this is known as **convergent evolution**. For example, sharks and dolphins have come to resemble one another physically despite belonging to different classes of vertebrates (sharks are members of Chondrichthyes, whereas dolphins are members of Mammalia). Despite different recent ancestors, they evolved certain similar features in adapting to the conditions of aquatic life.

Parallel evolution

Parallel evolution is similar to convergent evolution but occurs when a more recent ancestor can be identified. For example, marsupial (pouched) mammals and placental mammals are both in the class Mammalia but diverged due to geographic separation. Descendants of the ancestral marsupial mammal include the pouched wolf, anteater, mouse, and mole. These species have developed parallel to the placental wolf, anteater, mouse, and mole. Despite their geographic separation, the pouched mammals and their placental counterparts faced similar environments; thus, they developed similar adaptations.

Divergent evolution

In contrast, **divergent evolution** occurs when species with a shared ancestor develop differing traits due to dissimilarities between their environments. For example, bears of the family Ursidae within the class Mammalia share many similar traits but have diverged from a common ancestor to adapt to their specific environments. Polar bears have white coats to blend in with their arctic environment, whereas black bears have developed darker fur to blend in with their wet, forest environments. Over time, additional changes accumulated between these bears, resulting in the inability to cross-breed and eventual speciation.

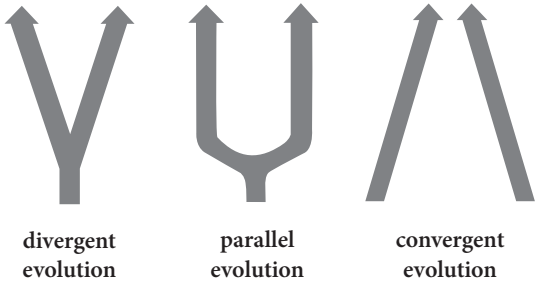


Figure 9.1

Adaptive radiation is the emergence of a number of lineages from a single ancestral species. A single species may diverge into a number of distinct species; the differences between them are those adaptive to a distinct lifestyle, or **niche**. A classic example is Darwin's finches of the Galápagos island chain. Over a comparatively short period of time, a single species of finch underwent adaptive radiation, resulting in 13 separate species of finches, some of them on the same island. Such adaptations minimized competition among the birds, enabling each emerging species to become firmly established in its own environmental niche.

Population Genetics

A **population** includes all members of a particular species inhabiting a given location. The **gene pool** of a population is the sum total of all the alleles for any given trait in the population. **Gene frequency** is the decimal fraction representing the presence of an allele for all members of a population that have this particular gene. In basic Mendelian genetics, only two alleles exist for a given trait: one dominant and one recessive. The letter p is used for the frequency of the dominant allele of a particular gene. The letter q represents the frequency of the recessive allele. Since by definition these are the only two alleles that can be present, for a given gene, $p + q = 1$.

The Hardy-Weinberg principle

Evolution can be viewed as a result of changing gene frequencies within a population. Gene frequency is the relative frequency of a particular allele. When the gene frequencies of a population are not changing, the gene pool is stable and the population is not evolving. However, this is true only in ideal situations in which the following conditions are met:

- The population is very large.
- No mutations affect the gene pool.
- Mating between individuals in the population is random.
- There is no net migration of individuals into or out of the population.
- The genes in the population are all equally successful at reproducing.

Under these idealized conditions, a certain equilibrium will exist among all of the genes in a gene pool, which is described by the **Hardy-Weinberg equation**.

For a gene with only two alleles, T and t, p = the frequency of allele T and q = the frequency of allele t. For that gene, $p + q = 1$ since the combined frequencies of the alleles must total 100 percent. Thus,

$$(p + q)^2 = (1)^2 \text{ , and}$$

$$p^2 + 2pq + q^2 = 1$$

where p^2 = frequency of TT (dominant homozygotes)
$2pq$ = frequency of Tt (heterozygotes)
q^2 = frequency of tt (recessive homozygotes)

The Hardy-Weinberg equation may be used to determine gene frequencies in a large population in the absence of microevolutionary change (defined by the five conditions given previously).

For example, individuals from a nonevolving population can be randomly crossed to demonstrate that the gene frequencies remain constant from generation to generation. If you know that the gene frequency of the dominant gene for tallness, T, is 0.80, and the gene frequency of the recessive gene for shortness, t, is 0.20, then $p = 0.80$ and $q = 0.20$. In a cross between two heterozygotes, the resulting F1 genotype frequencies will be 64% TT, 16% + 16% = 32% Tt, and 4% tt:

	p = 0.80 (T)	q = 0.20 (t)
p = 0.80 (T)	(p^2 = 0.64)	(pq = 0.16)
	TT = 64%	Tt = 16%
q = 0.20 (t)	(pq = 0.16)	(q^2 = 0.04)
	Tt = 16%	tt = 4%

The gene frequencies of the F1 generation can be calculated as follows:

64% TT = 64% T allele + 0% t allele
32% Tt = 16% T allele + 16% t allele
4% tt = 0% T allele + 4% t allele

Gene frequencies = 80% T allele + 20% t allele

Thus, $p = 0.80$ and $q = 0.20$. These frequencies are the same as those in the parent generation, demonstrating Hardy-Weinberg equilibrium in a nonevolving population.

Microevolution

No population can be represented indefinitely by the Hardy-Weinberg equilibrium because such idealized conditions do not exist in nature. Real populations have **unstable** gene pools and **migrating** populations. The agents of microevolutionary change—natural selection, mutation, assortive mating,

genetic drift, and gene flow—are all deviations from the five conditions of a Hardy-Weinberg population.

Natural selection

Genotypes with favorable variations are selected through natural selection, and the frequency of favorable genes increases within the gene pool. Genotypes with low adaptive values tend to disappear.

Mutation

Gene mutations change allele frequencies in a population, shifting gene equilibria by introducing additional alleles. These gene mutations can either be favorable or detrimental for the offspring.

Assortive mating

If mates are not randomly chosen but rather selected according to criteria such as phenotype and proximity **(sexual selection)**, the relative genotype ratios will be affected and will depart from the predictions of the Hardy-Weinberg equilibrium.

Genetic drift

Genetic drift refers to changes in the composition of the gene pool due to chance. Genetic drift tends to be more pronounced in small populations or new populations, where it is sometimes called the **founder effect**.

Gene flow

Migration of individuals between populations will result in a loss or gain of genes, thus changing the composition of a population's gene pool.

EVIDENCE OF EVOLUTION

Fossil Record

Fossils are direct evidence of evolutionary change. They represent the preserved remains of an organism. Fossils are generally found in sedimentary rocks.

Types of fossils

Many types of fossils can provide information. Paleontologists can find actual remains, including teeth, bones, etc., in rock, tar pits, ice, and **amber** (the fossil resin of trees). **Petrification** is the process by which minerals replace the cells of an organism. **Imprints** are impressions left by an organism (e.g., footprints). **Molds** form hollow spaces in rocks as the organisms within decay. **Casts** are formed by minerals deposited in molds.

Significant fossil discoveries

The trilobite is a primitive arthropod (similar to lobsters and crabs), which was a dominant form of the early Paleozoic era. Dinosaurs were ancient animals related to both reptiles and birds. Various forms lived on all the ancient continents. They were a dominant form of the Mesozoic era. Eohippus, the dawn horse, was a primitive horse the size of a fox with four toes and short teeth with pointed cusps for feeding on soft leaves. Fossil evidence indicates a gradual evolution within the horse lineage to the modern horse, which has one toe (hoof) and two vestigial toes as side splints, flat teeth with

ridges for grinding grain and tough prairie grass, and long legs for running. The woolly mammoth was a hairy elephant found in the Siberian ice. Saber-tooth tigers have been preserved in asphalt tar pits. Insects have been discovered preserved in amber. *Archaeopteryx* is a link between reptiles (it has teeth and scales) and birds (it also has feathers).

Comparative Anatomy

Homologous structures

Homologous structures have the same basic anatomical features and evolutionary origins. They demonstrate similar evolutionary patterns with late divergence of form due to differences in exposure to evolutionary forces. Although the origins and anatomical features of these structures are similar, their functions may not be. Examples of homologous structures include the wings of a bat, the flipper of a whale, the forelegs of horses, and the arms of humans.

Analogous structures

Analogous structures have similar functions but may have different evolutionary origins and entirely different patterns of development. The wings of a fly (membranous) and the wings of a bird (bony and covered with feathers) are analogous structures. Analogous organs demonstrate a superficial resemblance that cannot be used as a basis for classification.

Comparative Embryology

The **stages of development** of the embryo resemble the stages in an organism's evolutionary history. The human embryo passes through stages that demonstrate common ancestry with other organisms. The two-layer **gastrula** is similar to the structure of the hydra, a cnidarian. The three-layer gastrula is similar in structure to the flatworm. Gill slits in the embryo indicate a common ancestry with fish. The similarity of these stages suggests a common ancestry and development history.

The earlier the stage at which the development begins to diverge, the more dissimilar the adult organisms will be. For example, it is difficult to differentiate between the embryo of a human and that of a gorilla until relatively late in the development of each embryo.

Embryological development suggests other evidence of evolution from common ancestors. The avian embryo has teeth, suggesting shared ancestry with reptiles. The larvae of some mollusks resemble annelids. Human embryos possess a tail, like most other mammals.

Comparative Biochemistry (Physiology)

Most organisms demonstrate the same basic needs and metabolic processes. They require the same nutrients and contain similar cellular organelles and energy storage forms (ATP). For example, respiratory processes are very similar in most organisms. The similarity of the enzymes involved in these processes suggests that all organisms must contain some DNA sequences in common. The more recently organisms shared a common ancestor, the greater the similarity of their chemical constituents (enzymes, hormones, antibodies, blood) and genetic information. Thus, we can conclude that all organisms are descended from a single common ancestral form. The chemical similarity of the blood of different organisms very closely parallels the evolutionary pattern. A chimpanzee's blood shows close similarity to that of a human but is quite different from that of a rabbit or fish. Thus, the more time that has elapsed since the divergence of two species, the more different their biochemical characteristics.

Vestigial Structures

Vestigial structures have no known current function but apparently had some ancestral function. There are many examples of vestigial structures in humans, other animals, and plants:

- In humans, the appendix is small and useless. In herbivores, it assists in the digestion of cellulose.
- In humans, the tail is reduced to a few useless bones (coccyx) at the base of the spine.
- Splints on the legs of horses are the vestigial remains of the two side toes of more primitive horses.
- Python "legs" are reduced to useless bones embedded in the sides of the adult. The whale has similar hind-limb bones.

Geographic Barriers

Species multiplication is generally accompanied by **migration** to lessen **intraspecific competition**. Separation of a widely distributed population by emerging geographic barriers increases the likelihood of genetic adaptations on either side of the barrier. Each population may evolve specific adaptations to the environment in which it lives in addition to accumulating neutral (random, nonadaptive) changes. These adaptations will remain unique to the population in which they evolve—provided that interbreeding is prevented by the barrier. In time, genetic differences will reach the point where interbreeding becomes impossible between the populations and **reproductive isolation** would be maintained even if the barrier were removed. Following are two examples:

- **Marsupials:** A lineage of pouched mammals (marsupials) paralleling the development of placental mammals developed on the Australian side of a large water barrier. The geographic barrier protected the pouched mammals from competition and hybridization with modern placental mammals. This barrier resulted in the development of uniquely Australian marsupials, such as kangaroos and pouched wolves, as well as other Australian plants and animals, such as the eucalyptus tree and the duck-billed platypus.
- **Darwin's finches**: Over a comparatively short period of time, a single species of Galápagos finch underwent adaptive radiation to form 13 different species of finches. Slight variations in the beak, for example, favored ground or tree feeding. Such adaptations minimized the competition among the birds, enabling each emerging species to become firmly entrenched in its environmental niche. The evolution of these adaptations was helped by the geographic isolation of some of these species on different islands of the Galápagos island chain.

ORIGIN AND EARLY EVOLUTION OF LIFE

The Heterotroph Hypothesis

The first forms of life lacked the ability to synthesize their own nutrients; they required preformed molecules. These "organisms" were heterotrophs, which depended upon outside sources for food. The primitive seas contained simple inorganic and organic compounds such as salts, methane, ammonia, hydrogen, and water. Energy was present in the form of heat, electricity, solar radiation (including X-rays and ultraviolet light), cosmic rays, and radioactivity.

The presence of these building blocks and energy may have led to the synthesis of simple organic molecules such as sugars, amino acids, purines, and pyrimidines. These molecules dissolved in the "**primordial soup**," and after many years, the simple monomeric molecules combined to form a supply of macromolecules.

Evidence of organic synthesis

In 1953, Stanley L. Miller set out to demonstrate that the application of ultraviolet radiation, heat, or a combination of these to a mixture of methane, hydrogen, ammonia, and water could result in the formation of complex organic compounds. Miller set up an apparatus in which the four gases were continuously circulated past electrical discharges from tungsten electrodes.

After circulating the gases for one week, Miller analyzed the liquid in the apparatus and found that an amazing variety of organic compounds, including urea, hydrogen cyanide, acetic acid, and lactic acid had been synthesized.

Formation of primitive cells

Colloidal protein molecules tend to clump together to form **coacervate droplets** (a cluster of colloidal molecules surrounded by a shell of water). These droplets tend to absorb and incorporate substances from the surrounding environment. In addition, the droplets tend to possess a definite internal structure. It is highly likely that such droplets developed on the early Earth. Although these coacervate droplets were not living, they did possess some properties normally associated with living organisms.

Most of these systems were unstable; however, a few systems may have arisen that were stable enough to survive. A small percentage of the droplets possessing favorable characteristics may have eventually developed into the first primitive cells. These first primitive cells probably possessed nucleic acid polymers and became capable of reproduction.

Development of Autotrophs

The primitive heterotrophs slowly evolved complex **biochemical pathways**, enabling them to use a wider variety of nutrients. They evolved anaerobic respiratory processes to convert nutrients into energy. However, these organisms required nutrients at a faster rate than they were being synthesized. Life would have ceased to exist if autotrophic nutrition had not developed. Autotrophs are able to produce organic compounds, including energy-containing molecules, from substances in their surroundings. The pioneer autotrophs developed primitive photosynthetic pathways, capturing solar energy and using it to synthesize carbohydrates from carbon dioxide and water.

Development of Aerobic Respiration

The primitive autotrophs fixed carbon dioxide during the synthesis of carbohydrates and released molecular oxygen as a waste product. The addition of molecular oxygen to the atmosphere converted the atmosphere from a **reducing** to an **oxidizing** one. Some molecular oxygen was converted to ozone, which functions in the atmosphere to block high-energy radiation. In this way, living organisms destroyed the conditions that made their development possible. Once molecular oxygen became a major component of the Earth's atmosphere, both heterotrophs and autotrophs evolved the biochemical pathways of aerobic respiration. Now equilibrium exists between oxygen-producing and oxygen-consuming organisms.

General Categories of Living Organisms

All living organisms can be divided into four basic categories. The **autotrophic anaerobes** include chemosynthetic bacteria. The **autotrophic aerobes** include the green plants and photoplankton. The **heterotrophic anaerobes** include yeasts. The **heterotrophic aerobes** include amoebas, earthworms, and humans.

REVIEW PROBLEMS

1. Can the muscular strength that a weight lifter gains be inherited by the athlete's children?

2. Which organism has a greater evolutionary fitness: one that lives 70 years and has five fertile offspring or one that lives 40 years and has ten fertile offspring?

3. Homologous structures are

A. similar in function but not in origin.
B. similar in origin but not necessarily in function.
C. completely dissimilar.
D. found only in mammals.
E. similar in function and origin.

4. Will chance variation have a greater effect in a large or a small population? What is this effect called?

5. As the climate got colder during the Ice Age, a particular species of mammal evolved a thicker layer of fur. This is an example of what kind of selection?

6. At what point are two populations descended from the same ancestral stock considered separate species?

7. In a nonevolving population, there are two alleles, R and r, which code for the same trait. The frequency of R is 30 percent. What are the frequencies of all the possible genotypes?

8. As the ocean became saltier, whales and fish independently evolved mechanisms to maintain the concentration of salt in their bodies. This can be explained by

A. homologous evolution.
B. analogous evolution.
C. convergent evolution.
D. parallel evolution.
E. heterologous evolution.

9. In a particular Hardy-Weinberg population, there are only two eye colors: brown and blue. Thirty-six percent of the population has blue eyes, the recessive trait. What percentage of the population is heterozygous for brown eyes?

10. In a certain population, 64 percent of individuals are homozygous for curly hair (CC). The gene for curly hair is dominant to the gene for straight hair, c. Use the Hardy-Weinberg equation to determine what percentage of the population has curly hair.

11. Which of the following was NOT a belief of Darwin's?

A. Evolution of species occurs gradually and evenly over time.
B. There is a struggle for survival among organisms.
C. Genetic mutation and recombination are the driving forces of evolution.
D. Those individuals with fitter variants will survive and reproduce.
E. More offspring are produced in a population than can survive.

12. The proposed "primordial soup" was composed of organic precursor molecules formed by interactions between all of the following elements EXCEPT

A. oxygen.
B. helium.
C. nitrogen.
D. hydrogen.
E. carbon.

SOLUTIONS TO REVIEW PROBLEMS

1. No. The only characteristics that are inherited are those genetically coded for, not those acquired through the use or disuse of body parts. Therefore, the musculature of the weight lifter, an acquired characteristic, cannot be inherited by that athlete's children.

2. The organism that lives 40 years and has ten fertile offspring has the greater evolutionary fitness because it makes a greater genetic contribution to the next generation. It has twice as many direct descendants as the organism that lives 70 years and has five fertile offspring.

3. B Homologous structures are similar in origin but not necessarily similar in function. Analogous structures are similar in function but not in origin. Homologous structures are not limited to mammals; e.g., the forelimbs of crocodiles and birds are homologous structures.

4. Chance variation will have a greater effect in a small population because any one variant individual is a greater percentage of the whole population. This effect is called genetic drift.

5. This is an example of natural selection, the phenotypic norm of a particular species shifting to adapt to a selective pressure, such as an increasingly colder environment. Only those individuals with a thick layer of fur were able to survive during the Ice Age, thus that trait led to greater fitness (the production of more offspring, in this case due to living longer).

6. Two populations are considered separate species when they can no longer interbreed and produce viable, fertile offspring.

7. The frequency of R = 30%. Thus, $p = 0.30$. The frequency of recessive gene r = 100% – 30% = 70%. Thus, $q = 0.70$. Frequency of genotypes = $p^2 + 2pq + q^2 = 1$, where p^2 = RR, $2pq$ = Rr, and q^2 = rr.

p^2	=	$(0.3)^2$	=	0.09	=	9% RR
$2pq$	=	$2(0.3)(0.7)$	=	0.42	=	42% Rr
q^2	=	$(0.7)^2$	=	0.49	=	49% rr

8. C Whales and fish have similar body structures (streamlined body with fins and tail), although they belong to different classes of vertebrates. When organisms that differ phylogenetically develop in similar ways when exposed to similar environments, the process is known as convergent evolution.

9. The percentage of the population with blue eyes (genotype = bb) = 36% = $q^2 = 0.36$; therefore, $q = 0.6$. Because $p + q = 1$, $p = 0.4$. The frequency of heterozygous brown eyes is $2pq = 2(0.4)(0.6) = 0.48$. So 48% of the population is heterozygous for brown eyes.

10. The variable p represents the frequency of the dominant allele (C), and q represents the frequency of the recessive allele (c). The CC frequency is 64%, which means that $p^2 = 0.64$, or $p = 0.8$. Because $p + q = 1$, $q = 1 - 0.8 = 0.2$.

The problem asks for the percentage of the population with curly hair; this includes both homozygotes and heterozygotes (CC and Cc). The genotype frequencies can be found using the equation $p^2 + 2pq + q^2$.

CC	=	p^2	$= (0.8)^2$	=	0.64	=	64% homozygous curly
Cc	=	$2pq$	$= 2(0.8)(0.2)$	=	0.32	=	32% heterozygous curly
cc	=	q^2	$= (0.2)^2$	=	0.04	=	4% straight hair

Therefore, the percentage of the population with curly hair is 64% + 32% = 96%.

11. C Darwin believed the driving force behind evolution was the fitness of the organism for its particular environment.

12. B He, a noble gas, is inert and does not form molecules with other atoms.

CHAPTER NINETEEN

Animal Behavior

The preceding biology chapters focused mainly on vertebrate systems (with some information about plants as well). However, on Test Day you will see a few questions about non-vertebrate, non-plant systems: three questions on the diversity of life and taxonomic relationships as well as four questions on evolution, ecology, and behavior, which will contain a mixture of questions about human and nonhuman populations. This chapter on Animal Behavior and the following two chapters on Ecology and Taxonomy contain the information you need to successfully answer questions about non-vertebrate systems on Test Day. However, as you are studying, keep in mind that these types of questions will likely constitute only ten percent or less of the Biology questions on your exam.

This chapter on animal behavior describes the individual and social activities of various organisms, how evolution has shaped those behaviors in the long term, and how learning can influence those behaviors in the short term.

PATTERNS OF ANIMAL BEHAVIOR

Simple Reflexes

Reflexes are automatic responses to simple stimuli and are recognized as reliable behavioral responses following a given environmental stimulus. A **simple reflex** is controlled at the **spinal cord,** connecting a two-neuron pathway from the **receptor** (afferent neuron) to the **motor** (efferent neuron). The efferent nerve innervates the effector (e.g., a muscle or gland). Reflex behavior is important in the behavioral response of lower animals. It is less important in the behavior in higher forms of life, such as vertebrates. A simple reflex arc is shown in Figure 19.1.

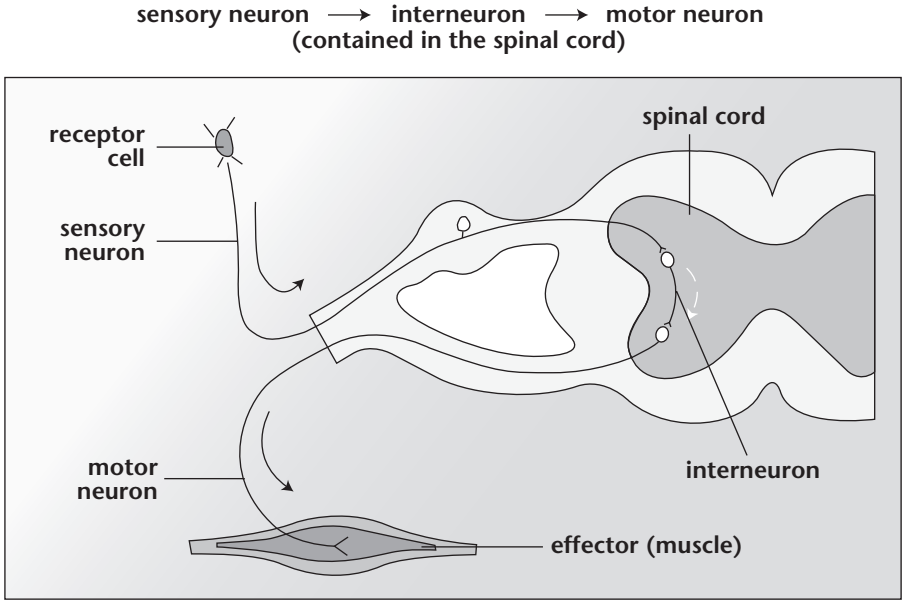


Figure 19.1

Complex Reflexes

More complex reflex patterns involve neural integration at a higher level of the **brainstem** or even the **cerebrum.** For example, the "**startle response**" alerts an animal to a significant stimulus. It can occur in response to potential danger or to hearing one's name called. The startle response involves the integration of many neurons in a system termed the **reticular activating system,** which is responsible for sleep–wake transitions and behavioral motivation.

Complex Reflexes

Fixed-action patterns are complex, coordinated, **innate** behavioral responses to specific patterns of stimulation in the environment. The stimulus that elicits the behavior is referred to as the **releaser.** Because fixed-action patterns are innate, they are relatively unlikely to be modified by learning. An animal has a repertoire of fixed-action patterns and only a limited ability to develop new ones. The particular stimuli that trigger a fixed-action pattern are more readily modified, provided certain cues or elements of the stimuli are maintained. An example of a fixed-action pattern is the retrieval and maintenance response of many female birds to an egg of their species.

Certain kinds of stimuli are more effective than others in triggering a fixed-action pattern. For example, an egg with the characteristics of that species will be more effective than one that only crudely resembles the natural egg. Another type of fixed-action pattern is the characteristic movements made by animals that herd or flock together, such as the swimming actions of fish and the flying actions of locusts.

Behavior Cycles

Daily cycles of behavior are called **circadian rhythms**. Animals with such behavior cycles lose their exact 24-hour periodicity if they are isolated from the natural phases of light and dark. Cyclical

behavior, however, will continue with approximate day-to-day phasing. The cycle is thus initiated intrinsically but modified by external factors.

Daily cycles of eating, maintained by many animals, provide a good example of cycles with both internal and external control. The internal controls are the natural bodily rhythms of eating and satiation. External modulators include the elements of the environment that occur in familiar cyclic patterns, such as dinner bells and clocks.

Sleep and wakefulness are the most obvious examples of cyclic behavior. In fact, these behavior patterns have been associated with particular patterns of brain waves.

Environmental Rhythms

In many situations, patterns of behavior are established and maintained mainly by periodic **environmental stimuli.** (A human example of this is the response to traffic light signals.) Just as environmental stimuli influence many naturally occurring biological rhythms, biological factors influence behavior governed by periodic environmental stimuli.

LEARNING

Learned behavior involves **adaptive responses** to the environment. Learning is a complex phenomenon that occurs to some extent in all animals. In lower animals, instinctual or innate behaviors are the predominant determinants of behavior patterns, and learning plays a relatively minor role in the modification of these predetermined behaviors. In higher animals, learning plays a more significant role. The capacity for learning adaptive responses is closely correlated with the degree of **neurologic development** (i.e., the capacity of the nervous system, particularly the cerebral cortex, for flexibility and plasticity).

Habituation

Habituation is one of the simplest learning patterns involving the suppression of the normal start response to stimuli. In habituation, repeated stimulation results in decreased responsiveness to that stimulus. The normal autonomic response to that stimulus would serve no useful purpose since the stimulus becomes a part of the background environment; thus, the response to the stimulus is suppressed. If the stimulus is no longer regularly applied, the response tends to recover over time. This is referred to as **spontaneous recovery.** Recovery of the response can also occur with modification of the stimulus.

Classical Conditioning

Classical or **Pavlovian** conditioning involves the association of a normally **autonomic** or visceral response with an environmental stimulus. For this reason, the response learned through Pavlovian conditioning is sometimes called a **conditioned reflex.** In Pavlovian conditioning, the normal, innate stimulus for a reflex is replaced by one chosen by the experimenter. This is illustrated in Figure 19.2.

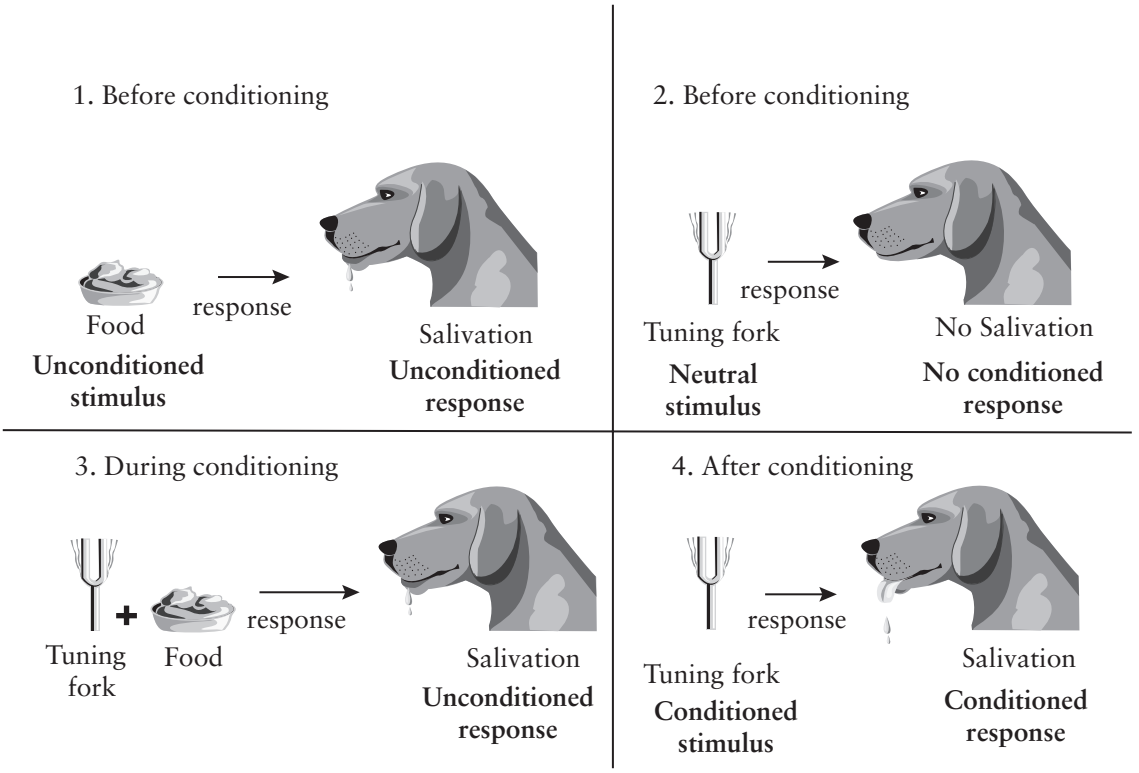


Figure 19.2

Pavlov's experiments

Ivan Pavlov, who won a Nobel Prize for his work on digestive physiology, studied the **salivation reflex** in dogs. In 1927, he discovered that if a dog was presented with an **arbitrary stimulus** (e.g., a bell) and then presented with food, it would eventually salivate on hearing the bell alone. The food elicited the unconditioned response of salivation. After repeated association of the bell with the food, the bell alone could elicit the salivation reflex. Thus, the innate or unconditioned response would occur with the selected stimulus. Pavlov's terminology, still used today, is described below:

- An established (innate) reflex consists of an **unconditioned stimulus** (e.g., food) and the response that is naturally elicited, termed the **unconditioned response** (e.g., salivation).
- A neutral stimulus is a stimulus that will not by itself elicit the response (prior to conditioning). During conditioning, the neutral stimulus (the bell) and the unconditioned stimulus (the food) are presented together. Eventually, the neutral stimulus is able to elicit the response in the absence of the unconditioned stimulus, and it is then called the conditioned stimulus. Pavlov's example of a conditioned stimulus is the sound of a bell for salivation.
- The product of the conditioning experience is termed the **conditioned reflex.** The conditioned reflex in Pavlov's experiment was salivation (the conditioned response) following a previously neutral stimulus (now the conditioned stimulus), such as the sound of a bell.
- Pavlov defined **conditioning** as the establishment of a new reflex (association of stimulus with response) by the addition of a new, previously neutral stimulus to the set of stimuli that are already capable of triggering the response.

Pseudoconditioning

Pseudoconditioning is a phenomenon that can be confused with true classical conditioning. A critical test of conditioning is the determination of whether the conditioning process is actually necessary for the production of a response by a previously "neutral" stimulus. In many cases, the "neutral" stimulus is able to elicit the response even before conditioning and, hence, is not really a neutral stimulus. Pseudoconditioning can be avoided by carefully evaluating all prospective stimuli before conditioning begins.

Operant or Instrumental Conditioning

Operant or instrumental conditioning involves conditioning responses to stimuli with the use of **reward** or **reinforcement.** When the organism exhibits a specific behavioral pattern that the experimenter would like to see repeated, the animal is rewarded. The reinforcement or reward increases the likelihood that the behavior will appear; it has been "reinforced." Although this instrumental conditioning was originally applied to conditioning responses under the voluntary control of the organism, it has been successfully applied more recently to the conditioning of visceral responses, such as changes in heartbeat.

Experiments of B. F. Skinner

B. F. Skinner first demonstrated the principles of operant conditioning and reinforcement. In the original operant conditioning experiments he used the well-known "Skinner box," which consists of a cage with a lever or key and a food dispenser. A food pellet was delivered whenever the animal pressed the lever. Thus, depression of the lever was the **operant response** under study. In later experiments, Skinner varied the type of reinforcement. Reinforcement fell into two categories: positive reinforcement and negative reinforcement.

Positive reinforcement

Positive reinforcement or reward includes providing food, light, or electrical stimulation of the animal's brain "pleasure centers." Following positive reinforcement, the animal was much more likely to repeat the desired behavioral response (e.g., to press the bar). In a sense, the animal has developed a positive connection between the action (response) and the reward (stimulus that followed). This type of conditioning is likely to be involved in normal habit formation.

Negative reinforcement

Negative reinforcement also involves stimulating the brain's pleasure centers. However, in contrast to positive reinforcement, negative reinforcement links the lack of certain behavior with a reward (e.g., a bird may learn that it will receive a food pellet if it does *not* peck on a yellow circle in its cage).

In this case, the animal has developed a negative connection between action (response) and reward (stimulus that followed). Thus, the animal has developed a *positive* connection between the lack of the action and the reward, and the animal is less likely to repeat the behavioral response.

Punishment

Punishment involves conditioning an organism so that it will stop exhibiting a given behavior pattern. Punishment may involve painfully shocking the organism each time the chosen behavior appears. After punishment, the organism is less likely to repeat the behavioral response. The animal develops a negative connection between the stimulus and the response.

Habit family hierarchy

A stimulus is usually associated with several possible responses, each response having a different probability of occurrence. These stimulus–behavioral associations are believed to be ordered in a **habit family hierarchy.** For example, a chicken may respond to a light in many ways, but if one particular response is rewarded, the rewarded response will occur with a higher probability in the future. Reward strengthens a specific behavioral response and raises its order in the hierarchy. Punishment weakens a specific behavioral response and lowers its order in the hierarchy.

Modifications of Conditioned Behavior

Extinction

Extinction is the gradual **elimination** of conditioned responses in the absence of reinforcement (i.e., the "unlearning" of the response pattern). In **instrumental** and **operant conditioning,** the response is diminished and finally eliminated in the absence of reinforcement. The response is not completely unlearned but rather is inhibited in the absence of reinforcement. It will rapidly reappear if the reinforcement is returned. In **classical conditioning,** extinction occurs when the unconditioned stimulus is removed or was never sufficiently paired with the conditioned stimulus. The conditioned stimulus must be paired with the unconditioned stimulus, at least part of the time, for the maintenance of the conditioned response. After sufficient time elapses following extinction, the conditioned response may again be elicited by the conditioned stimulus. The recovery of the conditioned response after extinction is called **spontaneous recovery.**

Generalization and discrimination

Stimulus generalization is the ability of a conditioned organism to respond to stimuli that are similar, but not identical, to the original conditioned stimulus. The less similar the stimulus is to the original conditioned stimulus, the less the response will be. For example, an organism may be conditioned to respond to a stimulus of a 1,000 Hz tone, but it may respond to stimuli somewhat higher or lower in pitch as well. **Stimulus discrimination** involves the ability of the learning organism to respond differentially to slightly different stimuli. For example, if rewards are given during only a very narrow range of sound frequencies (such as a tone of 990 to 1,010 Hz) but not to stimuli outside this range, the organism will learn not to respond to stimuli that are different in tone. A **stimulus generalization gradient** is established after the organism has been conditioned, whereby stimuli further and further away from the original conditioned stimulus elicit responses with decreasing magnitude.

LIMITS OF BEHAVIORIAL CHANGE

Imprinting

Imprinting is a process in which environmental patterns or objects presented to a developing organism during a brief **critical period** in early life become accepted permanently as an element of its behavioral environment (i.e., "stamped in" and included in an animal's behavioral response). A duckling passes through a critical period in which it learns that the first large moving object it sees is its mother. In the natural environment, the first large moving object it sees is typically its mother. However, other objects can be substituted during this period, and the duckling will follow anything that is substituted for its mother. This phenomenon was first identified by the ethologist Konrad Lorenz, who swam in a pond amongst newly hatched ducklings separated from their mother and found that they eventually followed him as if he was their mother.

Critical Period

Critical periods are specific time periods during an animal's early development when it is physiologically able to develop specific behavioral patterns. If the proper environmental pattern is not present during the critical period, the behavioral pattern will not develop properly. Some animals have a **visual critical period.** If light is not present during this period, visual effectors will not develop properly.

INTRASPECIFIC INTERACTIONS

Intraspecific interactions occur as a means of communication between members of a species.

Behavioral Displays

A display may be defined as an **innate behavior** that has evolved as a signal for **communication** between members of the same species. According to this definition, a song, call, or intentional change in an animal's physical characteristics is considered a display. Categories of displays include the following:

- **Reproductive displays** are specific behaviors found in all animals, including humans. Many animals have evolved a variety of complex actions that function as signals in preparation for mating.
- **Agonistic displays** are such things as a dog's display of appeasement when it wags its tail or the dog's antagonistic behavior when it directs its face straight and raises its body.
- Other displays include various **dancing** procedures exhibited by **honeybees,** especially the scout honeybee, to convey information concerning the quality and location of food sources. Displays utilizing auditory, visual, chemical, and tactile elements are often used as a means of communication.

Pecking Order

The relationships among members of the same species living as a contained social group frequently become stable for a period of time. When food, mates, or territory are disputed, a **dominant** member of the species will prevail over a **subordinate** one. The social hierarchy is frequently referred to as the **pecking order.** It minimizes violent intraspecific aggressions by defining stable relationships among members of the group.

Territoriality

Members of most land-dwelling species defend a limited area or **territory** from intrusion by other members of the species. These territories are typically occupied by a male or a male–female pair and are frequently used for mating, nesting, and feeding. Territoriality serves the adaptive functions of distributing members of the species, so the environmental resources are not depleted in a small region, and reducing intraspecific competition. Although there is frequently a minimum size for any species' territory, the territory size varies with the population size and density. The larger the population, the smaller the territories are likely to be.

Response to Chemicals

The **olfactory sense** is immensely important as a means of communication in many animals. Many animals secrete substances called **pheromones,** which influence the behavior of other members of the same species. Pheromones can be classified as one of two types:

- Releaser pheromones trigger a reversible behavioral change in the recipient. For example, female silkworms secrete a very powerful attracting pheromone so powerful that a male responds to one ten-millionth of a gram from a distance of two miles or more. **Sex-attractant** pheromones are secreted by many animals, including cockroaches, queen honeybees, and gypsy moths. In addition to serving as sex attractants, releaser pheromones may also be secreted as **alarm** or **toxic defensive** substances.
- Primer pheromones produce long-term behavioral and physiological alterations in receiving animals. For example, pheromones from male mice may affect the estrous cycles of females. Pheromones have also been shown to limit sexual reproduction in areas of high animal density. Primer pheromones are important in social insects such as ants, bees, and termites, where they regulate role determination and reproductive capacities.

REVIEW PROBLEMS

1. Explain the difference between a complex reflex and a fixed-action pattern.
2. How does pseudoconditioning differ from classical conditioning?
3. What is negative reinforcement?
4. Describe the critical period.
5. What is the difference between releaser pheromones and primer pheromones?

SOLUTIONS TO REVIEW PROBLEMS

1. A complex reflex involves neural integration at a high level, such as the brainstem or the cerebrum. It involves the neurons within the reticular activation system and as such has a more complex reflex arc than a simple reflex. Fixed-action patterns are coordinated behavioral responses to patterns of stimulation. They are innate, as with reflexes, and the triggers that stimulate a fixed-action pattern can be modified.

2. The determining factor is whether the conditioning process is necessary to get a response by a stimulus that previously did not evoke such a response. That is, often the stimulus being tested could elicit the response even without conditioning and therefore is not a "neutral stimulus." In pseudoconditioning, the stimulus that the animal has been conditioned to respond to can evoke the conditioned response without conditioning, therefore differentiating it from classical conditioning.

3. In contrast to positive reinforcement, where a reward is given following a desired behavior, in negative reinforcement the reward is given following a lack of a certain behavior. In both cases a reward is given, but in negative reinforcement it is rewarding a behavior the animal did not do rather than one it did do.

4. The critical period is a time in an animal's early development when it can develop specific behavior patterns. If the animal does not properly interact with the environment during this time, the behavioral pattern will not develop or will not develop properly.

5. Releaser pheromones trigger a reversible change in the recipient, whereas primer pheromones produce long-term behavioral and physiological changes in the recipient.

CHAPTER TWENTY

Ecology

Ecology is the study of the interactions between organisms and their environment. The **environment** encompasses all that is external to the organism and is necessary for its existence. An organism's environment contains two components: the physical or nonliving (**abiotic**) environment, and the living (**biotic**) environment. The abiotic environment includes climate, temperature, availability of light and water, and the local topology. The biotic environment includes all living things that directly or indirectly influence the life of the organism, including the relationships that exist between organisms.

LEVELS OF BIOLOGICAL ORGANIZATION

Organism

The organism is the individual unit of an ecological system, but the organism itself is composed of smaller units. The organism contains many organ systems, which are made up of **organs.** Organs are formed from **tissues,** tissues from **cells,** cells from many different **molecules,** molecules from **atoms,** and atoms from subatomic particles.

Population

A **species** is any group of similar organisms that are capable of producing fertile offspring. A **population** is a group of organisms of the same species living together in the same location. Examples of populations include dandelions on a lawn, flies in a barn, minnows of a certain species in a pond, and lions in a grassland. Environmental factors, such as nutrients, water, and sunlight limitations, aid in maintaining populations at relatively constant levels.

Communities

A community consists of populations of different plants and animal species interacting with each other in a given environment. The term **biotic community** is used to include only the population and not their physical environment. An **ecosystem** includes the community and the environment. Generally, a community contains populations from all five kingdoms (monera, protists, plants, fungi, and animals), all depending upon each other for survival. The following are examples of communities:

- A lawn contains dandelions, grasses, mushrooms, earthworms, nematodes, bacteria, etc.
- A pond contains dragonflies, algae, minnows, insect larva, etc.

- A forest contains moss, pine, bacteria, lichens, ferns, deer, chipmunks, spiders, foxes, etc.
- A sea contains fish, whales, plankton, etc.

Ecosystem

An ecosystem or ecological community encompasses the interaction between living biotic communities and the nonliving environment. In studying the ecosystem, the biologist emphasizes the effects of the biotic community on the environment and the environment on the community. The examples listed previously for communities are also examples of ecosystems.

Biosphere

The biosphere includes all portions of the planet that support life: the **atmosphere,** the **lithosphere** (rock and soil surface), and the **hydrosphere** (the oceans). It is a relatively thin zone extending a few feet beneath the Earth's surface several miles into the deepest sea, and several miles into the atmosphere.

THE ENVIRONMENT

Physical Environment

Water

Water is the major component of the internal environment of all living things. Water may be readily available, or the organism may possess adaptations for storage and conservation of water.

Temperature

Temperature must be maintained at an optimal level. Protoplasm is destroyed at temperatures below 0°C and at high temperatures. Organisms have adaptations necessary for protection against these extremes. The temperature of a geographic location depends upon its latitude and altitude. In fact, the same changes in habitat that occur as one approaches colder polar regions (changes in latitude) occur as one ascends toward the colder regions of a mountain top (changes in altitude).

Sunlight

Sunlight is the ultimate source of energy for all organisms. Green plants must compete for sunlight in forests. They have adapted to capture as much sunlight as possible by growing broad leaves, branching, growing to greater height, or producing vine growths. The **photic zone,** the top layer of water through which light can penetrate, is where all aquatic photosynthetic activity takes place. In the **aphotic zone,** only animal life and other heterotrophic life exist.

Oxygen supply

This poses no problem for **terrestrial** life since the air contains approximately 20 percent oxygen. Aquatic plants and animals utilize the small amount of oxygen dissolved in water. Pollution can significantly lower oxygen content in water and threaten aquatic life.

Substratum (soil or rock)

The substratum determines the nature of plant and animal life in the soil. Soil is affected by a number of factors:

- Soil **acidity,** or **pH,** may determine what types of plants grow in what types of soil. Some plants, such as rhododendrons and pines, are more suited for growth in acid soil. Acid rain may make soil pH too low for most plant growth.
- The **texture** of soil and its clay content determine the water-holding capacity of the soil. Willows require moist soil. Most plans grow well in **loams,** which contain high percentages of each type of soil.
- **Minerals,** including **nitrates** and **phosphates,** affect the type of vegetation that can be supported. Beach sand has been leached of all minerals and is generally unable to support plant life.
- **Humus** quantity is determined by the amount of decaying plant and animal life in the soil.

Biotic Factors in the Environment

Organisms belonging to the same or different species influence each other's development. Living things interact with other living organisms and with their physical environment.

INTERACTIONS WITHIN THE ECOSYSTEM

Complex interactions exist among the constituents of an ecosystem. These interactions involve a cyclic flow of energy and materials.

The Niche

The **niche** defines the functional role of an organism in its ecosystem. The niche is distinct from the **habitat**—the latter is the physical place where an organism lies. The characteristics of the habitat aid in defining the niche, but additional factors must also be considered. The niche describes what the organism eats, where and how it obtains its food, what climactic factors it can tolerate and which are optimal, the nature of its parasites and predators, where and how it reproduces, etc. The concept of niche embodies every aspect of an organism's existence.

It is implicit in the definition of niche that no two species can ever occupy the same niche in the same location. Organisms occupying the same niche compete for the same limited resources: food, water, light, oxygen, space, minerals, and reproductive sites. There may be many organisms in this niche, but they are all of the same species and thus have the same requirements. The niche is so specific that a species can be identified by the niche it occupies.

Species occupying similar niches utilize at least one resource in common. Therefore, they will compete for that resource. This competition can have a number of outcomes:

- One species may be competitively superior to another and drive the second to **extinction.**
- One species may be competitively superior in some regions, and the other may be superior in other regions under different environmental conditions. This would result in the elimination of one species in some places and the other in other places.
- The two species may rapidly evolve in **divergent** directions under the strong selection pressure resulting from intense competition. Thus, the two species would rapidly evolve greater differences in their niches.

Nutritional Interactions within the Ecosystem

Autotrophs

Autotrophs are organisms that manufacture their own food. Green plants utilize the energy of the sun to manufacture food. Chemosynthetic bacteria obtain energy from the oxidation of inorganic sulfur, iron, and nitrogen compounds.

Heterotrophs

Heterotrophs cannot synthesize their own food and must depend upon autotrophs or other heterotrophs in the ecosystem to obtain food and energy.

Herbivores

These animals consume only plants or plant foods. The toughness of cellulose-containing plant tissues has led to the development of structures for crushing and grinding that can extract plant fluids. Herbivores have long digestive tracts that provide greater surface area and time for digestion. However, they cannot digest much of the food they consume. **Symbiotic bacteria** capable of digesting cellulose inhabit the digestive tracts of herbivores and allow the breakdown and utilization of cellulose.

Herbivores are more adept in defense than carnivores because they are often prey. Many herbivores, such as cows and horses, have hoofs instead of toes for faster movement on the grasslands. They have incisors adapted for cutting and molars adapted for grinding their food. Insects or other invertebrates can also be herbivores.

Carnivores

Carnivores are animals that eat only other animals. In general, carnivores, such as hyenas, possess pointed teeth and fanglike canine teeth for eating flesh. They have shorter digestive tracts due to the easier digestibility of animal food.

Omnivores

Omnivores, such as humans, are animals that eat both plants and animals.

Interspecific Interactions

A community is not simply a collection of different species living within the same area. It is an integrated system of species that are dependent upon one another for survival. The major types of interspecific interactions are symbiosis, predation, saprophytism, and scavenging.

Symbiosis

Symbionts live together in an intimate, often permanent association, which may or may not be beneficial to both participants. Some symbiotic relationships are **obligatory**; that is, one or both organisms cannot survive without the other. Symbiotic relationships are classified according to the benefits the symbionts receive. The types of symbiotic relationships include commensalism, mutualism, and parasitism.

Commensalism (+/0)

One organism is benefited (+) by the association, and the other is not affected (0). The host neither discourages nor fosters the relationship. Some examples include the following:

- Remora and shark: The remora (suckerfish) attaches itself by a holdfast device on the underside of a shark. Through this association the remora obtains the food the shark discards, wide geographic dispersal, and protection from enemies. The shark is totally indifferent to the association.
- Barnacle and whale: The barnacle is a sessile crustacean that attaches to the whale and obtains wider feeding opportunities through the migrations of the whale.

Mutualism (+/+)

A symbiotic relationship from which both organisms derive some benefit (+). Some examples include the following:

- Tick bird and rhinoceros: The bird receives food in the form of ticks on the skin of the rhinoceros. The rhinoceros has its ticks removed and is warned of danger by the rapid departure of the bird.
- Fungi and algae: In a lichen, the green algae produces food for itself and the fungus by **photosynthesis**. The meshes of fungal threads support the algae and conserve rainwater. The fungus also provides carbon dioxide and nitrogenous wastes for the algae, all of which are needed for photosynthesis and protein synthesis.
- Nitrogen-fixing bacteria and legumes: Nitrogen-fixing bacteria invade the roots of legumes, and infected cells grow to form root nodules. In the nodule, the legume provides nutrients for the bacteria and the bacteria fixes nitrogen (by changing it into a soluble nitrate, a mineral essential for protein synthesis by the plant). These bacteria are a major source of usable nitrogen, which is needed by all plants and animals.
- Protozoa and termites: Termites chew and ingest wood but are unable to digest the cellulose. Protozoa in the digestive tract of the termite secrete an enzyme that digests the cellulose. Both organisms share the carbohydrates. Thus, the protozoan is guaranteed protection and a steady food supply, while the termites are able to obtain nourishment from the ingested wood.
- Intestinal bacteria and humans; Bacteria utilize some of the food material not fully digested by humans and manufacture vitamin K.

Parasitism (+/–)

A parasite benefits (+) at the expense (–) of the host. Parasitism exists when competition for food is most intense. Few autotrophs (green plants) exist as parasites (mistletoe is an exception). Parasitism instead flourishes among organisms such as bacteria, fungi, and animals. Some parasites cling to the exterior surface of the host (**ectoparasites**) using suckers or clamps. They may bore through the skin and suck out blood and nutrients. Leeches, ticks, and sea lampreys employ these techniques. Other parasites (**endoparasites**) live within the host. To gain entry, they must pass through defenses such as skin, digestive juices, antibodies, and white blood cells. Parasites possess special adaptations to overcome these defenses.

Parasitism is advantageous and efficient. The parasite lives with a minimum expenditure of energy. Parasites may even have parasites of their own. Thus, a mammal may have parasitic worms, which in turn are parasitized by bacteria, which in turn are victims of bacteriophages. It is interesting to note that successful parasites do not kill their hosts; this would lead to the death of the parasite. The more dangerous the parasite, the less the chance it will survive. Some examples are the following:

- Virus and host cell: All viruses are parasites. They contain nucleic acids surrounded by a protein and are nonfunctional outside the host. Upon entry of the viral nucleic acids into the host, the virus takes over the host cell functions and redirects them into replication of itself. The life functions of the bacterial cell slow down or cease in favor of viral replication.

- Disease bacteria and animals: Most bacteria are either chemosynthetic (energy producing) or **saprophytic** (bacteria of decay). For example, diphtheria is parasitic upon humans, anthrax is parasitic upon sheep, and tuberculosis is parasitic upon cows or humans.
- Disease fungi and animals: Most fungi are saprophytic. Ringworm is parasitic on humans.
- Worms and animals: An example is the parasitic relationship that exists between the tapeworm and humans.

Predation

Predators are free-living organisms that feed on other living organisms. This definition of predation includes both **carnivores** and **herbivores**. The effects of predators on their prey vary. The predator may severely limit the numbers or distribution of the prey, and the prey may become extinct. On the other hand, the predator may only slightly affect the prey because the predator is scarce or commonly utilizes another food source. In many cases, the predator aids in controlling the numbers of the prey but not so much as to endanger the existence of the prey population. Predator–prey relationships evolve toward a balance in which the predator is a regulatory influence on the prey but not a threat to its survival. Examples of predators include the hawk, lion, human, and Venus flytrap.

Saprophytism

Saprophytes include those protists and fungi that **decompose** (digest) dead organism matter externally and absorb the nutrients; they constitute a vital link in the cycling of material within the ecosystem. Examples of saprophytes include mold, mushrooms, bacteria of decay, and slime molds.

Scavengers

Scavengers are animals that consume dead animals. They therefore require no adaptations for hunting and killing their prey. Decomposers, such as the bacteria of decay, may be considered scavengers. Examples of scavengers include the vulture and hyena. The snapping turtle is an organism that may be considered both a scavenger and a predator.

Intraspecific Interactions

Competition is not restricted to interspecific interactions (relations between species). Individuals belonging to the same species utilize the same resources; if a particular resource is limited, then these organisms compete with one another. Members of the same species compete, but they must also **cooperate**. Intraspecific cooperation may be extensive (as with the formation of societies in animal species) or may be nearly nonexistent. Relationships between individuals within a species are influenced by both disruptive and cohesive forces. Competition is the chief disruptive force. Cohesive forces include reproduction and protection from predators and destructive weather.

Interactions between Organisms and Their Environment

Osmoregulation

Animals have developed many adaptations for maintaining their internal osmolarity and conserving water.

- Saltwater fish live in a hyperosmotic environment, which causes them to lose water and take in salt. They are constantly in danger of dehydration and must compensate by constant drinking and active secretion of salt across their gills.

- Freshwater fish live in a hypoosmotic environment, which causes intake of excess water and excessive salt loss. These fish correct this condition by seldom drinking, absorbing salt through the gills, and excreting dilute urine.
- Insects excrete solid uric acid crystals to conserve water.
- Desert animals possess adaptations for avoiding desiccation (drying up). The camel can tolerate a wide range of body temperatures and possesses fat layers in regions that are exposed to solar radiation. The horned toad has thick, scaly skin, which prevents water loss. Other desert animals burrow in the sand during the day and search for food at night, thereby avoiding the intense heat that causes water loss.
- Plants possess adaptations for conservation of water. Nondesert plants possess waxy **cuticles** on leaf surfaces and stomata on the lower leaf surfaces only. They shed leaves in winter to avoid water loss. Desert plants have extensive root systems, fleshy stems to store water, spiny leaves to limit water loss, extra thick cuticles, and few stomata.

Thermoregulation

Cellular respiration only transfers a fraction of the energy derived from the oxidation of carbohydrates into the high-energy bonds of ATP. Roughly 60 percent of the total energy is given off as heat. The vast majority of animals and plants are cold-blooded or **poikilothermic**, and most of their heat energy escapes to the environment. The body temperature of poikilotherms is very close to that of their surroundings. Since an organism's metabolism is closely tied to its body temperature, the activity of poikilothermic animals is radically affected by environmental temperature changes. As the temperature rises, these organisms become more active. As temperatures fall, they become sluggish and lethargic.

Some animals, notably mammals and birds, are warm-blooded or **homeothermic**. They have evolved physical mechanisms that allow them to make use of the heat produced as a consequence of respiration. Physical adaptations like fat, hair, and feathers retard heat loss. Homeotherms maintain constant body temperatures that are higher than the temperature of environment. They are less dependent upon environmental temperature than poikilothermic animals and are able to inhabit a comparatively wider range of environments.

RELATIONSHIPS WITHIN THE ECOSYSTEM

Energy Flow

All living things require energy to carry on their life functions. The complex pathways involved in the transfer of energy through the living components of the ecosystem (biotic community) may be mapped in the form of a **food chain** or **food web**.

Food chain

A food chain is a single chain showing the transfer of energy. For example, energy from the sun enters living systems through the **photosynthetic** production of glucose by green plants. Within the food chain, energy is transferred from the original sources in green plants through a series of organisms, with repeated stages of consumption and finally decomposition. Thus, these are producers, primary consumers, secondary consumers, and decomposers.

Producers

The **autotrophic** green plants and **chemosynthetic** bacteria are the producers. They utilize the energy of the sun and simple raw materials (carbon dioxide, water, minerals), respectively, to manufacture carbohydrates, proteins, and lipids. The radiant energy of the sun is captured and stored in the C–H bond. Producers always form the initial step in any food chain. The wheat plant is a typical producer.

Primary consumers

Primary consumers are animals that consume green plants (herbivores). Examples include the cow, grasshopper, and elephant.

Secondary consumers

Secondary consumers are animals that consume the primary consumers (carnivores). These include frogs, tigers, and dragonflies.

Tertiary consumers

These are animals that feed on secondary consumers (also called carnivores).

Decomposers

Decomposers include saprophytic organisms and organisms of decay, which include bacteria and fungi. The producers and consumers concentrate and organize materials of the environment into complex living substances. Living things give off wastes during their lifetimes and eventually die. Bacteria and fungi decompose the organic wastes and dead tissues to simpler compounds, such as nitrates and phosphates, which are returned to the environment to be used again by living organisms. These processes are demonstrated in **food webs** and **material cycles** (nitrogen, carbon, and water).

Food web

The food web is not simply a linear chain but an intricate collection of interconnected food chains. Almost every species is consumed by one or more other species, some of which are on different food chain levels. The result is a series of branches and cross-branches among all the food chains of a community to form a web. The greater the number of pathways in a community food web, the more stable the community. For example, owls eat rabbits. If rabbits died off because of disease, there would be more vegetation available to mice. Mice would provide substitute food for owls. Meanwhile, the decimated rabbit population would have a better chance of recovering while owls concentrated their predation on mice.

Food pyramids

Without a constant input of energy from the sun, an ecosystem would soon run down. As food is transferred from one level of the food chain to the next, a transfer of energy occurs. According to the second law of thermodynamics, energy transfer involves a loss of energy. In addition to the energy lost in the transfer, each level of the food chain utilizes some of the energy it obtains from food for its own metabolism (i.e., to support life functions) and loses some additional energy in the form of heat. A pyramid of energy is thus a fundamental property of all ecosystems at all levels.

Pyramid of Energy

Each member of a food chain utilizes some of the energy it obtains from its food for its own metabolism (life functions) and loses some additional energy in the form of heat. Since this means a loss of energy at each feeding level, the producer organism at the base of the pyramid contains the greatest amount of energy. Less energy is available for the primary consumer and still less for secondary and tertiary consumers. The smallest amount of available energy is thus at the top of the pyramid.

Pyramid of Mass

Since organisms at the upper levels of the food chain derive their food energy from organisms at lower levels, and since energy is lost from one level to the next, each level can support a successively smaller biomass. Three hundred pounds of foliage (producer) may support 125 pounds of insects. This may support 50 pounds of insectivorous hens, which in turn may be just the right amount to sustain 25 pounds of hawks.

Pyramid of Numbers

Consumer organisms that are highest in the food chain are usually larger and heavier than those further down. Since the lower organism has a greater total mass, there must be a greater number of lower-level organisms. (A large bass eats tiny minnows but eats many of them.) With the greatest number of organisms at the base (producer level) and the smallest number at the top (final consumer level), we have a pyramid of numbers.

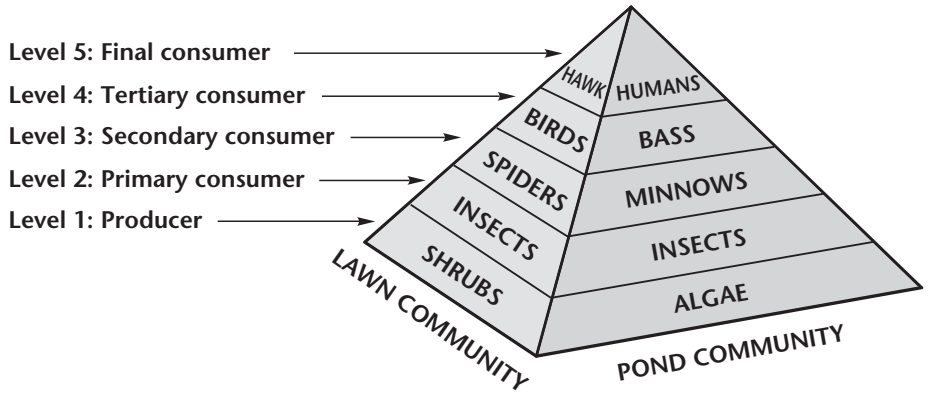


Figure 20.1

Since other factors, such as the generation time of the size of the organisms must be considered, the pyramids of numbers and biomass do not apply to all levels at all times (unlike the pyramid of energy). In general, as the pyramid is ascended, there is less energy content, less mass, and a lesser number of organisms.

Material Cycles

Material is cycled and recycled between organisms and their environments, passing from inorganic forms to organic forms and then back to the inorganic forms. Many of these cycles are accomplished largely through the action of scavengers (such as hyenas and vultures) and decomposers (saprophytes such as bacteria and fungi).

Nitrogen cycle

Nitrogen is an essential component of amino acids and nucleic acids, which are the building blocks of all living things. Since there is a finite amount of nitrogen on the Earth, it is important that it be recovered and reused.

- Elemental nitrogen is chemically inert and cannot be used by most organisms. Lightning and nitrogen-fixing bacteria in the roots of legumes change the nitrogen to usable, soluble nitrates.
- The nitrates are absorbed by plants and are used to synthesize nucleic acids and plant proteins.
- Animals eat the plants and synthesize specific animal proteins from the plant proteins.
- Nitrogen locked up in waste and dead tissues is released by the action of bacteria of decay, which convert the proteins into ammonia (NH_3).
- Two fates await the ammonia. Some is nitrified to nitrites by chemosynthetic bacteria and then to usable nitrates by nitrifying bacteria. The rest is denitrified. This means the ammonia is broken down to release free nitrogen, which returns to the beginning of the cycle. Note the four kinds of bacteria that are involved in this cycle: **decay, nitrifying, denitrifying,** and **nitrogen fixing**. The bacteria have no use for the excretory ammonia, nitrites, nitrates, and nitrogen they produce. These materials are essential, however, for the existence of other living organisms.

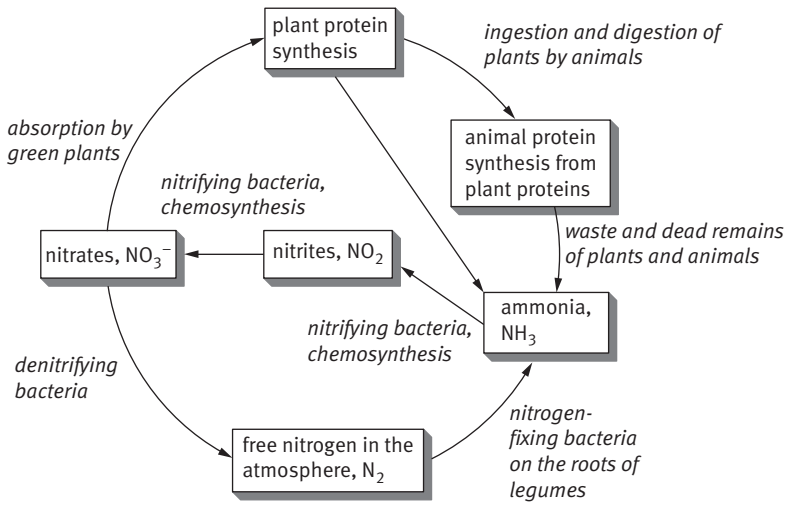


Figure 20.2

Carbon cycle

- **Gaseous CO_2** enters the living world when plants use it to produce glucose via photosynthesis. The carbon atoms from CO_2 are bonded to hydrogen and other carbon atoms. Plants use the glucose to make starch, proteins, and fats.
- Animals eat plants and use the digested nutrients to form carbohydrates, fats, and proteins characteristic of the species. A part of these organic compounds is used as fuel in respiration in both plants and animals.
- The metabolically produced CO_2 is released into the air. The rest of the organic carbon remains locked within an organism until its death (except for wastes given off), at which time decay processes by bacteria return CO_2 to the air.

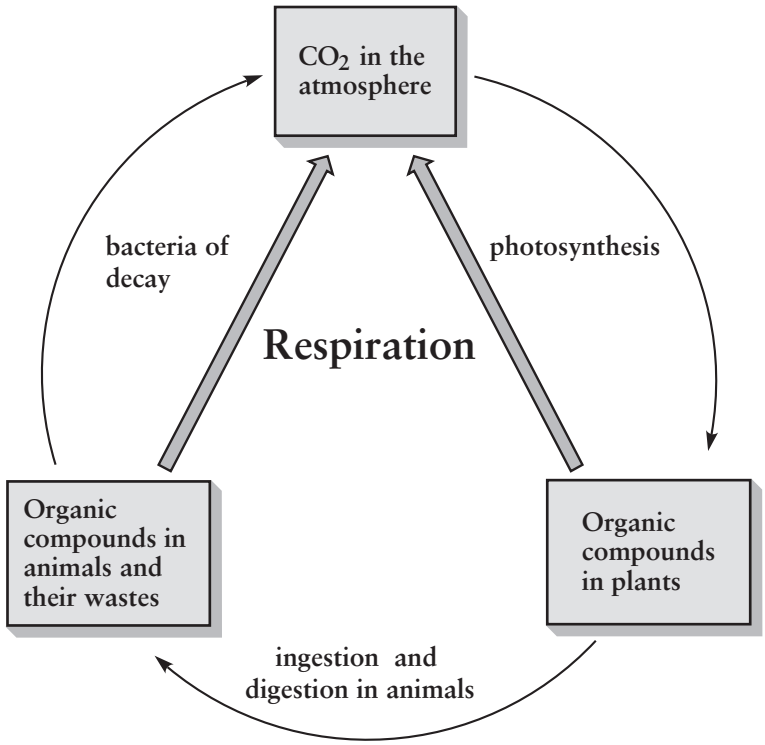


Figure 20.3

Other cycles

Other cycles recycle water, oxygen, and phosphorus. These substances are used by almost all living things and must be returned by the biotic community to the environment for reuse.

STABILITY WITHIN THE ECOSYSTEM

Conditions for Stability in an Ecosystem

An ecosystem is self-sustaining and, therefore, will be stable if three conditions are met. First, it needs a relatively stable physical environment (abiotic factors) and a relatively stable biotic community. Second, a stable ecosystem requires a constant energy source and a living system incorporating this energy into organic compounds. Lastly, the cycling of materials between the living system and its environment is critical for a stable ecosystem.

Ecological Succession

Ecological succession is the orderly process by which one biotic community replaces or succeeds another until a climax community is established. Each community stage, or **sere**, in an ecological succession is identified by a **dominant** species—the one that exerts control over the other species that are present. Thus, in a grassland community, grass is the dominant species.

Changes occur because each community that establishes itself changes the environment, making it more unfavorable for itself and more favorable for the community that is to succeed it. Successive communities are composed of populations that are able to exist under the new conditions. Finally, a stage occurs in which a population alters the environment in such a way that the original conditions giving rise to that population are recreated. Replacement stops and the climax community is created, which is the final and most stable stage of ecological succession. This climax community is permanent in the ecosystem unless the abiotic factors are drastically altered by climatic or geological upheavals. If this happens, a new series of successions is initiated.

- Example 1: Consider a barren rocky area in the northeastern United States, barren perhaps as a result of a severe forest fire. Lichen may be the first or pioneer organism to resettle this area. Recall that lichen is an association between an algae and a fungus. Acids produced by lichen attack the rocks and help to form bits of soil. Since lichens thrive only on a solid surface, conditions are now worse for the lichen but better for mosses. Airborne spores of mosses land on the soil and germinate. The result is a new sere with the moss as the dominant species in the community. As the remains of the moss build up the soil still more, annual grasses and then perennial grasses with deeper roots become the dominant species. As time goes on, we find shrubs and trees. The first trees are the sun-loving gray birch and poplar. As more and more trees compete for the sun, these trees are replaced by white pine and finally maples and beeches, which grow in deep shade—the climax community.

  The growth of maples and beeches produces the same conditions that originally favored their appearance. And so this community remains for thousands of years. In the final maple-beech community, you would find foxes, deer, chipmunks, and plant-eating insects. These are animals that would not have been found in the original barren rock terrain. However, one forest fire can kill the entire community. Ecological succession then starts all over again, commencing with lichen and bare rock.

  It is important to note again that the dominant species of the climax community depends on such physical factors as temperature, nature of the soil, rainfall, etc. Thus, the climax community in New York at higher elevations is hemlock-beech-maple, while at lower elevations, the climax plants are more often oak-hickory. In cold Maine, the climax community is dominated by pine; in the wet areas of Wisconsin, by cypress; in sandy New Jersey, by pine; on a cold windy mountain top, by scrub oak.
- Example 2: Ecological succession in a pond. A quick summary:

  Step 1: The pond contains plants such as algae and pondweed and animals such as protozoa, water insects, and small fish.

  Step 2: Shallow pools formed as the pond fills in bring reeds, cattails, and water lilies.

  Step 3: Moist land brings grass, herbs, shrubs, willow trees, frogs, and snakes.

  Step 4: Woodland brings the climax tree, perhaps pine or oak.

The Climax Community

A climax community is the stable, living (biotic) part of an ecosystem, in which populations exist in balance with each other and with the environment. The type of climax community depends upon all the abiotic factors: rainfall, soil conditions, temperature, shade, etc. A climax community persists until a major climactic or geological change disturbs the abiotic factors or a major biotic change (disease, mutation, etc.) affects the populations. Once the equilibrium is upset, new climax conditions are produced and new communities will be established in the ecosystem.

WORLD BIOMES (MAJOR COMMUNITIES)

Terrestrial Biomes

The evolutionary origin of plants and animals can be traced to the seas. To survive on land, these organisms had to develop adaptations to face an environment with: (1) a relative lack of water; (2) a relative lack of food and supporting medium; (3) varying temperature (as compared to the oceans, which have a relatively constant temperature); and (4) varying composition of the soil as compared to the definite salt composition in the oceans. The conditions in different terrestrial and climate regions selected for plants and animals possessing suitable adaptations. Each **geographic region** is inhabited by a distinct community, called a **biome**, existing in the major climate areas.

Land biomes are characterized and named according to the **climax vegetation** of the region. The climax vegetation is the vegetation that becomes dominant and stable after years of evolutionary development. Since plants are important as food producers, they determine the nature of the inhabiting animal population, and thus the climax vegetation determines the **climax animal population**. Some types of terrestrial biomes are as follows:

Desert biome

Deserts receive fewer than ten inches of rain each year; the rain is concentrated within a few heavy cloudbursts. The main growing season in the desert is restricted to those days after rainfalls. Generally, small plants and animals inhabit the desert. Most desert plants conserve water actively (cactus, sagebrush, and mesquite). Desert animals live in burrows (insects and lizards). Few birds and mammals are found in deserts except those that have developed adaptations for maintaining constant body temperatures. Examples of deserts include the Sahara in Africa and the Gobi in Asia.

Grassland biome

Grasslands are characterized by low rainfall (usually 10–30 inches per year), although this is considerably more than the desert biomes receive. Grasslands provide no shelter for **herbivorous mammals** (bison, antelope, cattle, and zebra) from carnivorous predators. Land animals that do inhabit the grasslands frequently have developed long legs, and many are hoofed. Examples of grasslands include the prairies east of the Rockies, the steppes of the Ukraine, and the pampas of Argentina.

Rainforest biome

Rainforests, sometimes known as jungles, are characterized by torrential rains. Tropical rainforests have high temperatures, whereas temperature rainforests are more moderate. They both include climax communities with dense growth of vegetation that does not shed its leaves. Vegetation, such as vines and **epiphytes** (plants growing on other plants), and animals, such as monkeys, lizards, snakes, and birds, inhabit rainforests. Trees grow closely together, and sunlight hardly reaches the forest floor. The floor is inhabited by **saprophytes,** which live off of dead organic matter. Tropical rainforests are found in Central Africa, Central America, the Amazon basin, and Southeast Asia. Temperate rainforests are much more rare but can be found in western North and South America as well as on islands off of eastern Asian and Australian coasts.

Temperate deciduous forest biome

Temperate deciduous forests have cold winters, warm summers, and moderate rainfall. Inhabitants include beech, maple, oaks, and willow trees, which shed their leaves during the cold winter months. Animals in temperate deciduous forests include deer, foxes, woodchucks, squirrels, and birds. These biomes are found in the northeastern and central-eastern United States and in Central Europe.

Temperate coniferous forest biome

These forests are cold, dry, and inhabited mainly by trees that do not lose their leaves, such as fir, pine, and spruce trees. Much of the vegetation has evolved adaptations for water conservation, such as needle-shaped leaves. These forests are found in the extreme northern part of the United States and in southern Canada and contain the largest biomass of any terrestrial biome, in large part due to massive trees, such as the redwood. Animal inhabitants include beavers, bears, sheep, squirrels, and birds.

Taiga biome

Taigas receive less rainfall than temperate forests. They have long, cold winters and, like coniferous forests, are inhabited by trees that do not lose their leaves, especially the spruce. The forest floors in the taiga are characterized by thin soil covered in moss and lichens. The chief animal inhabitants are moose and deer; however, bears, wolves, rodents, and birds are also found there. Taigas exist in the extreme northern parts of Canada and Russia.

Tundra biome

The tundra is a treeless, frozen plain found between the taiga and the northern ice sheets. The ground is covered in snow and ice for much of the year and can be described as **permafrost.** There is only a very short summer and thus growing season, during when the ground becomes wet and marshy. Lichens, mosses, polar bears, musk oxen, and arctic hares are found in the tundra.

Polar region

Polar regions surround the **polar ice caps** and are frozen areas with no vegetation and few terrestrial animals. Animals that do inhabit polar regions generally live near the oceans and include penguins and polar bears. Although ice is present, there is little precipitation (falling rain or snow), so most polar regions can also be considered deserts.

Terrestrial Biomes and Altitude

The sequence of biomes between the equator and the poles is comparable to the sequence of regions on mountains. The nature of those regions is determined by the same decisive factors—temperature and rainfall. For example, the base of a mountain would resemble the biome of a temperate deciduous area. As one ascends the mountain, one would pass a coniferous-like biome, then taiga-like, tundra-like, and polar-like biomes.

Aquatic Biomes

More than 70 percent of the Earth's surface is covered by water. Most of the Earth's plant and animal life is found in water. As much as 90 percent of the Earth's food and oxygen production (**photosynthesis**) takes place in the water. Aquatic biomes are classified according to criteria quite different from the criteria used to classify terrestrial biomes. Plants have little controlling influence on communities of aquatic biomes compared to their role in terrestrial biomes. Aquatic areas are the most stable ecosystems: the conditions affecting temperature, the amount of available oxygen and carbon dioxide, and the amount of suspended or dissolved materials are stable over very large areas

with little tendency to change. Therefore, aquatic food webs and aquatic communities are balanced. There are two types of major aquatic biomes: **marine** and **freshwater**.

Marine biomes

The oceans connect to form one continuous body of water, which controls the Earth's temperature by absorbing solar heat. Water has the distinctive property of being able to absorb or utilize large amounts of heat without undergoing a great temperature change. Marine biomes contain a relatively constant amount of nutrient materials and dissolved salts.

Although ocean conditions are more uniform than those on land, distinct zones in the marine biomes exist.

- **Intertidal zone:** The region exposed at low tides that undergoes variations in temperature and periods of dryness. Populations in the intertidal zones include algae, sponges, clams, snails, sea urchins, starfish, and crabs.
- **Neritic zone:** The region on the continental shelf that contains ocean with depths up to 600 feet and extends several hundred miles from the shores. Populations in littoral zone regions include algae, crabs, crustaceans, and many different species of fish.
- **Pelagic zone:** Typical of the open seas, this can be divided into photic and aphotic zones (see Figure 20.4).
- **Photic zone:** The sunlit layer of the open sea extending to a depth of 250–600 feet. It contains **plankton**, passively drifting masses of microscopic photosynthetic and heterotrophic organisms, and **nekton**, active swimmers such as fish, sharks, or whales that feed on plankton and smaller fish. The chief autotroph is the **diatom**, an alga.
- **Aphotic zone:** The region beneath the photic zone that receives no sunlight. There is no photosynthesis in the aphotic zone, and only heterotrophs exist here. Deep-sea organisms in this zone have adaptations enabling them to survive in very cold water with high pressures and in complete darkness. The zone contains nekton and **benthos** (the crawling and sessile organisms). Some are scavengers, and some are predators. The habitat of the aphotic zone is fiercely competitive.

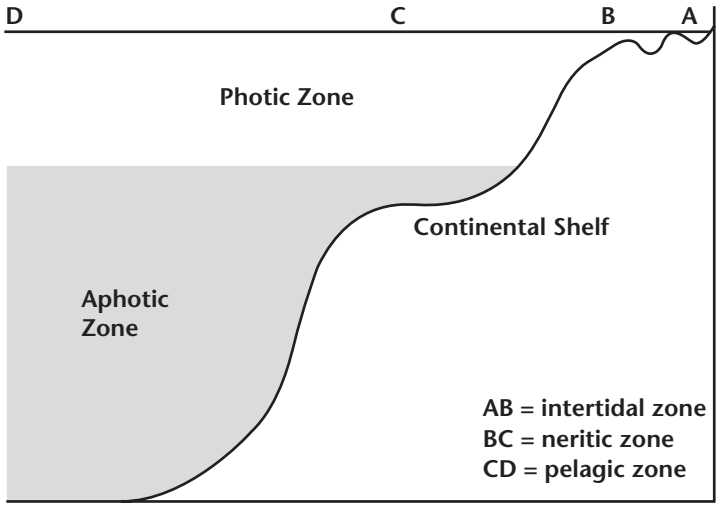


Figure 20.4

Freshwater biomes

Rivers, lakes, ponds, and marshes—the links between the oceans and land—contain freshwater. Rivers are the routes by which ancient marine organisms reached land and evolved terrestrial adaptations. Many forms failed to adapt to land and developed adaptations for freshwater. Others developed special adaptations suitable for both land and freshwater. As in marine biomes, factors affecting life in freshwater include temperature, transparency (suspended mud particles decrease illumination), depth of water, available carbon dioxide and oxygen, and most important, salt concentration. Freshwater biomes are different from saltwater biomes in three basic ways:

- Freshwater is **hypotonic**, creating a diffusion gradient that results in the passage of water into the cell. Freshwater organisms have homeostatic mechanisms to maintain water balance by the regular removal of excess water. These include the contractile vacuoles of protozoa and excretory systems of fish. Plant cells have rigid cell walls and thus build up cell pressure (cell **turgor**) as water flows in. This pressure counteracts the gradient pressure, stops the influx of water, and establishes water balance.
- In rivers and streams, strong, swift currents exist, and thus selection favored the survival of fish that developed strong muscles and plants with root-like **holdfasts**.
- Freshwater biomes, except very large lakes, are affected by variations in climate and water. The temperature of freshwater bodies may vary considerably; they may freeze or dry up; and mud from their floors may be stirred up by storms.

REVIEW PROBLEMS

1. Which of the following does not affect soil?

A. Texture
B. Nitrates
C. Phosphates
D. Loams
E. Acidity

2. What is NOT true about niches?

A. There may be many organisms of different species within the same niche.
B. What the organism eats helps define the niche.
C. Organisms in the same niche compete for resources.
D. A species can be identified by the niche it occupies.
E. Niches are different from habitats.

3. Which is an example of symbiosis?

A. Predation
B. Saprophytism
C. Scavenging
D. Commensalism
E. Cooperation

4. Which is an example of a secondary consumer?

A. Autotrophs
B. Herbivores
C. Carnivores
D. Decomposers
E. Bacteria

5. Which of the following is NOT true about the nitrogen cycle?

A. Elemental nitrogen cannot be used by most organisms.
B. Nitrates cannot be absorbed by plants.
C. Bacteria of decay convert proteins into ammonia.
D. Ammonia is broken down to release free nitrogen.
E. Chemosynthetic bacteria turn ammonia intro nitrites.

6. Which is NOT a region of a marine biome?

A. Intertidal zone
B. Nekton zone
C. Pelagic zone
D. Aphotic zone
E. Neritic zone

SOLUTIONS TO REVIEW PROBLEMS

1. D Loams contain high percentages of each type of soil, and most plants grow well in this type of environment. The other characteristics of soil affect the nature of plant and animal life that are able to live within the soil.

2. A No two species can ever occupy the same niche in the same location. All the other statements about niches are true.

3. D Symbionts live together in an association that may or may not be beneficial to both participants. In commensalism, one organism benefits from the association and the other is not affected. In predation, one free-living organism feeds on other living organisms. Saprophytes decompose dead organic matter to absorb the nutrients, and scavengers consume dead animals. Cooperation is an example of intraspecific interactions within members of the same species.

4. C Carnivores are secondary consumers because they consume primary consumers, which are herbivores. Autotrophs and bacteria are producers.

5. B Nitrates are in fact absorbed by plants and are used to synthesize nucleic acids and plant proteins. For a diagram of the nitrogen cycle, see Figure 20.2.

6. B Nekton are active swimmers such as fish and whales that feed on plankton and smaller fish. They are found in the photic zone.

CHAPTER TWENTY-ONE

Taxonomy

Billions of years of evolution have led to the great diversity of living organisms we see today. Scientists have tried to categorize relationships among the vast number of different organisms. The science of classification and the nomenclature used are known as **taxonomy**. The modern classification system seeks to group organisms on the basis of **evolutionary relationships**. In this system the bat, whale, horse, and humans are placed in the same class of animals because they have all descended from a common ancestor. Since much of early evolutionary history is not known, there is some disagreement among biologists as to the best classification system to employ, particularly with regard to groups of unicellular organisms. Taxonomy takes into account anatomical and structural characteristics; modes of excretion, movement, and digestion; genetic makeup; and biochemical capabilities. Taxonomic organization proceeds from the largest, broadest group to the smallest, most specific subgroups.

TAXONOMIC CLASSIFICATIONS

Biologists originally divided all living things into two categories: plants and animal. This division ignored a number of different organisms, and since then, several new systems have been proposed as additional knowledge is gained. The modern classification system used on the exam now separates the largest divisions of life by **domain** based on the degree of differences among them. The three domains are Archaea, Bacteria, and Eukarya. Within those domains are six **kingdoms**: Archaea, Eubacteria, Protista, Fungi, Plantae, and Animalia. Viruses fall somewhere outside of this system.

The modern scheme of taxonomy includes not only the three domains and six kingdoms but also further division. Each kingdom is divided into several major **phyla** (in the animal kingdom) or **divisions** (in other kingdoms). A phylum or division is further divided into **classes**. Each class includes multiple **orders**. Orders are subdivided into **families**, and each family is made up of many **genera** (singular *genus*). The **species** is the final major subdivision. Organisms of the same species can mate with one another to produce fertile offspring.

Each level also may have additional subdivisions, especially when many branching evolutionary paths are represented at one level. For example, humans can be classified as **Domain:** Eukarya, **Kingdom**: Animalia, **Phylum**: Chordata, **Subphylum**: Vertebrata, **Class**: Mammalia, **Order**: Primates, **Family**: Hominidae, **Tribe:** Homini, **Genus**: *Homo*, **Species**: *sapiens*.

All organisms are assigned a binomial name consisting of the genus and species name of that organism. Thus, humans are *Homo sapiens,* and the common housecat is *Felis domestica*.

The following sections outline specific information about the domains and kingdoms as well as examples of specific subdivisions within them. However, on Test Day, the entire field of taxonomy will only contribute to three Biology questions, which constitutes only 7.5 percent of the subtest. Since some (or all) of those questions may pertain to the broader ideas behind taxonomy listed above, the probability of seeing a specific species or even group is very low. Therefore, efficient use of your study time means not focusing on memorizing every phylum, class, and order but rather learning the general characteristics of the kingdoms and only quickly reviewing the more specific groupings. A good way to do this is to pick a model organism from each category that exemplifies the traits of that group. In that way, remembering one species will allow you to remember characteristics about all the members of that group. The following organisms will serve as great examples to memorize, or you can choose models of your own.

MONERA (ARCHAEA AND EUBACTERIA)

Monerans are **prokaryotes** (e.g., bacteria). They lack a nucleus or any membrane-bound organelles and are single-celled organisms that reproduce asexually. Monerans may exist as single cells or as aggregates of cells that stick together after division.

The kingdom Monera was part of the former, five-kingdom system but has since been divided into two separate kingdoms based on newly discovered differences among its members: the eubacteria and the archaea. Although both new kingdoms are composed of single-celled, prokaryotic organisms, they likely split down different evolutionary paths over three billion years ago.

Eubacteria

Bacteria are generally single-celled prokaryotes with a single double-stranded circular loop of DNA that is not enclosed by a nuclear membrane. Almost all forms have **cell walls**. They play active roles in **biogeochemical cycles**, recycling various chemicals such as carbon, nitrogen, phosphorus, and sulfur. Bacteria may be classified by their **morphological** appearances: **cocci** (round), **bacilli** (rods), and **spirilla** (spiral). Some forms are **duplexes** (diplo–), **clusters** (staph–), and **chains** (strepto–). Bacteria are ubiquitous, and many possess a wide variety of complex biochemical pathways.

Cyanobacteria

Cyanobacteria are types of bacteria that live primarily in fresh water but also exist in marine environments. They possess a cell wall and **photosynthetic pigments** but have no flagella, true nuclei, chloroplasts, or mitochondria. They can withstand extreme temperatures and are believed to be directly descended from the first organisms that developed photosynthetic capabilities. Cyanobacteria are sometimes called blue-green algae, but be careful not to confuse them with other forms of algae, which are eukaryotic and members of the Protista kingdom instead.

Archaea

Archaea were formerly thought to be types of bacteria, but recent evidence shows that they are fundamentally different and in fact compose both their own domain and kingdom. Archaea are prokaryotes, like bacteria, and often have cell walls and flagella. However, they also exhibit several unique variations on the basic prokaryote plan, such as having cell membranes composed of glycerol-ether lipids, which is different from both Bacteria and Eukarya since they use glycerol-ester lipids instead. Further differences include changes to the molecules involved in basic biochemical processes, such as metabolism and translation; some of Archaea's enzymes correspond instead with Eukarya, and some are wholly unique. This may be due to the fact that Archaea inhabit a wide variety of environments, including extreme areas with high temperatures or high acidity. Scientists still have much to learn about Archaea, so having only a basic knowledge of their existence will be sufficient for Test Day.

PROTISTA

The Protist kingdom contains primitive eukaryotic organisms with membrane-bound nuclei and organelles. These organisms are either single cells or colonies of similar cells with no differentiation of specialized tissues. Each protist cell possesses the capability to carry out all of the life processes. The Protist kingdom contains all simple eukaryotes that cannot be classified as plants or animals. For example, the protists of the genus *Euglena* demonstrate the motility of animals and the photosynthetic capabilities of plants. The kingdom is divided into many phyla, which fall primarily into the categories of **protozoa** and **algae**.

Protozoa

Protozoa are single-celled organisms that are **heterotrophic** and in some ways are similar to little animals. This category of protists includes a number of different groups. The **rhizopods**, including amoebas, move with cellular extensions called pseudopods. The **ciliophors** have cilia that are used for feeding and locomotion.

Algae

Algae are primarily **photosynthetic** organisms. Blue, green, red, and brown algae all fit in this category. However, blue-green algae are not traditional algae and do *not* fit in this kingdom because they are prokaryotic rather than eukaryotic (see the Cyanobacteria section above). Examples of algae include the tiny **phytoplankton**, which are important sources of food for many marine organisms, as well as the **kelp**, which are large seaweeds of the brown algae family that can grow to be longer than 150 feet.

Slime Molds

The **slime molds** were formerly placed in the Fungi kingdom. However, they are now considered to belong to the Protist kingdom. They are arranged in a **coenocytic** (many nuclei) mass of **protoplasm**. The slime mold undergoes a unique life cycle containing animal-like and plant-like stages. These stages include fruiting bodies and unicellular flagellated spores. Slime molds reproduce asexually by sporulation.

FUNGI

Fungi may be considered nonphotosynthetic plants (i.e., they resemble plants in that they are eukaryotic, multicellular, differentiated, and nonmotile). However, their cell walls are composed of chitin and not cellulose, which is used by plants.

Fungi are eukaryotes and primarily multicellular. All fungi are **heterotrophs**. This differentiates them from the plant kingdom. They may be **saprophytic,** decomposing dead organic material (e.g., bread mold), or parasitic, extracting nutrients from their hosts (e.g., the fungus that causes athlete's foot, *Epidermophyton floccosum*). In either case, fungi absorb food from their environment.

Fungi reproduce by asexual **sporulation** or by intricate sexual processes. Notable types are **mushrooms** (traditional macroscopic fungi), **yeast** (unicellular fungi), and **lichens** (fungi in symbiotic relationships with other, photosynthetic organisms).

PLANTAE

The plant kingdom includes multicellular organisms that exhibit differentiation of tissues and are **nonmotile photosynthetic**. Because plants are able to make their own energy rather than relying on consuming other organisms, they are known as **autotrophs**. Many plants also exhibit an alternation of generations and a distinct embryonic phase.

Plants have developed complex differentiated tissues to adapt to a terrestrial life. Photosynthetic tissue layers contain **chloroplasts** for the manufacture of carbohydrates. Supportive tissues provide mechanical support facilitating the typical upright radial construction of plants. Absorptive tissues, like specialized roots and simpler **rhizoids**, project into soil to absorb water and minerals. **Conducting** or **vascular** tissues include specialized tubes that transport water, minerals, and nutrients to all parts of the plant. Waxy **cuticles** on exposed surfaces minimize loss of water while permitting the transmittance of light. Cells are in direct contact with the external environment by means of air spaces called **stomata**, making elaborate respiratory and excretory systems unnecessary.

Bryophytes

The bryophyta, hepatophyta, and anthocerotophyta divisions (informally called **bryophytes** as a collective) are simple plants with few specialized organs and tissues. They lack the water-conducting woody material (**xylem**) that functions as support in tracheophytes and retain flagellated sperm cells that must swim to the eggs, which means they must live in moist places.

These types of plants undergo alternation of generations. The **gametophyte** is the dominant generation; it is the "main" plant and is larger and nutritionally independent. The **sporophyte** is smaller and shorter-lived, growing off the gametophyte from the **archegonium**. It resembles a heterotrophic parasite in that it obtains its organic and inorganic materials from the autotrophic gametophyte.

Mosses are classic bryophytes in which the sporophyte and gametophyte generations grow together. **Liverworts** are flat, horizontal, and leaf-like plants with differentiated dorsal and ventral surfaces.

Tracheophytes

Vascular plants (**tracheophytes**) are complex plants with a great degree of cell differentiation. They contain vascular tissues: **xylem** (water-conducting) and **phloem** (food-conducting). Tracheophytes have radial symmetry about a main vertical axis and are anchored by deep roots instead of rhizoids. Their extensive woody or nonwoody support systems allow them to grow to great heights. They have developed excellent provisions for water conservation (waxy surfaces) and gas exchange (stomata). Cellular water storage creates turgid cells.

In contrast to bryophytes, in vascular plants, the sporophyte generation is dominant. The gametophyte is short-lived and either independent (in primitive tracheophytes such as ferns) or small and parasitic (in more advanced tracheophytes such as seed plants).

Non-seed-bearing

There are two extant divisions of non-seed-bearing vascular plants: Pteriodphyta and Lycophyta. Those that remain are evidence of prior evolutionary linkage to the bryophytes.

Pterophytes, of the division Pteridophyta, include the familiar **fern**. They grow from an underground stem called the **rhizome** and contain large leaves (megaphylls) that possess many vascular bundles. Ferns grow lengthwise, not in diameter, and contain xylem with elongated **tracheid** cells that transport water and salts. They do not produce seeds, and their short-lived gametophyte generation possesses heart-shaped leaves; the fern's normal leaves are part of the sporophyte generation. Sporangium on the underside of the leaves produce monoploid spores, which germinate to form gametophytes.

Lycophytes belong to an ancient subdivision known as Lycopodiophyta. They have roots, are nonwoody, and contain microphyll leaves (e.g., **club mosses**).

Angiosperms

Angiosperms are members of the division Angiospermae, which contains the greatest number of different plant species of all the extant plant divisions. They have covered seeds and are the most abundant of all plants. Angiosperms have flowers, not cones, as their principal reproductive structures. The **anther** of the male **stamen** produces **microspores** (pollen grains), while the ovary of the female **pistil** produces **megaspores**. Successful pollination results in the germination of pollen tubes, which aid in fertilization of female eggs in the gametophyte. The embryo develops into a seed within the ovary. The ovary eventually ripens into fruit, which is how the seeds are dispersed. Xylem-conducting cells are in the form of vessels as well as tracheids, allowing for better conduction of water.

Dicotyledons (dicots) are angiosperms with net-veined leaves and vascular bundles around a ring within the central cylinder. Dicotyledons contain two **cotyledons** (seed leaves) within the seed. Many have cambium and can be woody. They have flower parts in multiples of four or five. Some examples of dicotyledons are the maple and apple trees, potatoes, carrots, goldenrods, and buttercups.

Monocotyledons (monocots) are angiosperms that contain leaves with parallel veins, scattered vascular bundles, and seeds with single cotyledons. Most monocots do not possess cambium and therefore are nonwoody (herbaceous). They contain flower parts in multiples of three. Some examples are **grasses** such as wheat, corn, rye, and rice. Other monocots include sugar cane, pineapple, irises, bananas, orchids, and palms (woody monocots).

Gymnosperms

Gymnosperms are naked-seeded plants. The gametophyte stage of gymnosperms is short-lived and microscopic. The male microspore produces pollen that can be carried by the wind; thus, the requirement of a water environment for flagellated sperm is eliminated and the gymnosperms are truly terrestrial. Sperm nuclei fertilize the egg with the aid of a pollen tube, and the embryo develops within the exposed seed.

The presence of a specialized cambium tissue allows for secondary growth of secondary xylem (wood) and secondary phloem. Gymnosperms can grow in diameter as well as in length and are woody, not herbaceous (green with soft stems) plants. Most gymnosperms are evergreens (non-deciduous).

Conifers of the division Pinophyta make up the largest grouping of gymnosperms. They include pines, spruce, and firs. Conifers have cones, spiral clusters of modified leaves. There are two different types of cones: large female cones with sporangia that produce **megaspores** and small male cones with sporangia that produce microspores.

The remaining three divisions of gymnosperms contain fewer species and are Cycadophyta (**cycads**), Gnetophyta (**gnetophytes**), and Ginkgophyta (**ginkgo**). Cycads are stout, cylindrical trees with pinnate (feather-like) leaves. Gnetophytes have widely varying properties but tend to be vine like. Ginkgophyta only has one extant species: *Ginkgo biloba*, also known as the Ginkgo tree, which grows pungent seeds and is sometimes used in herbal medicine.

ANIMALIA

The animal kingdom contains **multicellular**, generally **motile**, **heterotrophic** organisms that have **differentiated** tissues (and organs in higher forms). With the exception of some parasites like the tapeworm, animals ingest bulk foods, digest them, and then eliminate the remains. Animals usually employ some form of locomotion to acquire nutrients, but some are **sessile** (stationary) and create currents to trap food. Nevertheless, locomotion can also be important for protection, mate selection, and reproduction.

Simple multicellular animals, such as sponges, coelenterates, and flatworms, have minimal differentiation. Most of their cells are in direct contact with the outside environment. In these organisms, only a few systems (such as the digestive and reproductive systems) are required to support the life processes. In more advanced animals, specialized tissues and systems facilitate digestion, locomotion, circulation, message conduction (nervous system), and support.

Most animals also have right and left sides that are mirror images of one another, which is known as **bilateral symmetry**. However, some animals, such as the echinoderms and cnidarians, have **radial symmetry**.

Examples of Phyla

The **Porifera** phylum contains sea sponges, which have two layers of cells, pores, and a low degree of cellular specialization. Sponges are usually sessile, meaning they cannot move on their own during most of their life.

Cnidaria is a phylum with species that contain a digestive sac that is sealed at one end (gastrovascular cavity). Two layers of cells are present: the **ectoderm** and the **endoderm**. Cnidarians can have many

specialized features, including tentacles, stinging cells, and nerve nets. Examples of cnidarians include hydra, jellyfish, sea anemones, and coral.

The **Platyhelminthes** phylum is characterized by flatworms with ribbon-like, **bilaterally symmetrical** bodies that possess three layers of cells, including a solid mesoderm. They do not have circulatory systems, and their nervous system consist of eyes, an anterior brain ganglion, and a pair of longitudinal nerve cords.

The **Nematoda** phylum contains roundworms that possess long digestive tubes and anuses. A solid mesoderm is present. Nematodes lack circulatory systems but possess nerve cords and an anterior nerve ring. Examples include hookworms, trichina, and free-living soil nematodes.

The phylum **Annelida** contains segmented worms that possess a **coelom** (true body cavity) contained in the mesoderm. Annelids have well-defined systems, including nervous, circulatory, and excretory systems. Examples of annelids include earthworms and leeches.

Members of the phylum **Mollusca** are soft-bodied and possess mantels that often secrete calcareous (calcium carbonate) exoskeletons. They breathe by gills and contain chambered hearts, blood sinuses, and a pair of ventral nerve cords. Examples include clams, snails, and squid.

Arthropoda species have jointed appendages, chitinous exoskeletons, and open circulatory systems (**sinuses**). The three most important classes of arthropods are insects, arachnids, and crustaceans. **Insects** possess spiracles and tracheal tubes designed for breathing outside of an aquatic environment. They also have three pairs of legs. **Arachnids** have four pairs of legs and book lungs. Examples include scorpions and spiders. **Crustaceans** have segmented bodies with a variable number of appendages and also possess gills. Examples include lobsters, crayfish, and shrimp.

Echinodermata members are spiny, radially symmetrical, contain a water-vascular system, and possess the capacity for regeneration of parts. There is evolutionary evidence suggesting a link between echinoderms and chordates. Echinoderms include the starfish and the sea urchin.

Members of the phylum **Chordata** are characterized by a stiff dorsal rod, called the **notochord**, present at some stage of embryologic development. They have paired gill slits and a tail extending beyond the anus at some point during development. The lancelets and tunicates (like amphioxus) are chordates but not **vertebrates.** This means they have notochords but no backbones.

Vertebrata is an important subphylum of Chordata. Vertebrates include **amphibians**, **reptiles**, **birds**, **fish**, and **mammals**. In addition to the chordate characteristics described above, vertebrates also possess bones, called vertebrae, which form the backbone. Bony vertebrae replace the notochord of the embryo and protect the nerve cord. A bony case (the skull) protects the brain. Vertebrates can be divided into fish, amphibians, reptiles, birds, and mammals.

Classes of Vertebrata

Jawless fish make up the superclass **Agnatha**. Jawless fish are eel-like, retain the notochord throughout life, and have a cartilaginous internal skeleton. They have no jaws and possess a sucking mouth. Examples include the lamprey and the hagfish.

Cartilaginous fish possess jaws and teeth and are in the **Chondrichthyes** class. A reduced notochord exists as segments between cartilaginous vertebrae. An example is the shark.

Bony fish are the most prevalent type of fish. They are in the **Osteichthyes** class, have scales, and lack a notochord in the adult form. During development, cartilage is replaced by a bony skeleton. Examples include the sturgeon, trout, and tuna.

Members of the **Amphibia** class have larval stages found in water but adult stages that live on land. Larvae possess gills and a tail with no legs, whereas adults have lungs, two pairs of legs, no tail, a three-chambered heart, and no scales. Amphibians utilize external fertilization; eggs are laid in water with a jellylike secretion and subsequently fertilized. Examples include the frog, salamander, toad, and newt.

Individuals in the class **Reptilia** are **terrestrial** animals since they live on land. They breathe air by means of lungs, lay leathery eggs, and utilize **internal fertilization**. Reptiles are cold-blooded (**poikilothermic**) and have scales and a three-chambered heart. Examples include the turtle, lizard, snake, and crocodile.

Birds, which are in the **Aves** class, possess four-chambered hearts. They are warm-blooded (**homoeothermic**), and their eggs are surrounded by shells. Examples include the hen and the eagle.

Finally, the **Mammalia** class includes animals that are warm-blooded and feed their offspring with milk produced in mammary glands. Members of the **Monotremata** order lay leathery eggs, have horny bills, and produce milk via mammary glands with numerous openings but no nipples. Examples of monotremes include the duck-billed platypus and spiny anteater. Marsupials make up an infraclass of pouched mammals known as **Marsupialia**. The embryo begins development in the uterus and completes development while attached to nipples in the abdominal pouch. Examples include the kangaroo and opossum. Placental mammals of the infraclass **Placentalia** have embryos that develop fully in the uterus. The placenta attaches the embryo to the uterine wall and provides for the exchange of food, oxygen, and waste material. Examples include the bat, whale, mouse, and human.

VIRUSES

Viruses have not been placed in any of the six kingdoms because they do not carry out physiological or biochemical processes outside of a host. Although they are highly advanced parasites, they may be considered **nonliving**. Viruses are capable of taking over their host's cellular machinery and directing the replication of the rival genome and protein coat. Viruses have **lytic** and **lysogenic** life cycles. They contain either **DNA** or **RNA** and some essential enzymes surrounded by a protein coat. Viruses that exclusively infect bacteria are called **bacteriophages**.

REVIEW PROBLEMS

1. Select the proper progression of the taxonomy classification system.

A. Kingdom, order, phylum, class, genus, family, species
B. Kingdom, phylum, class, order, family, genus, species
C. Kingdom, order, phylum, class, family, genus, species
D. Kingdom, phylum, order, class, family, genus, species
E. Kingdom, phylum, order, class, genus, family, species

2. Which of the following is NOT true about viruses?

A. They may be considered nonliving.
B. They have lytic and lysogenic life cycles.
C. They contain only DNA and not RNA.
D. They are surrounded by protein coats.
E. They cannot conduct physiological processes outside a host.

3. Which of the following does NOT belong to the kingdom Protista?

A. Protozoa
B. Cyanobacteria
C. Algae
D. Phytoplankton
E. Rhizopods

4. Which contains the most number of different species of plants?

A. Angiospermae
B. Coniferophyta
C. Tracheophyta
D. Bryophyta
E. Pterophyta

5. Which is NOT a type of worm?

A. Platyhelminthes
B. Nematoda
C. Annelida
D. Porifera
E. None of the above

SOLUTIONS TO REVIEW PROBLEMS

1. B See the taxonomic classifications section within this chapter.

2. C Viruses can contain either DNA or RNA and also often contain some necessary enzymes within their protein coat.

3. B Cyanobacteria are part of the kingdom Monera. All other listed organisms belong to the kingdom Protista.

4. A Angiosperms have covered seeds and are the most abundant of all plants. They use flowers as their principal reproductive structures.

5. D Porifera are sponges and are not classified as worms. All the other classes of animals listed are types of worms.