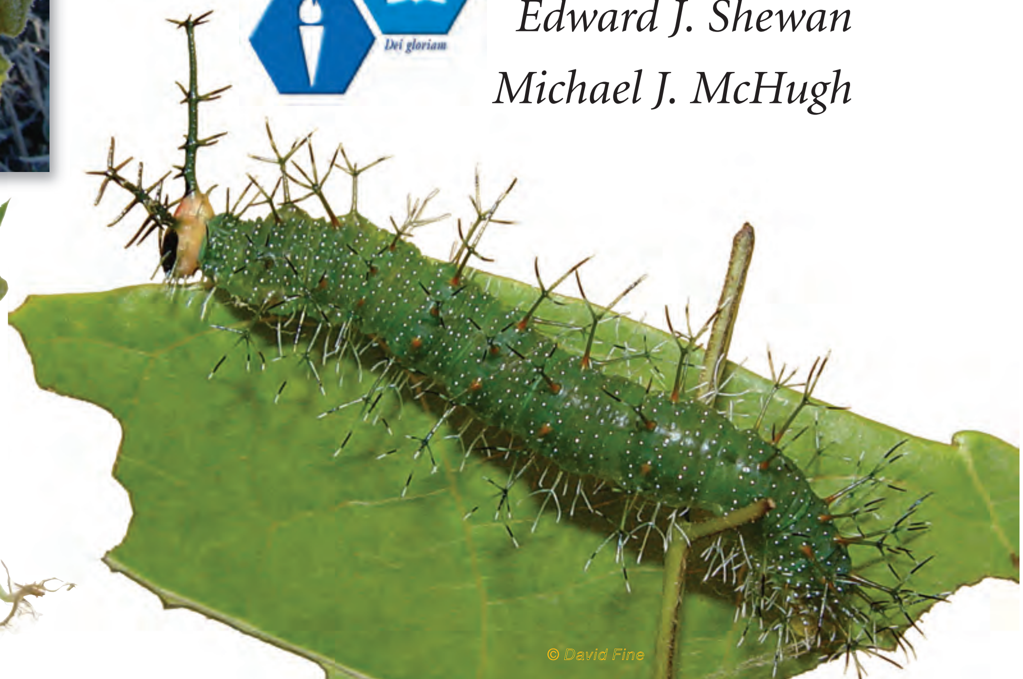
Biology: A Search for Order in Complexity

Second Edition

Editors and Consultants:

Leslie Mackenzie
David K. Arwine
Edward J. Shewan
Michael J. McHugh



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Original Editors: *John N. Moore, M.S., Ed.D.*
Harold S. Slusher, M.S., Ph.D.

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2013 Printing

A publication of
Christian Liberty Press
502 West Euclid Avenue
Arlington Heights, Illinois 60004

Editors: *Leslie Mackenzie, B.S., M.S.*
David K. Arwine, B.S., M.S.
Edward J. Shewan, B.S., M.Div.
Michael J. McHugh, B.S.

Copyediting: *Diane C. Olson*

Cover and Text Design: *Bob Fine*

Graphics: *Bob Fine* and *Edward J. Shewan*

Photography: *Bob Fine* (except where otherwise noted)

ISBN 978-1-930367-92-0
1-930367-92-9

Printed in the United States of America

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Acknowledgements

The second edition of this book represents more than two years of editorial activity to rewrite and update the text by a team of editors and consultants. Each member has generously contributed his or her talent and time to this task. Special mention should be made of the extensive amount of writing and editing done by Leslie Mackenzie, who taught biology at Evangelical Christian Academy (Colorado Springs, Colorado). Her efforts are greatly appreciated. Special thanks is also due to the contribution of David K. Arwine, who is the Assistant Headmaster and biology instructor at Christian Liberty Academy (Arlington Heights, Illinois). In addition, the editorial assistance of Edward J. Shewan and Michael J. McHugh is worthy of recognition. Acknowledgment is due to the original coeditors, Drs. John N. Moore and Harold S. Slusher, for their editing and contribution to the first edition, as well. Dr. Henry M. Morris (Founder and President Emeritus of the Institute for Creation Research) and the Board of Directors of the Creation Research Society also gave substantial assistance to the original project.

Bob Fine was in charge of the graphics and layout. His contributions and expertise added greatly to the overall updating and accuracy of the images. All photographs in the text were taken by Bob Fine, except those obtained from various sources, as acknowledged. Another person who made a major contribution is entomologist David Fine, former lab manager of Butterfly World, Coconut Creek, Florida. Of particular interest are the photographs given by William E. Meister, Sr., of his sandal-like fossil print in a trilobite bed. These photographs are reproduced from the Creation Research Society Quarterly, Vol. 5, No. 3 (Dec. 1968). In addition, special thanks is given to Mike Bergmann for permission to photograph fossil specimens used in chapter 21.

Valuable reviews were made for the first edition by Marion E. Cornelius, Professor of Chemistry, Biology, and Home Economics at Central Arizona College (Coolidge, Arizona) and former Science Supervisor for the Kansas City, Missouri, Public Schools; Dr. P. William Davis, Associate Professor, Hillsborough Junior College (Tampa, Florida); Dr. Elton H. Hall, Battelle Memorial Institute (Columbus, Ohio); and Dr. John C. Whitcomb, Jr., Professor of Old Testament and Director of Post-graduate Studies (Grace Theological Seminary, Winona Lake, Indiana).

Grateful acknowledgement is extended to Harold S. Slusher for granting Christian Liberty Press permission to utilize copyrighted material from the first edition of *Biology: A Search for Order in Complexity* during its completion of the second edition text.

To all these we express our gratitude. Because of this cooperative effort, *Biology: A Search for Order in Complexity, Second Edition* is a distinctive contribution to the sphere of scientific inquiry.

Introduction

As the title of the book implies, the science of biology is a search for order in the complexity of living things. The word *biology* itself comes from two Greek words, *bios* (life) and *logos* (discourse). Because life is extremely complex, searching for the orderly processes in biology ranks as one of the most challenging adventures in science. It is hoped that this book will motivate readers to participate in this adventure.

Progress in any science depends upon the discovery and application of its underlying principles; those principles which describe the orderly processes that occur in the midst of change. For example, progress came in biology when Mendel discovered that in spite of many changes, which showed up in his garden peas from generation to generation during his experiments, there was an orderly process behind these changes. He described this orderly process by means of his famous laws of genetics. These laws have become the guiding principles employed by plant and animal breeders. By means of Mendel's laws, we can predict, statistically, many of the hereditary characteristics that can occur in offspring.

More recent research seeks to find orderly processes at the bio-chemical level. To keep the reader abreast of some of the unifying factors at that level, a unit describing the relationships between chemistry and the study of biological science has been provided.

Although the unifying theme of the entire text is the orderly processes described by the principles of biology, the content is not limited to an exposition of those principles. The book also contains a useful and comprehensive background of biological information. This additional knowledge of the facts of biology helps the student apply the basic principles and also gives him an understanding of the need for a continuing search for the fundamental properties of living things.

This book is designed for use as a textbook for high school biology. It has numerous illustrations, questions at the end of each section in a chapter, review questions at the end of each chapter, "Taking It Further" suggestions, and supplementary material to challenge the advanced students. Although the editors acknowledge their indebtedness to many other books (as will be seen by the references cited), this textbook has a wealth of new material that has a new approach to the subject. It is hoped that the student and teacher will find this nonconventional approach refreshing and rewarding.

As you prepare your mind to enter into the rigors of scientific study and the wonders of God's creation, it would be wise for you to follow the noble example of the great scientist, George Washington Carver. This brilliant botanist, of the nineteenth and early twentieth centuries, had the humility and wisdom to ask the Creator to give him a proper understanding of how to comprehend what he was studying in the plant kingdom. Carver himself wrote often of how he would begin his day of study with a simple, child-like prayer; "Lord, I don't understand the mysteries and functions of this plant, but I know You do—show me." May the same Creator God, who gave such grace and usefulness to George Washington Carver, strengthen your heart to understand that we often have not because we ask not.

CHAPTER 9

CLASSIFICATION OF ORGANISMS

DEVELOPMENT OF CLASSIFICATION

9-1 The Kinds of Organisms

Most likely one talks about God's creation in terms of "plants" and "animals." He thinks of trees, grasses, and weeds as plants. He also thinks of dogs, cats, and horses as animals. The differences between plants and animals seem obvious. Many plants are green and stay in one place, but animals move about. Perhaps he uses the word "animal" to apply to four-footed creatures like dogs, but he classifies creatures with two legs and feathers as "birds." Grasshoppers may be called "insects." The biologist, however, identifies all these creatures by the term "animals," or *animalia*. Likewise, he categorizes organisms that usually stay in one place and are made of such structures as leaves, stems, roots, and flowers by the term "plants," or plantae.

This common way of **classifying** (or grouping) organisms is not as simple as it appears. There are some organisms that are difficult to classify as plant or animal. Before one begins to search for order among the many kinds of complex organisms, he must first learn something of how organisms are grouped or classified.

9-2 Early Methods of Classification

Early biologists soon recognized that plants and animals could be divided into distinct groups. Without any grouping, the study of organisms is confusing and difficult. By the mid-eighteenth century, scientists recognized thousands of kinds of animals and plants. Today the number of known kinds of animals is in the millions, with additional ones being added every year. Likewise, the known number of plants is about 500,000 species and increasing.

Though ancient peoples were interested in naming plants and animals, they were far from systematic in their attempts to classify them. **Aristotle** (387–322 B.C.), the great Greek philosopher who seemed to have discussed everything in his wide range of interest, divided plants into the following three groups: those with soft stems, called **herbs**; those with several woody stems, called **shrubs**; and those with but a single stem or trunk, called **trees**. He divided animals into land, water, and air dwellers. Other systems, strictly environmental or ecological, were used.

Theophrastus (372–287 B.C.), often called the Father of Botany, was the author of the first known botanical work. Written in Greek, his one set of nine volumes was titled *Historia Plantarum* ("On the History of Plants"). He studied the structure of the stems and leaves of plants and grouped them into families on the basis of the likenesses he found in them. Classification of organisms as Theophrastus attempted to do is called **taxonomy**.

During the seventeenth and eighteenth centuries, scholars began to compile long lists of known plants and animals. The lists of plants were called **herbals**, and the lists of animals were called **bestiaries** (bĕs´chē•ĕr´ēs, "pertaining to beasts"). The bestiaries included some strange creatures. One, called "Parandus," had movable horns; and the "Yale" had horns pointing forward and a large pair of teeth protruding from the lower jaw. In time, such imaginary creatures were eliminated from animal taxonomies.

As late as the seventeenth century, the Englishman and Father of Natural History, **John Ray** (1627–1705), presented the first clear concept of species, which he defined as offspring of similar parents. He stated that God reveals "more of His Wisdom in forming such a vast Multitude of different Sorts of Creatures, and all with admirable and [flawless] Art, than if He had created but a few; for this declares the Greatness and unbounded Capacity of His Understanding." In systematic classification, Ray had no successor until **Carolus Linnaeus** (1707–1778), the great Swedish biologist and Father of Taxonomy. Linnaeus focused almost exclusively on classification, but Ray began to use classification to address issues in **physiology** (fĭ´zē•ä´lə•jē), the functions and activities of living organisms and their parts.

Until the time of Linnaeus, plants and animals were described and classified very haphazardly. The common name of an animal in one part of the world meant and still means something quite different from the meaning of the same name in another part (e.g., *gophers* are called "turtles" in Florida; in the Midwest, they are called "ground squirrels"; and in California, "burrowing rodents"). Obviously, with this sort of system progress is hindered. There must be some way by which everyone who reads biological reports on new knowledge can be sure of what is being described.

Often in ill health and easily overcome with weariness, Linnaeus nevertheless accomplished more than any other biologist in laying the foundation for an orderly system in the study of nature. He was accorded the honor of full professorship at the University of Uppsala, Sweden, in 1741, at the age of only thirty-four years. He taught botany, natural history, mineralogy, pharmacy, chemistry, and dietetics. His lectures began at 10 A.M., in the Gustavian Lecture Hall during the winter and in the botanical garden in the spring and fall. His students admired him, and while he charged the rich a heavy tuition fee, the poor could attend free of charge. The lectures were given in Latin, which he spoke with a rich Swedish accent.

His rivals credited Linnaeus's amazing collection of plants and animals as the reason for his success as a lecturer. These he used as illustrations in his lectures. It was a marvel in those days to see a rose from the Cape of Good Hope, amaryllis from Asia, monkeys and snakes from Africa, and parrots from South America. His lectures were written as notes on oblong pieces of paper held between his fingers, marking with his thumb the place he had reached at the end of each day. Those hearing his lectures on the introduction to *Systema Naturae*, on God, man, the Creation, and nature, were more stirred by them than by the best-delivered sermon. As his student Sven von Hardin said, "If he spoke on the work of the Creation and His Majesty, God the Creator, reverence and admiration were painted on all faces."

Over two hundred students went on his annual spring expedition, all clad in uniforms of linen jackets and trousers and all armed with butterfly nets and safety pins. They returned with wreaths of flowers and butterflies pinned to their hats. They marched in good order, Linnaeus leading the procession. They were never too weary to shout a resounding "Vivat Linnaeus," before leaving his home.

His outlook may best be summarized by the following quote from Norah Gourlie's *The Prince of Botanists*.

> The further a man goes the more does he become obliged to admire and praise Him. From this we see how far the knowledge of nature leads us to more theology itself and how completely it depicts for us the Creator's Magnificent work—the marvelous mountains are a proof of His might, the plants a witness of His skill, the animals an example of His providence—the whole nature confirms He is wise, and the entire world [substantiates] that its Creator is a divine and Almighty Lord.

Questions: Development of Classification

1. Why is it important to have a universal system of classification?
2. List some of the different early methods of classification.
3. How did John Ray define the term *species*?

Taking It Further: Development of Classification

1. Look up one of the scientists mentioned in this section and list the major works of his career.

THE SYSTEM OF CLASSIFICATION

9-3 Structural Classifications

Linnaeus classified all living things as plants or animals and called these classifications **kingdoms**. In each kingdom are natural structural classifications called **phyla** (fī´lə; *sing.* phylum [fī´ləm]). In turn, phyla show distinct groups called **classes**; classes are divided into **orders**; orders are composed of **families**; families are composed of different **genera** (jĕn´ər•ə; *sing.* genus [gē´nəs]); and genera are comprised of **species** (spē´shēs). There often are subdivisions of these classifications. The dog is classified this way:

Kingdom	**Animalia** (animals)
Phylum	Chordata (animals with notochord–a rod of cartilage or backbone in the dorsal side)
Subphylum	**Vertebrata** (animals with vertebra or true backbone)
Class	Mammalia (animals with hairs on the body and mammary, or milk glands)
Order	**Carnivora** (flesh-eating mammals)
Family	Canidae (carnivores with dog-like characteristics)
Genus	***Canis*** (the dogs)
Species	*C. familiaris* (the familiar dog)

(The scientific name consists of the genus and species; *Canis familiaris*; see Figure 9-1 for classifications of other common organisms.)

> The following **mnemonic device** will help you remember the Linnaean system of classification (**k**ingdom, **p**hylum, **c**lass, **o**rder, **f**amily, **g**enus, and **s**pecies).
>
> **K***ing* **P***hilip* **c***ame* **o***ver* **f***or* **g***rilled* **s***hark.*

The higher levels of classification are usually easy to distinguish. It is at the species level that problems arise in many instances. No single definition of a species satisfies all **taxonomists** (those who classify). A species is most commonly defined as a group of organisms that closely resemble each other and interbreed freely among themselves without breeding with other groups under ordinary

Category	Gorilla	Dog	Cat	Honeybee	Rose	Pine
Kingdom	Animalia	Animalia	Animalia	Animalia	Plantae	Plantae
Phylum	Chordata	Chordata	Chordata	Anthropoda	Tracheophyta	Tracheophyta
Class	Mammalia	Mammalia	Mammalia	Insectica	Angiospermae	Gynospermae
Order	Primates	Carnivora	Carnivora	Hymenoptera	Rosales	Pinales
Family	Pongidae	Canidae	Felidae	Apidae	Rosaceae	Pinaceae
Genus	*Gorilla*	*Canis*	*Felis*	*Apis*	*Rosa*	*Pinus*
Species	G. gorilla	C. familiaris	F. domestica	A. mellifera	R. chinensis	P. ponderosa

Figure 9-1 Classification of some common organisms

circumstances. There are instances where organisms classified as different species do interbreed when their ranges overlap. The flicker (a large woodpecker) is an example. The flickers in the eastern part of the United States have yellow feathers in their wings and tails, but western birds have orange-red feathers. In areas where the ranges overlap the two species crossbreed freely.

Linnaeus used the Latin language since it is unchanging and was universally used by students at that time. Many descriptive words in Latin or Latinized Greek are very precise and thus ideally suited for identifying particular parts of the plant or animal described. The genus of plants always begins with a capital letter, such as *Rosa*, which is known as "rose." Usually a genus consists of many kinds of plants or animals, each having many characteristics possessed in common by all. The species name is in small letters unless named for a person or special location, in which case some authors use the capital. The scientific name is always underlined in manuscripts and italicized in printed descriptions. Thus, it is *Rosa chinensis*, which refers to the rose shrub from China (where it grows wild). In regard to animals, it is *Felis* for lions, tigers, cats, and similar animals. *Felis concolor* is the mountain lion, or American lion, also known as the cougar, panther, puma, and catamount. The ordinary house cat is *Felis domestica*.

As mentioned above, the basis for Linnaeus's classification was always **structural similarity**, usually the bone structure of animals. Accordingly, this system gives much information, since one can be sure that all animals placed in the same genus are physically very similar in structure. This makes preservation simpler in that, as each species is described, it is the duty of the scientist who describes it to file a specimen in some recognized museum, either as an **herbarium** (ər´bâr´ē•əm) **sheet** for a plant or a well-mounted specimen for an animal such as a bird. The art of preparing these animals is called **taxidermy** (tăk´sə•dər´mē) and is a most important profession for practical museum maintenance. Insects are usually preserved by pinning them inside airtight boxes, to protect them from the destructive boring of the Dermestid beetles (*Dermestes maculatus*). The chemical repellent *paradichlorobenzene* (pâr´ə•dē•klôr´ə•bĕn´zēn) is placed in the box to keep the beetles out.

Linnaeus did not believe that species were so created as to have each individual exactly like every other one, as any careful study of his book *Systema Naturae* (1758) will show. He recognized rather wide variation and even **hybridization**, often refusing to list certain plants as species because he quite correctly recognized that they were naturally occurring hybrids. He also recognized that much of the variation in the specimens, which he personally collected or were sent to him, was due to the effects of hybridization within the species, or what is now called **varietal hybrids**.

9-4 Concept of Fixity of Species

As time went on, students following the concepts of Linnaeus identified more and more plants and drew ever more precise limits to the species they described. In spite of the clear warnings of Linnaeus, they increasingly stressed the fixity of the species, giving the idea that their entities were absolutely unvarying for the distinctions used by them in setting up their descriptions.

Although they recognized minor variations in leaf shape and size, any departure from published descriptions was called a new species. Genera were thus often broken up into ridiculously small units. By the time of **Louis Agassiz** (1807–1873), the absolute fixity of species had become a sort of dogma. Naturally, the stage was set for a critical look at what nature really was like and just how constant species really were.

Questions: The System of Classification

1. List the different levels of classification from the broadest to the most specific.
2. Describe the levels of classification to which dinosaurs belong (e.g., Kingdom–*Animalia*, etc.).

Taking It Further: The System of Classification

1. Give the seven classification levels (including any sublevels) for a horse.

UNCERTAINTIES IN CLASSIFICATION

9-5 What is a Species?

There has been endless discussion as to what really constitutes a species. Obviously, merely being different from another plant or animal is not sufficient reason to give specific names. For example, notice the amazing variation in dogs; yet, it is known that these have resulted from hybridization and breeding. They are also **interfertile** (capable of interbreeding) except for occasional cases as those caused by such extreme size differences, such as those of a Pekinese and a Doberman pinscher. Yet these two do crossbreed with other dogs and so contribute to the common gene pool.

There is a wide range of variation in human beings. Yet, all human beings are classified as *Homo sapiens*, since all are capable of interbreeding; note, it is said that humans are *capable of* interbreeding. Actually, under certain conditions and for various reasons, there was practically no intermarriage (endogamy) between the Indian tribes. Strong taboos against this existed. The same is true with most primitive tribes unaffected by modern civilization.

If structural distinctions do not necessarily demand ranking an assemblage of plant or animal as **distinct** (invariably separate) species, what does? First, many organisms have unfortunately been given a specific rank when so little was known about them. During the years from about 1780 to 1950, over a dozen species of song sparrows were described. But as **ornithologists** (ôr′nə•thäl′ə•jĭsts, those who study birds) became better acquainted with this widespread bird, they realized that all of them were merely geographic races, since they interbred at the boundaries of their habitations and thus formed a continuous series.

A close study of the song sparrow reveals that all the varieties have the same *pattern* of genetic expression. The differences are mostly those of size, color of the feathers as to light or dark, and size of the neck, and similar features resulting from selective adaptation of various combinations of genes from the common gene pool. In general, the forms from dry desert areas have small bodies and light gray coloration. By contrast, the swamp sparrow has a distinctive conformation of the head and body as well as a rusty cap, gray breast, and white throat. The whole pattern of this bird is distinct from that of the song sparrow. To prove common ancestry would involve demonstrating that variation of such features as the rusty red cap, general body conformation, and breast markings all showed gradation, so as to indicate the origin from a common gene pool. So far this has not been done, so it seems a person is on safe ground in considering these as truly distinct species. The swamp sparrow is *Melospiza georgiana*, and the song sparrow is *Melospiza melodia*.

Usually some sterility results when truly distinctive species are crossed with each other. The mule, a cross between the horse and the donkey, usually is sterile. In birds, such controlled hybridization is very difficult, possibly because of strong psychological reasons. Therefore, tests on bird species have only recently been made. With plants, much more has been done along this line, and truly distinctive species usually show a considerable amount of sterility, both in the production of fertile ovules and effective pollen.

Investigation of forms such as the fungi, where such studies can be rather easily made, has shown that this sterility results from a major difference in the arrangement of the DNA sequence of nucleotides. In higher plants where studies have been done, study of the chromosomes shows great differences in

Figure 9-2 The mare (second from left) was bred to a male donkey (far left) to produce the two mules.

These hybrids between two species are sterile and, thus, do not represent a new species.

USDA

the shape of certain pairs, in absolute size, and often in chromosome number.

A good guide to the study of variation is the study of how mankind has differentiated over the years since he was created male and female. Among mankind are various races, and within the races, distinctive tribes. With few exceptions, all are *interfertile*. However, psychological barriers limit inter-mating. Similarly, one would expect to find many species of animals and plants showing a tremendous variation. Much of the confusion results from taxonomists' refusing to consider species as variable units. However, with song sparrows and roses, rapid progress is being made in separating the basic species from the derived ones.

9-6 The Origin of Variation

A distinction must be made between *variation* and *mutation*. According to the evolutionary concept, variation is essentially due to mutation, since from this point of view all species of a genus, for example, were originally alike and diverged as mutants that were advantageous and thus incorporated into the DNA pattern. It is clear, however, that at the present level of observation, some differences occur too seldom to be considered as mutational, and others occur in regularly observed patterns of **Mendelian inheritance.** Creationists contend that this situation has always been true and that the various categories were created with **variability potential**, making it more readily possible for them to survive in the various environmental situations to which they are exposed. In other words, there are latent recessive genes that later become expressed. Also, some variation (from this viewpoint) is simply an expression of the Creator's desire to show as much beauty of flower, variety of song in birds, or interesting types of behavior in animals as possible. It would be a monotonous world if all roses looked alike, or if all birds sang like the meadowlark, lovely as the song of this bird is.

9-7 Classification Problems: Protista, Monera, and Fungi

Linnaeus classified flowering plants according to structure, using the flower as a basis. It is easy to see the difference between roses and pine trees. Mammals are easily distinguished from birds. But classification isn't always so simple. Among one-celled organisms are species that are difficult to classify as plants or animals. *Euglena* (yū•glĕ´nə) is an example of a microscopic organism that behaves like an animal in some ways, yet has **chlorophyll** (klôr´ə•fĭl´, green photosynthetic pigment) that manufactures nutrients like a plant. It is because of the difficulty in classifying some organisms that some biologists place certain organisms into three separate kingdoms—**Protista** (or Protoctista), **Monera** (or Prokaryotae), and **Fungi**. Most organisms are distinctly either plants or animals, but to classify the one-celled organisms this way is difficult. Biologists differ as to which organisms should be included in these kingdoms. These organisms are generally single-celled or very simply organized beings as contrasted to plants and animals that are usually multicellular and more complex. Any system of classification involves a certain amount of arbitrariness in deciding whether certain organisms should be classified as a plant, an animal, or in one of the other three kingdoms. There is general agreement that the bacteria and blue-green algae, which are normally classified under Monera (mə•nēr´ə, prokaryotes), should be included in Kingdom Protista. But the problem is where to stop. Should all algae be included in the Protista? The algae include not only the blue-green forms but also the giant seaweeds. Slime molds are fungous plants, but the fungi also include mushrooms and the large bracket fungi. These used to be classified under Protista, but now have their own kingdom, Fungi.

The most difficult group is the **photosynthetic** (fō´tō•sĭn•thĕ´tĭk, producing carbohydrates with the aid of light) **flagellates** (flăj´ə•lĭts, small organisms that move by means of tiny threadlike extensions). These organisms include the *Euglena* and related organisms. They possess chlorophyll and can manufacture carbohydrates. When denied light, however, the organisms are able to absorb nutrients from water. Therefore, they have the feature of **photosynthesis**, which is characteristic of the plant kingdom, and simultaneously have the abilities of *locomotion* and *ingestion*, which are traits of the animal kingdom. This confusion stems from the necessarily arbitrary nature of the system of classification.

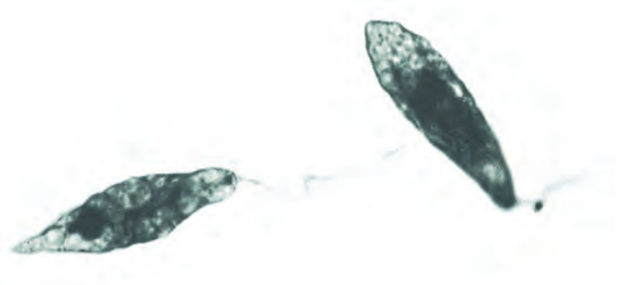

Figure 9-3 Among the photosynthetic flagellates, *Euglena* presents difficulties in classification because it possesses both animal and plant characteristics.

Courtesy Carolina Biological Supply Company

Classification is largely a matter of opinion, and taxonomists frequently disagree. They do not disagree, however, about the characteristics of the organisms under consideration. They often do disagree about the categories to be used in dividing these characteristics into separate classifications. Nature is not classified, but it is man who imposes the system of classification on the natural world, as he observes it. The confusion lies not with the natural world, but with the categories that man develops. One scientist may assert organism *A* must be classified with organism *B* because of some similarity, but another may be equally convinced that organism *B* should be classified with organism *C* because of some other similarity. Both scientists are using objective, observable facts, but they are drawing subjective conclusions from their observations. That is to say, their way of thinking or point of comparison may arbitrarily determine their conclusions.

Classification is a matter of convenience. If a person speaks of the **Canidae**, one knows he means dogs, wolves, coyotes, foxes, and hyenas. Likewise, the group **Rosaceae** includes roses, peaches, plums, and other roselike plants. So far as convenience is concerned, it does not matter whether organisms are classified into two kingdoms—*Plantae* and *Animalia*—or whether the system of five kingdoms is used. If the student knows what system is being used, he can get an orderly understanding of the living world; for there is order in complexity in the kinds of organisms making it up.

A complicating factor in classifying one-celled organisms is evolutionary conjecture. Evolutionists are attracted to these microorganisms because some life forms seem to combine both plant and animal characteristics; consequently, evolutionists conclude that these organisms are the common ancestor of both plants and animals. Yet, due to the fact that there are so few fossils, such hypothetical relationships are difficult to establish.

Young scientists, in such cases, should learn how to distinguish between *facts* (which are subject to experimental or observable verification) and *conceptual schemes*, theories, or hypotheses. Evolutionists and creationists, by and large, do not disagree concerning verifiable laws or facts. It is the philosophical assumption, conclusion, or prediction regarding those facts about which they disagree.

Questions: Uncertainties in Classification

1. Name the five kingdoms and give examples of the members in each.
2. What is the difference between observable facts and theories?
3. Why are there more ways than one to classify the natural world?

Taking It Further: Uncertainties in Classification

1. What is the role of the arbitrary system of classification in supporting different theories of origin?

Questions: Chapter Review

1. What are the divisions of a class called? What are the divisions of a family called?
2. What is the disadvantage of using descriptions instead of names?
3. Why not list all animals alphabetically, as in a dictionary?
4. From what language are scientific names chosen? Why?
5. How is a species different from a pure line? (See chapter 7, section 12, “Johannsen and Selection.”)
6. How do latent recessive genes cause variation?
7. How is a geographic race different from a true species?

CHAPTER 16

Form and Major Functions of the Human Body

The various functions of the human body are discussed in the following two chapters. Though biologists differ on how to classify these functions, this book divides the body into ten systems—chapter 16 covers the *skeletal*, *muscular*, *circulatory*, *respiratory*, *digestive*, *excretory*, and *integumentary* systems; chapter 17 examines the *nervous*, *endocrine*, and *reproductive* systems. Sometimes, the bone marrow, tonsils, thymus, spleen, lymph (i.e., lymphatic fluid), lymph nodes and nodules, and lymphatic vessels are assigned to a separate system—the *lymphatic system*. This system returns water, proteins, and other components from tissues back to blood (**fluid balance**); and it defends against foreign organisms (**immunity**). In this text, the bone marrow, tonsils, spleen, lymph nodes, and lymphatic vessels are listed with the *circulatory system*, and the thymus is discussed under the *endocrine system*.

SKELETAL SYSTEM

16-1 The Internal Skeleton

Man is a vertebrate and, like all other vertebrates, has an internal skeleton, or **endoskeleton** (ĕn´dō•skĕ´lə•tən), which has several functions. These include providing support and shape for the body; protecting vital organs such as the heart, lungs, and brain; providing levers for the muscles to move the body; and producing new red blood cells. The skeleton is held together and joined to muscles by connective tissues called *ligaments* and *tendons*. These connective tissues are formed relatively late in the embryo, and with good reason, for their primary functions are not needed until after birth.

Like all other parts of an animal or plant, the bones of the skeleton are formed by cells. These cells, called **osteoblasts** (äs´tē•ə•blăsts´), produce thick walls of calcium carbonate and calcium phosphate between each other. The cells remain in the bone, receiving blood for nourishment through tiny canals. Cells that secrete a glassy, elastic substance between each other also form cartilage. If a fracture occurs, the building process of cells repairs the injury.

16-2 Parts of the Human Skeleton

The skeleton (Figure 16-1) consists of two parts—the **axial skeleton**, located in the head, neck, and trunk; and the **appendicular** (ă´pən•dĭ´kyə•lər) **skeleton**, in the limbs, shoulders, and hips. The grouping of these bones is very similar to that found in mammals.

The axial skeleton includes the **skull**, the **vertebral** (or spinal) **column**, the **ribs**, and the **sternum**. The vertebral column is the great supporting axis of the whole skeleton and is made up of 33 bones (vertebrae) arranged as follows from above downward: 7 *cervical*, 12 *thoracic*, 5 *lumbar*, 5 *sacral* (in the adult, united into a single bone), and 4 *coccygeal* (käk•sĭ´jē•əl). It normally curves slightly backward in the thoracic (thə•ră´sĭk) region and forward in the lumbar region. These curvatures may be abnormally increased by poor posture. Any lateral curvature of the column is abnormal.

Each vertebra consists of a solid body from which extends a ring of bone that surrounds the **spinal cord**, the main axis of the nervous system. Arthropods and annelids also have a nerve cord, but in them it is on the ventral instead of the dorsal side and is not surrounded by bone. Projections of bone also extend from a vertebra in the human body, one backward, one to the right and one to the left; they serve for the attachment of muscles.

Between the bodies of adjoining vertebra, except in the sacrum and coccyx, are thick pads of cartilage, called **disks**, which are fairly elastic. This allows the back to bend and also to absorb shock as, for instance, when jumping. Many people have trouble with their backs when these become loosened, and they are said to have "slipped a disk."

The first two vertebrae of the neck are different from the five below them. The skull is fastened to the first vertebra, which is called the **atlas**, in a manner that allows tilting the head forward or backward. This may bring to mind the legend of Atlas, the giant in Greek mythology who held the world on his shoulders. The second vertebra, called the **axis**, is well named because it has a central projection that extends up through an open space in the atlas. This enables the neck to turn sideways. Bands of connective tissue loosely connect the atlas and axis, allowing ample motion of the head. This type of joint is referred to as a **pivot joint**.

Each of the twelve **thoracic vertebrae** has a pair of ribs attached to it. The upper seven pairs are attached to the sternum by cartilage. The eighth, ninth, and tenth ribs have the cartilage attached to the seventh; and the eleventh and twelfth are unattached at the front (Figure 16-1).

The skull consists of the **cranium** (the case that contains the brain) and the bones of the face. Most of the skull bones are fastened together by processes shaped like saw teeth, called **sutures** (sū´chərs), to fit together securely. Some of these processes are not yet developed at birth, allowing the head of an infant to change shape slightly while being born. A "soft spot" between the skull bones is usually evident at birth. This membrane-covered opening is called a **fontanel** (făn´tən•ĕl´).

Certain special features should be noted. The spinal cord passes through an opening in the **occipital** (äk•si´pə•təl) **bone** at the lower side of the cranium. The spinal cord develops early in the embryo, and the occipital bone forms around it. The middle ear and the inner ear are located in a hollow space in the **temporal bone**. The **mastoid** (măs´toid´) **process** of this bone is behind and below the external ear. In this process are a number of small cavities, connected with each other and with the middle ear. Infection in the middle ear accompanying a head cold may invade the mastoid cavities, sometimes making a surgical operation necessary.

The *pectoral girdle* is a ring made up of the collarbone, or **clavicle** (klă´vĭ•kəl), and the shoulder blade, or **scapula** (skăp´yə•lə). They are so arranged as to allow freedom of movement in the shoulder. The *pelvic girdle* is firmer because it has to support a great weight. In childhood it consists of three bones on either side—the **ilium** (ĭ´lē•əm), **ischium** (ĭs´kē•əm), and **pubis** (pyū´bĭs, or *pubic bone*); but in the adult these are fused together. The ilium is the large bone that can be felt on the side of the hip. It is attached to the sacrum. The limbs are attached to both of these girdles by what is called a **ball-and-socket joint**. There is a carved depression in each girdle, into which fits a ball-shaped end of the limb. This joint has the most freedom of movement.

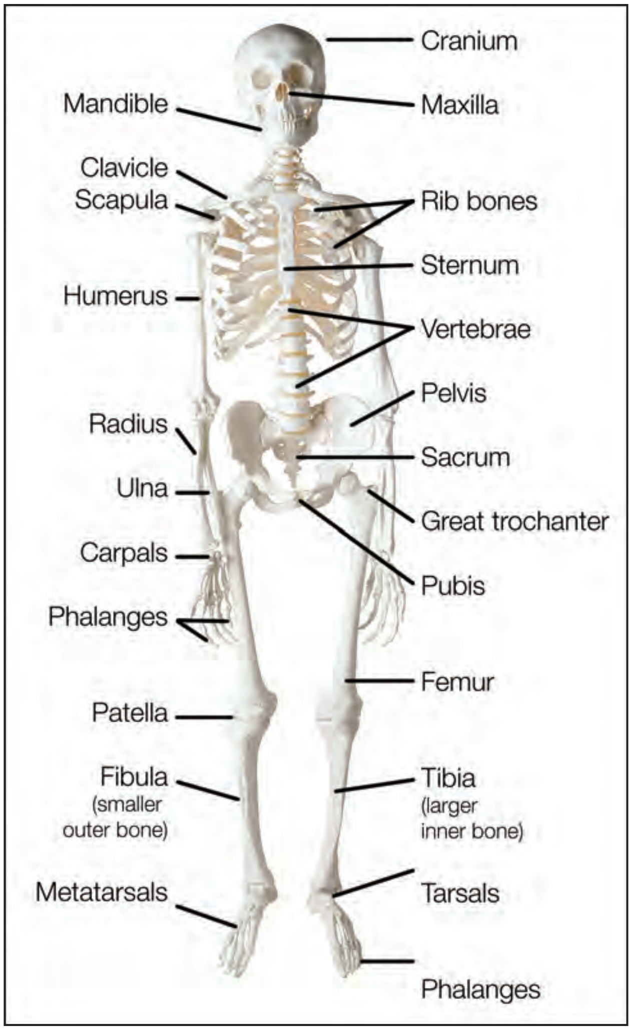

Figure 16-1 The human skeleton

PhotoDisc, Inc.

Other joints, such as the elbow and knee, can be moved in only one plane and are comparable to a door hinge. This type is called a **hinge joint. Gliding joints** are those that allow limited movement in the wrist and vertebra. There are several other types of joints, also. Not all joints are movable, however; sutures are joints between the skull bones, which are immovable in adults, and sometimes are so tightly fused in skulls of elderly individuals that they are hard to distinguish.

The knee has an additional bone, the **patella** (pə•tĕ´lə). The patella is actually enclosed in a ligament and increases leverage in the leg. In addition, it provides protection for a vulnerable joint. You can easily feel that it is loose and not attached directly to another bone. The knee is also one of the most common areas of trouble for athletes: the cartilage pad between the upper and lower leg bones may tear, the patella may be split, or ligaments may be torn.

A large amount of information can be learned about a person from his bones. For example, evidence obtained from the skeletal remains found at a crime scene exhibit **sexual dimorphism** (dī•môr′fĭ•zəm, male and female skeletal remains differ in appearance). A victim's gender can be determined by two primary sets of bones, the *skull* and the *pelvis*. The skull is the easiest, because males have a sloping forehead, while females have a straighter forehead. A victim's age, race, and stature can also be determined by the science of **skeletal forensics** (skĕ′lə•təl fə•rĕn[t]′sĭks).

Questions: Skeletal System

1. Name the components of the axial and appendicular skeleton.
2. List the different types of joints and give examples of where they are found in the body.
3. What is the *patella*? What purpose does it serve?
4. What are the main functions of the skeletal system?

Taking It Further: Skeletal System

1. What types of joints, other than those mentioned, can be found in the body?
2. How does a forensic anthropologist help the police positively determine the identity of a crime victim from his skeletal remains?

MUSCULAR SYSTEM

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16-3 Muscles

Muscles make up a large part of the human body. You have seen the flesh of mammals such as cattle and hogs; all the red meat in these animals is muscle. In frogs and turtles the muscles are white. Every kind of tissue has some specialization, and muscle tissue has the special ability to shorten, or contract. When a muscle shortens, it also thickens and tends to maintain the same volume. All movements of the body are the result of this contractile property of muscles.

Muscles not only produce movement, but also have several other functions. Some muscle contraction helps a person to maintain his posture. Poor posture can often be corrected by merely getting the proper muscle "in tone." Some muscles lie in sheets around a space such as the wall of the stomach or of an artery. Their contraction changes the size or shape of the organ of which they are parts. Muscle contraction is also a source of heat for the body.

Muscles are arranged in pairs in such a way that one can reverse the action of the other. The forearm is drawn up by the **biceps** (bī′seps′, "two-headed" muscles), the large muscle of the upper arm (Figure 16-2). Draw your own arm up and feel the bulging muscle. The **triceps** (trī′sĕps′, "three-headed" muscles) on the back of the upper arm straightens the arm. When the biceps contract, the triceps must relax, and vice versa. Muscle pairs such as this are called *antagonistic* (ăn•tă′gə•nĭs′tĭk) *pairs*, because these pairs work against each other.

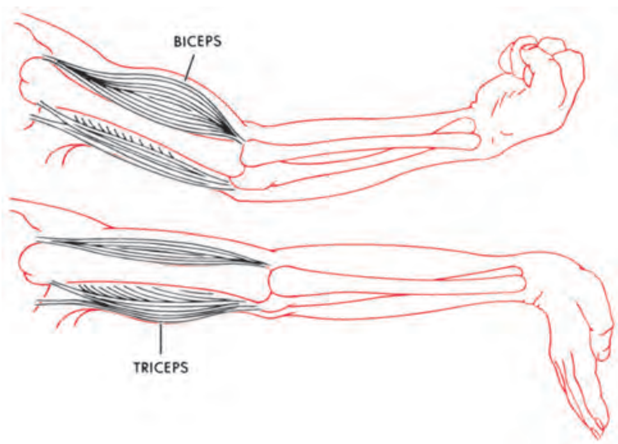


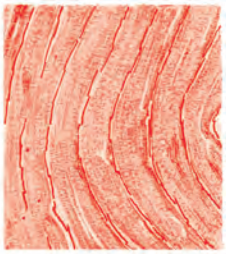
Figure 16-2 Human arm muscles. Many muscles, called antagonistic muscles, act in opposing pairs; as one muscle contracts, the opposing muscle relaxes.

A muscle in a limb is attached to two bones and always extends past a joint. Muscles may be attached directly to bones, but many are attached by means of a cord of connective tissue called a **tendon** (tĕn′dən). Tendons may be seen and felt on the back of the hand where they extend from the fingers to muscles in the forearm. The bands and cords of connective tissue that connect bones with bones are called **ligaments** (lĭ′gə•mənts). It is obvious that ligaments do not hold bones in close contact at a joint, for if they did, no movement would be possible. Ligaments are long and loose. Muscles, which are elastic enough to stretch when the joint moves, hold the bones in close contact with each other.

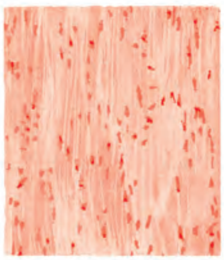
16-4 Cellular Structure of Muscles

Like other tissues of the human body, muscles are composed of cells and fibers. Unlike bone structure, there is very little substance between the cells. The human body has three basic types of muscle cells, each serving a different function.

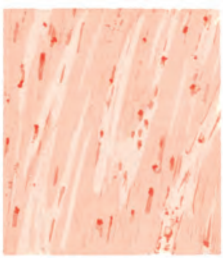
1. *Skeletal muscles* are the most common. They are attached to the skeleton and are the primary muscles used to produce motion. Each muscle fiber may reach up to 35 mm (13.78 in.) in length, but the diameter is very small, the largest being 0.055 mm (0.00217 in.). These fibers have more than one nucleus and have alternating light and dark bands, from which they get the name **striated** (strī´ā´təd) **muscles**. Skeletal muscles are under your own *voluntary control*; that is, you can consciously lift your hand or kick a ball. The other muscles of the body are under *involuntary control* and function automatically without conscious effort.


skeletal

2. The muscles that occur in sheets in the walls of internal organs are called *smooth muscles*, for they have no striations. They function in digestion, enlarging or reducing sizes of blood vessels, and producing movements in the other internal organs (the wavelike motion of the intestinal tract is known as **peristalsis**, pâr´ə•stäl´səs).


smooth

3. *Cardiac muscle*, found only in the heart, is the most specialized of all muscles. It is a highly branched network with the muscle fibrils passing through the cell boundaries. This makes a continuous net. When a contraction begins, it sweeps through the walls of that chamber of the heart and progresses to the other chambers until the blood is forced out into the arteries. It is especially amazing that the heart beats continuously, over 100,000 times a day, for as long as one lives. No other muscle can come close to that record.


cardiac

16-5 Muscular Contraction

A muscle that has been removed from an animal such as a frog can be made to contract experimentally by a sudden application of *stimuli* (pressure, heat, or electricity). In the human body, an impulse is normally received from nerves, with which the muscles are well supplied. This impulse causes the molecules inside the muscle fibers to be realigned, making each muscle shorter and thicker.

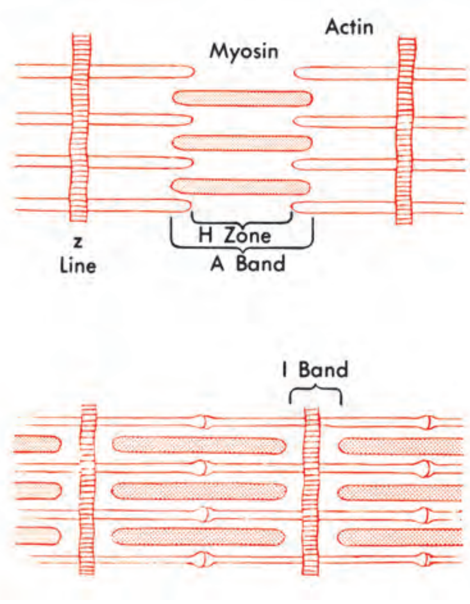


Figure 16-3 Muscle, relaxed and contracted

Contraction involves the use of energy, and the source of this energy is food. All of man's important foods are changed by digestion into one of four substances: glucose, glycerol, fatty acid, or amino acid. Any of these foods can yield **energy** (the power to do work) if they undergo the chemical process of **oxidation** (äk´sə•dā´shən). In other words, when they are burned, they produce heat.

Burning wood is a familiar form of oxidation, in which the wood (a compound of carbon, hydrogen, and oxygen) unites with oxygen of the air, giving off carbon dioxide, water vapor, and heat. This oxidation starts when a certain temperature is reached. It is hindered by the presence of water. Oxidation of food is different in a number of respects. Enzymes allow oxidation of food to take place at low temperatures, and only a small amount of heat is produced. Oxidation of food is a very complex process, and it is not hindered by water. But the final products are the same—*carbon dioxide*, which is removed by the lungs (with help from the circulatory system); and *water*, which is used in the body. The following equation is a simplified summary of the process:[1]

$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ H_2O + 6\ CO_2 + \text{energy}$
(glucose) (oxygen) (water) (carbon dioxide)

Normally, muscles do cellular respiration, as mentioned above; however, under greater exertion, when oxygen cannot reach the muscles fast enough, they switch over and perform **lactic acid fermentation** (fər'mən•tā'shən). In this process, the 3-carbon pyruvic acid molecules are turned into lactic acid. It is the presence of lactic acid in the muscles that makes them so

Type	Shape	Control	Striations	Nuclei	Methods of Stimulation	Type of Contraction
skeletal	long and straight	voluntary	yes	many per fiber	motor nerve	rapid
smooth	spindle	involuntary	no	one per cell	autonomic nerve chemical other smooth muscle cell	prolonged
cardiac	network	involuntary	yes	one per cell	pacemaker nerve fibers other cardiac muscle cell	rhythmic

Figure 16-4 Comparison of muscle types

sore. Once the muscles form lactic acid, it remains in them until it is gradually removed by the blood. This is why a person's muscles feel stiff and sore even if they have not been physically injured.

Nearly all of this energy is carried in the compound called **adenosine triphosphate** (ə•dĕ´nə•sēn´ trī•fäs´fāt´, ATP). The "triphosphate" part of the name comes from three groups of atoms containing phosphorus. The removal of one of these groups changes triphosphate to **diphosphate** (dī•fäs´fāt´, ADP), and energy is set free for the use of the muscle. It is this energy that realigns the molecules and contracts the muscle. This energy is classified as chemical energy and is like heat, light, and electricity in that it has the ability to do work.

ADP has less energy than ATP, and needs to be built up again into the latter, which serves as an agent of power. This is accomplished by the oxidation of glucose or some other digested food. The complexity of the process may be noted from the fact that at least ten chemical reactions are involved, each with its own enzyme.

Skeletal muscles are composed of thick filaments (**myosin**, mī´ə•sən) and thin filaments (**actin**, ăk´tən) that are in close connection (see Figure 16-3). The arrangement of these filaments produces what is seen as striations. Most biologists accept the *Sliding Filament Theory of Muscle Contraction*. This says that ATP activates a reaction between the two filaments, producing **actomyosin** (ăk´tə•mī´ə•sən). When this happens, the filaments "slide" alongside each other, causing the muscle to contract. The movement of these filaments in this manner can be observed under a microscope. Expansion is a passive action, with these filaments being pulled back out by contraction of the antagonistic muscle, expansion being permitted by the elasticity within the cells. This theory does not explain contraction of smooth muscles, however, which have no striations (although both myosin and actin filaments are present).

Muscle Groups	Muscle Description
Pectoralis Major	large chest muscles on front of rib cage
Pectoralis Minor	small chest muscles under large pectorals
Latissimus Dorsi	large, fan-shaped muscles on lower back
Trapezius	long, trapezoid-shaped muscles on upper back
Biceps Brachii	two-headed muscles on upper arm
Triceps Brachii	three-headed muscles on back of upper arm
Abdominals	group of muscles on the front and sides of the lower half of torso
Deltoids	three-headed muscles that crown the shoulders
Quadriceps	group of four muscles that sit on the front of the thigh
Hamstrings	group of three muscles that sit underneath the *Gluteus Maximus* on the pelvic bone and attach on the tibia
Gastrocnemius	two-headed calf muscles on the front of the lower leg
Soleus	lies underneath the *Gastrocnemius* on the back of the lower leg
Adductors	group of muscles that originate on the pelvic bone and attach at intervals along the length of the femur
Gluteus Maximus	large muscles of the buttocks that originate along the pelvic bone crests and attach to the back of the femur
Gluteus Medius and Minimus	smaller muscles of the buttocks that originate in the same spot as the *Maximus* but attach to the sides of the femur
Rotator Cuff	group of muscles that work in the shoulder joint to hold the humerus in place
Iliopsoas	two muscles that originate on the pelvic crest (*Iliacus*) or on the lumbar vertebrae (*Psoas Major*) and attach to the femur

Figure 16-5 Muscle group chart

The size and strength of muscles are influenced by several factors, including exercise, nutrition, and absence of irritants. Persons who fix their attention on exercise and take all other factors for granted have a faulty attitude. Nourishing food and good digestion are indispensable if one wants to excel in athletics. The food should not have an excess of sugar or fat. Exercise should be regular and not too strenuous at the beginning, for violent exercise when one is not in training weakens rather than strengthens. Remember that it is the response to exercise that gives strength, not the exercise directly. The heart is the most important muscle that must grow and be strengthened. Sometimes one hears of a heart that is enlarged, but this condition is due to a response to a leaky valve rather than to exercise.

16-6 Motor Units and Muscle Tonus

Each skeletal muscle is composed of a great number of muscle fibers. These fibers in turn are grouped together into small **motor units**. The biceps, for example, have numerous motor units, each consisting of several muscle fibers. Each motor unit contracts as a whole, with the entire unit responding to one nerve. When one motor unit contracts, it does so with all of its force ("All or None" law). The way a person gets different strengths of contraction in his biceps is not by stronger or weaker contractions of motor units, but by having different numbers of motor units contracting in unison (a nerve cell that controls a motor unit is called a **motor neuron** [nū´rän´]). The more strength he needs to lift something, the greater should be the number of motor units that contract.

Even when a person is at complete rest, some of his motor units in his body are taking turns contracting. This is known as **muscle tonus** (tō´nəs). This helps him to stand or sit up and maintain his posture. It also is thought to be related to keeping the muscles in functioning order for when he really needs them. Muscles that are not used lose some of their tonus and become weakened. A good example of this is the **atrophy** (ă´trə•fē, wasting away of body tissue) that takes place in an arm or leg kept in a cast for long periods.

Questions: Muscular System

1. What is an antagonistic pair of muscles?
2. List the different types of muscle tissues and give an example of where each may be found.
3. From what does the body get the energy to perform muscle contractions?
4. What is the difference between ATP and ADP?
5. How does the Sliding Filament Theory account for muscle contractions?
6. What are the main functions of the muscular system?

Taking It Further: Muscular System

1. Why is the skeletal system vital to the function of the muscular system?

CIRCULATORY SYSTEM

16-7 Circulation

As already mentioned, the movement of the body is done by contraction of muscles acting on the skeletal system. Contraction requires the energy produced by oxidation of food. In order for the above to take place, then, a means of transporting oxygen and food to the muscles is needed. Excess water, carbon dioxide, and other wastes

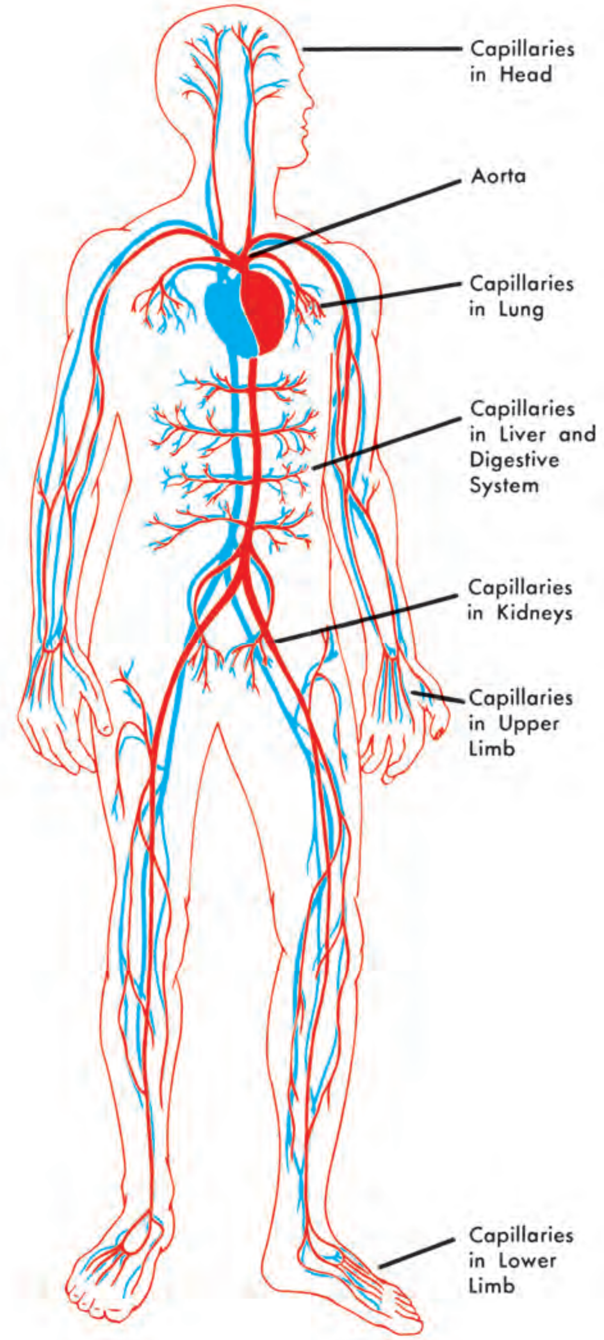


Figure 16-6 The circulatory system. Note the arteries and veins lying in parallel pairs.

must also be transported away from the cells. This job is performed by the **circulatory** (sər´kyə•lə•tôr´ē) **system**. In addition to transporting substances throughout the body, the circulatory system helps to regulate body temperature and maintain the body by preventing infection.

In the past, the second-century physician, **Claudius Galen** (A.D. 129–216), accepted the ancient idea that life was sustained by food that was converted into blood by the liver and that this blood nourished the body's organs. He wrongly advocated that blood flowed *back and forth* in the veins of the body. For nearly a century and a half, scientists used Galen's ideas without verifying them. It was not until 1628 that **William Harvey** (1578–1657) properly showed that blood pumps from the heart throughout the body and returns to the heart, *circulating in a closed system*.

In small organisms, materials move readily by **diffusion** (dĭ•fyū´zhən), or **osmosis** (äz•mō´səs), without special mechanisms for transportation. In some plant cells, the cytoplasm moves in circular fashion, as one can observe through a microscope. In mosses, sap diffuses from one part to another, and in larger plants there is a system of tubes. Also remember that the earthworm has a system of blood vessels in which the blood circulates.

In the human body, the **capillaries** (kă´pə•lâr´ēs) are the smallest vessels of circulation. Capillaries are microscopic in size, with walls only one cell in thickness, and it is these vessels that bring food and oxygen to the cells of all tissues and remove waste products. But if a person had only capillaries, the circulation would be too slow, and the blood would become saturated with wastes long before it reached the lungs and kidneys to be purified. Larger vessels, called **arteries** (är´tə•rēs) and **veins** (vāns´), connect to the capillaries to make the blood move faster. Arteries carry blood from the heart, while veins return blood to the heart.

In ancient and medieval times, no one knew how the blood flowed in the human body. There were various ideas, but most people thought the blood flowed through the veins out to the various parts of the body, where it was used up. It was thought that the arteries carried no blood but a kind of gas called "vital spirit," which kept the body alive.

Strange as it seems now, there were reasons for such a conclusion. When a human body was dissected, no blood was found in the arteries. It is now known that the connective tissue will cause constriction of the vessel, and the smooth muscle in the vessel walls may contract, even after the heart has stopped; and, therefore, the arteries become empty. Another reason for such a theory is that when a person presses an artery it feels as if a pressurized gas were inside. The conclusion of medieval people was based upon observation, but it was incomplete observation.

English physiologist **William Harvey** gave the explanation of blood circulation that has become well established. He was born in England in 1578 and was educated at Cambridge, England, and at Padua, Italy. It is remarkable that, at this early period, Harvey used the scientific method of exact observation, experimentation, and mathematical calculation to prove his theory. He had no microscope capable of revealing the capillaries, but he reasoned that there must be such a connection between arteries and veins. Many people in Harvey's day refused to accept his explanation, especially those who favored established ideas. But capillaries were soon demonstrated by means of the microscope, and the pathway of the blood was thoroughly established later.

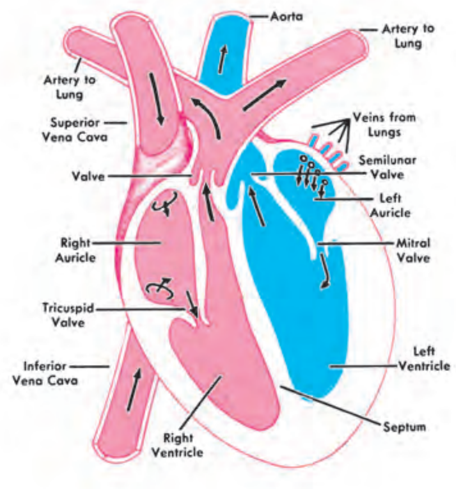


Figure 16-7 Structure of the heart

16-8 The Heart

The blood is propelled by a muscular pump, called the **heart**. Blood flows into a chamber of the heart; then the entrance is closed by a valve, and the chamber is contracted, forcing the blood into a second chamber and then into an artery.

The heart is actually two pumps—the right and left pumps. The wall between the two sides closes at the time of birth, so that blood no longer goes from one side to the other. The left pump is somewhat larger and stronger than the right pump. Its function is to receive blood from the lungs (oxygenated blood) in its upper chamber, or **atrium** (ā´trē•əm), and send it out all over the body from its lower chamber, the **ventricle** (vĕn´trĭ•kəl). If one looks at the heart of an animal, he will note that the atrium has very thin walls. When it is contracted, it is very small.

The right side of the heart receives blood from the veins (deoxygenated blood) of the body in its atrium, passes it down into the right ventricle, which contracts and sends it to the lungs. From the lungs, the blood returns to the left atrium (Figures 16-6 and 16-7).

16-9 Blood Flow

The blood comes from the left ventricle in a spurt, which causes a pressure wave known as the pulse, which can be felt at the wrist and several other places where the arteries lie near the surface. In a normal adult, the blood pressure equals the weight of 120 millimeters of mercury. If it is much higher than this—that is, 200 or more—it may have sudden and serious results. Low blood pressure, 100 or less, causes one to feel weak and run down.

When a person has his blood pressure taken, the doctor records it as two numbers (e.g., 120/80). The larger of these is called the **systolic** (sĭs•tä´lĭk) **pressure.** This represents the pressure due to the *contraction* of the ventricles, when the blood surges from the heart into the arteries. When the ventricles *relax* (and the atrium contracts), the heart is not pumping blood into the **aorta** (ā•ôr´tə), so the pressure gradually drops. This is called the **diastolic**

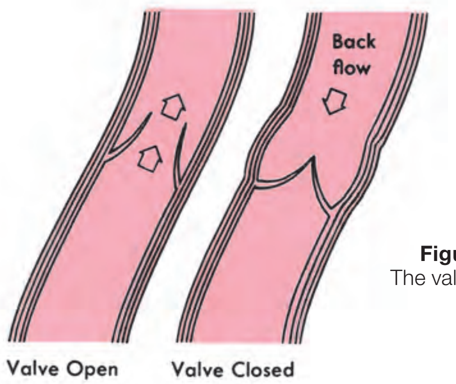


Figure 16-8
The valve in a vein

(dī´ə•stä´lĭk) **pressure.** The fact that the arteries are muscular and elastic enables them to expand during systole and absorb some of the increase of pressure. During diastole (dī•ăs´tə•lē´), on the other hand, the arterial muscles contract and help to maintain the pressure considerably.

The veins have thinner walls than the arteries, and the blood is under much less pressure in them. In many of the veins there are valves that allow the blood to flow freely toward the heart but stop its flow in the reverse direction (Figure 16-8).

16-10 Composition of Blood

The blood consists of two parts—the liquid (**plasma**, plăz´mə) and the cells (**corpuscles**, kôr´pə•səls). Plasma is water containing nutrients, wastes from cells, hormones, and several other substances. The three basic kinds of particles in the blood are the *red corpuscles,* the *white corpuscles*, and the *platelets* (plāt´ləts).

The *red corpuscles* (or **erythrocytes**, ĭ•rĭth'rə•sīts') are produced in the **red marrow** (mâr'ō) of the bones and in a few other places. They are called corpuscles because once they leave the marrow they are no longer true cells, as they have lost their **nuclei** (nū´klē•ī). Without a nucleus to control their functions, they live only from 60 to 120

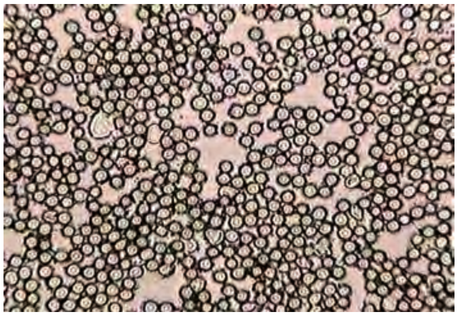


Figure 16-9 Human blood cells. Red corpuscles resemble little lifesavers, thicker at the edges and thinner in the middle. They are much smaller than the white cells, which vary in appearance.

days before they must be replaced. This replacement takes place constantly in a healthy body. If red corpuscles are reduced in number, the blood is lacking in color and the person has **anemia** (ə•nē´mē•ə). The red color comes from a substance called **hemoglobin** (hē´mə•glō´bən), a compound of oxygen, hydrogen, carbon, nitrogen, and iron (Figure 16-9). Hemoglobin is a very important part of the blood. It has a strong tendency to pick up oxygen, but can also release this oxygen easily to the cells of the body. Blood that has little oxygen in it is a dark red color. When the hemoglobin combines with oxygen, it produces **oxyhemoglobin** (äk´sĭ•hē´mə•glō´bən), which is bright red. The oxygen is carried to the cells of the body, where it is used for oxidation of food.

Hemoglobin also has a strong affinity for carbon monoxide. Unfortunately, it will not release the carbon monoxide as readily as it will oxygen. Because of this, a molecule of hemoglobin that combines with carbon monoxide cannot transfer oxygen. If enough of the hemoglobin is combined with carbon monoxide, the body cannot get enough oxygen, and one will soon suffocate. Once it reaches this point, only a **transfusion** (trăns•fyū´zhən) can save the person's life.

White corpuscles (or **leukocytes**, lū'kə•sīts) are less numerous than the red and have the ability to change their shape like an amoeba. In this way, they can penetrate the wall of a capillary and mingle with the body cells. Their principal function is to devour foreign particles such as bacteria or viruses that cause disease. In addition to actually consuming bacteria, some white corpuscles produce antibodies that chemically destroy the foreign particles.

The third type of particle of the blood is the *platelets.* These are tiny disks, which are much smaller than the red corpuscles. These function in forming clots to prevent loss of blood from cuts. When the platelets touch the torn surface of a vessel, they stick to it and disintegrate. This initiates a series of chemical reactions that enable some sticky fibers to form a netlike structure over the wound. Red corpuscles stick to this net, which finally shrinks and squeezes out the plasma, leaving behind a dry, hard clot, or **scab**. At the same time, white corpuscles rush to the scene to fight off any infectious material that may have entered the wound.

The fluid between the cells in the tissues is called **tissue fluid** (or *lymph*, lĭm[p]f´); the fluid part of the blood is *plasma*. The tissue fluid leaves the capillaries and flows around the cells. It carries food and oxygen to the cells. Some blood proteins found in plasma do not pass outside the capillaries; and thus the two fluids are not exactly the same. Much of the tissue fluid, or lymph, is returned to the veins by a system of tubes called **lymphatic vessels**. These unite into larger vessels resembling the veins and finally empty into the veins in the shoulder.

At certain points along the lymphatic vessels, there are structures called **lymph nodes.** These serve to filter the lymph before it is returned to the bloodstream. The **spleen** (splēn´), the largest lymphatic organ, destroys dead blood cells (*erythrocytes*), filters the blood, and stores red and white corpuscles. Probably the most common lymphatic organs are the **tonsils** (tän´səls). At one time, if a person was in the hospital, doctors would remove his tonsils even if they were not infected. Tonsils were considered to be useless organs, but today it is known that they are important to the body's defense against infection. Now tonsils are removed only when they "lose the battle" and become infected. All of these lymphatic organs also produce white corpuscles and antibodies that fortify the body's **immunity.** These organs, vessels, and nodes are often classified as part of a separate system called the **lymphatic** (lĭm•fă´tĭk) **system.**

16-11 Blood Transfusion

In chapter 7, the danger in mixing blood of different types was mentioned. The inheritance of blood types also was explained. In chapter 11, the entrance of foreign substances called **antigens** (ăn´tĭ•jəns) into the body was cited along with the defense mechanism of antibodies. Review of these discussions would be helpful at this time.

If blood of the wrong type is mixed with a person's blood, it induces a similar reaction as a bacterium or any foreign antigen. The antibodies in the blood cause the clumping of the red corpuscles, and the result is that they cannot pass through the capillaries. The two major blood antigens have been named A and B. Four major blood groups are recognized—A, B, AB and O. Group A blood contains type A antigen. Group B blood contains type B antigen. Group AB has both A and B type antigens, and group O blood has neither antigen.

On the other hand, the blood of a type-A person contains antibody *b*. The blood of a type-B person contains antibody *a*. The blood of a type-AB person contains neither antibody, and the blood of a type-O individual contains both antibody *a* and *b*.

It is obvious how important it is to know one's blood group and also the blood type of the donor before a transfusion is begun. Antigen A must be kept away from antibody *a*, and antigen B from antibody *b*.

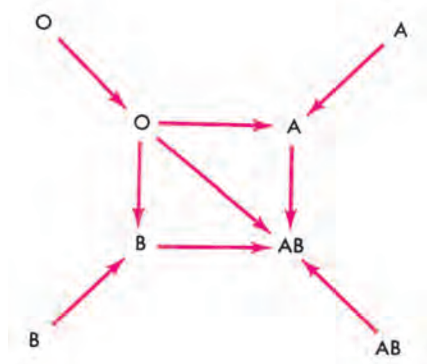


Figure 16-10 Possible blood transfusions. Arrows point towards recipients and away from donors. Whenever possible, an individual should receive his own blood type. Blood type O can be considered the universal donor and blood type AB the universal recipient.

Since the antigens are on the red corpuscles, sometimes these cells are removed from the blood to be used for transfusion, leaving the plasma, which may even be dried for ease of handling. Plasma may be used in transfusions for any person without matching of blood types. Much plasma, including dried plasma, was used in World War II.

Questions: Circulatory System

1. What is the main organ of the circulatory system?
2. What is the difference between *veins* and *arteries* and how are they connected?
3. What are the different components of blood and what type of cells and substances can be found in each?
4. Why is it important to know a patient's blood type? Give examples.
5. What are the functions of the lymphatic system?
6. What are the main functions of the circulatory system?

Taking It Further: Circulatory System

1. How are the circulatory and skeletal systems interdependent?

RESPIRATORY SYSTEM

16-12 Gas Exchange

From the discussion of muscle action, it is known that oxygen is needed for the oxidation of food to release the chemical energy of the food. In one-celled animals, oxygen diffuses in through the outer membrane. Even the frog breathes partly through the skin, but this does not afford enough surface for the diffusion of oxygen. Therefore, it has lungs also. Human skin is too thick and dry for oxygen to penetrate. The lining of the **alveoli** (ăl•vē´ə•lī´, air sacs) in the lungs has the same function as the skin of a frog. Likewise, they are kept moist, and they are richly supplied with capillaries, as is frog skin. The alveoli are so numerous that their linings provide a surface area much greater than that of the entire skin surface.

16-13 Breathing Organs

Although air may enter the body through the mouth, breathing is preferred through the nose, as it has special protective devices. Near the opening of the nostrils there are hairs, which filter the dust from the air, while the nasal passages and sinuses located further back warm and humidify the air before it reaches the lungs.

Air is carried toward the lungs by the **trachea** (trā´kē•ə). Within this tube are numerous *cartilaginous* (kär´tə•lă´jə•nəs) *rings*, which keep it from collapsing while maintaining lightness and flexibility. Lining the inside of the trachea is a mucus secretion, which collects dust and foreign particles. Cilia, embedded in this lining, sweep these particles upward to the throat, where they are swallowed.

At the top of the trachea is the **larynx** (lâr´ĭ[ng]ks), or voice box, where sound is produced by the **vocal cords**. At the opening of the voice box is a cartilage flap, called the **epiglottis** (ĕ´pĭ•glä´təs), which closes when a person swallows, to keep food and liquids out of the lungs. When it fails and food enters his trachea, an involuntary response causes him to cough violently, forcing the food back up and out of the trachea.

At the lower end, the trachea divides into the **bronchi** (brä[ng]´kī´), which enter the lungs. These divide into smaller and smaller tubes until they divide into the alveoli, where all the gas exchange takes place.

The lungs are enclosed in a moist **pleural membrane**, which protects them by reducing friction on their surface. The lungs are not muscular and cannot force air into themselves. Instead, they are entirely passive, depending on the rib muscles and **diaphragm** (dī′ə•frăm′, which is below the lungs) for drawing air into them. For inhalation, the rib cage is expanded, and the diaphragm is pulled downward. The pressure in the **thoracic cavity** is reduced as it expands, and air from outside the body rushes into the lungs to equalize the pressure. The elastic recoil of the body causes the air to be exhaled.

Normally, air pressure keeps the pleural membranes firmly against the thoracic wall. But if air is admitted through an opening in the wall of the thorax, the lung will collapse and cease to function. A person can live with one lung if he does not work hard. If a lung is diseased, as in tuberculosis, a doctor sometimes makes such an incision to collapse a lung so that it will heal more readily. After a time, the air between the lung and the thoracic wall will be absorbed, and the lung will be distended again.

In the discussion on muscles, it was specified that some are under *voluntary control* and others *involuntary control*. The muscles controlling breathing are unique. Usually a person's breathing is involuntary. He is able to choose to breathe deeply or hold his breath, but he can hold his breath only up to a point, when his involuntary mechanism takes over. It is also this involuntary mechanism that maintains his breathing while he sleeps.

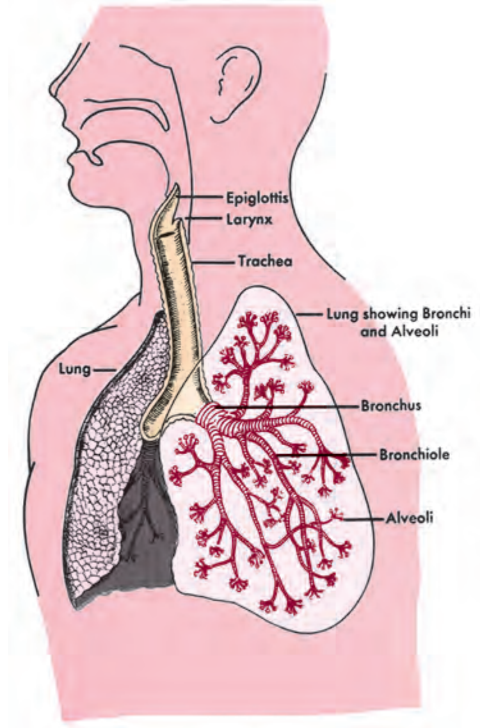


Figure 16-11 The lungs

16-14 Gas Composition

Air varies somewhat in composition but is composed of about 21 percent oxygen, 78 percent nitrogen, and .04 percent carbon dioxide; the rest is made up of rare gases including argon and neon. Nitrogen is breathed in and out without being utilized or changed very much in its amount. All of the nitrogen needs of the body are met by compounds of that element in food, not by free nitrogen in the air.

When air is breathed out, it contains about 78 percent nitrogen, 16 percent oxygen, and 5.3 percent carbon dioxide. It usually is more moist and warmer than the air that is breathed in, for a person loses both heat and water in breathing. In the various cells of the body, an exchange takes place that is the reverse of that in the lungs. Oxygen diffuses through the wall of the blood vessel and the cell wall into the cell, while carbon dioxide diffuses from the tissues into the bloodstream.

Questions: Respiratory System

1. List the components of the respiratory system.
2. What is special about the muscles involved in respiration? Why is this characteristic vital?
3. What are the functions of the respiratory system?

Taking It Further: Respiratory System

1. Why is it harder to breathe at higher elevations? Give specific reasons.
2. Why is it important for people to be good stewards of plant life?

DIGESTIVE SYSTEM

16-15 Digestion

While the lungs are the largest organs in the thorax, the digestive organs make up the bulk of the organs of the lower cavity, the **abdomen**, which is below the diaphragm. The processes of taking in food, chewing, swallowing, digestion, and elimination of the undigested portion are together called *alimentation* (ă′lə•mĕn•tā′shən). The series of organs in which these processes are accomplished is called the **alimentary canal** (Figure 16-13).

Digestion begins in the mouth, where saliva from the three pairs of **salivary glands** near the mouth begins the breakdown of starches. Before saliva or any other digestive enzyme will function effectively, large pieces of food must be broken down into parts that can be digested more easily. This is the function of the teeth. Teeth are composed of a hard, bonelike substance called **dentine** (dĕn′tēn′), surrounded by very hard, smooth **enamel**. In the center of a tooth is the **pulp cavity**, which contains blood vessels and nerves. **Dental caries** (dĕn′təl kâr′ēz, tooth decay) are the result of acid wastes produced by bacteria that break down food particles left between the teeth. This process is slow in the hard enamel; but once it reaches the softer dentine, it proceeds very rapidly. A caries that penetrates to the pulp cavity not only is painful but also can spread infection to the rest of the body through the blood vessels.

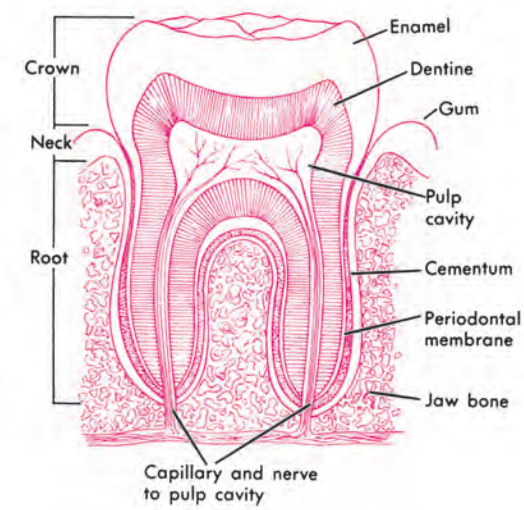


Figure 16-12 Cross section of a tooth

Different types of teeth perform different functions. The **incisors** (ĭn•sī′zərs) across the front of the mouth cut the food; **canines** (eyeteeth) are used to tear or rip meat; and **premolars** and **molars** are used to grind and chew food. Animals that eat primarily meat (carnivores) will have large canines, whereas plant eaters (herbivores) have larger molars and usually no canines. Human beings have a varied diet (being omnivorous); and none of their teeth are specialized to any extreme.

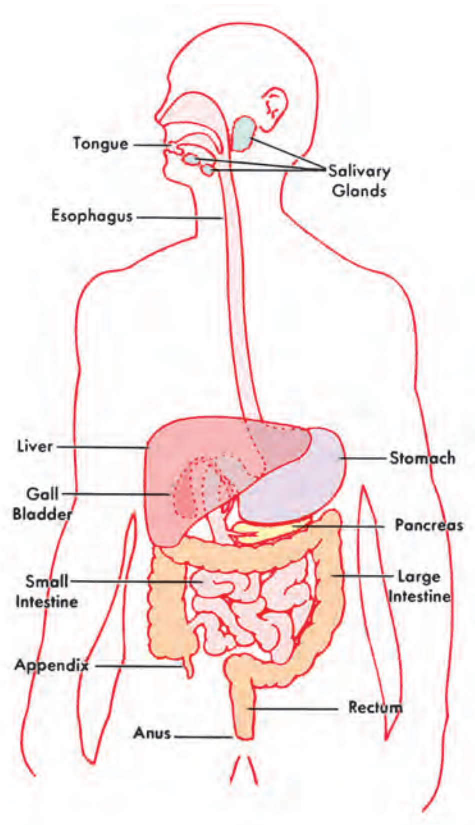


Figure 16-13 The digestive sytem

The **tongue** is used not only for speech, but also to push food between the teeth while one is chewing. This is an amazing feat, considering that the tongue is only rarely bitten in the process. Once the food is chewed well, the tongue also pushes it back to the throat where it is swallowed. Although gravity aids in getting food into the **esophagus** (ĭ•sä′fə•gəs), it is not needed once the food enters because the walls of the esophagus contain smooth muscles that contract in a wavelike motion and push the food in front of the contraction toward the stomach. This wavelike contraction is called **peristalsis** (pâr′ə•stäl′səs). It occurs throughout the alimentary canal.

The **stomach** continues the digestion of food. It produces not only the *hydrochloric acid* that creates the proper acidic environment for the stomach's enzymes to function, but also enzymes that begin to break down proteins. The stomach has a muscular wall with many ridges, or **rugae** (rū′gī or rū′jē). As the muscles twist the stomach walls, these rugae mix and churn the food with the digestive enzymes. The **pyloric** (pī•lôr′ĭk) **valve** at the end of the stomach remains closed until the food reaches the consistency of a thick paste, called **chyme** (kīm′), and then allows it to pass to the small intestine. The amount of time required for this to take place depends on the type of food involved.

The acid and the enzymes released from **gastric** (găs′trĭk, stomach) **glands** are necessary for digestion, but they can also be the cause of problems. Normally, a mucus lining lubricates the stomach and the entire digestive tract and protects them from the action of the acid and enzymes. Conditions like tension, nervousness, and eating too much of the wrong foods can cause the acids and enzymes to be produced in greater than normal quantities, and at a time when food is not present. The acids break down this mucus lining and expose certain areas of the stomach lining. The enzyme **pepsin** (pĕp′sən) of the stomach digests protein, and the stomach lining, being protein itself, is then partially digested by the pepsin. The result is a **peptic ulcer** (pĕp′tĭk əl′sər).

The majority of digestion occurs in the first one third of the **small intestine** (which is smaller in diameter, though greater in length, than the large intestine). Enzymes are produced in the intestinal linings, and others come into it through ducts from the **gall bladder** or the **liver** and the **pancreas.** In the remaining two thirds of the small intestine, absorption of the digested food into the bloodstream occurs. The walls of the small intestine are covered with tiny fingerlike projections called **villi** (vĭ′lī′). These provide a greatly enlarged surface area and, being filled with capillaries and lymphatic vessels, they absorb the food through the intestinal linings.

The **large intestine** (or *colon*, which is larger in diameter than the small intestine) is basically for absorption of liquid materials. Once the food materials and water are absorbed, the concentrated wastes are passed into the muscular **rectum** (rĕk′təm) for temporary storage. At a convenient time, the rectum muscles contract, forcing the feces out through the **anus** (ā′nəs).

16-16 Need for Food

All living creatures need food, and nearly all food comes directly or indirectly from plants. It is easy to see the need for materials to be used in growth and repair. Even more food is used to supply energy, as learned in the study of muscles. Energy is needed not only for muscle action, but also to maintain the heat of the body. Animals that do not maintain a constant temperature, like fish, have a relatively small need for food. In addition, small but important amounts of certain foods are needed for regulation of the digestive system.

Foods that are used for growth and repair are of two types—**minerals** and **proteins**. Although minerals are needed in very small amounts, they are essential. Examples are *calcium carbonate* and *calcium phosphate* for bone structure, and *iron* compounds for red corpuscles. Other elements that are needed by the body have been explained in the chapters on chemistry.

As it has also been mentioned, proteins are a major part of all living tissue. Specific proteins are found as follows: *myosin* (mī′ə•sən) in lean meat, *casein* (kā′sēn′) in cheese and milk, *albumen* (ăl•byū′mən) in egg white and *legumen* (lĕ•gyū′mĕn) in beans and peas. These foods contain other substances also, in addition to the protein. Proteins in food are utilized to build tissues in the body.

Foods used for energy, either heat or motion, are principally *fats* and *carbohydrates*. The carbohydrates are *sugars*, *starch*, and *cellulose*. They are called "carbohydrates" because they contain carbon (*carbo*, C_n), hydrogen (H_{2n}), and oxygen (O_n) in the same ratio as found in water (H_2O, two parts H to one part O—thus *hydrate*). Fats yield a large amount of energy when oxidized because of the large proportion of carbon and hydrogen, with oxygen in smaller amounts. Only bacteria digest **cellulose** (sĕl′yə•lōs′, this type of bacteria is found in the rumen of cows and like animals).

It is also possible to use protein for energy when other foods are not available, but this is not efficient. Before protein is oxidized, the liver splits it into an amino part and a carbohydrate. Then only the carbohydrate is oxidized, and the amino part is thrown off as waste. Since most protein foods are relatively expensive, this waste may amount to a large expense after a time. A good ratio of foods is four parts of carbohydrate, to one part of protein, to one part of fat.

The value of foods in energy production has been measured by burning quantities of those foods in the laboratory. The vessel containing the burning food is surrounded by water, which absorbs the heat produced. The standard unit of heat is the **calorie** (kă′lə•rē), which is the amount of heat necessary to raise the temperature of 1 kilogram of water 1° Celsius (called a "large calorie," 1000 gram calories).

When resting, the average person needs 1,700 calories of food a day; and a man working hard in cold weather may need 4,000 calories. In many countries it is hard to obtain this much food, but in the United States there is so much food that many people have to be careful not to overeat.

16-17 Vitamins

Among the regulatory foods, the most important are the **vitamins**. The precise physiological functions of most of the vitamins in the body are not known; but, from the physical effects caused by lack of them in the diet, their possible functions have been deduced by research scientists. There is no generally accepted theory as to how they influence nutrition. Some act as coenzymes or influence enzyme systems within cells. Minute quantities are effective; for example, only 0.5 mg. of vitamin B_1 is required daily by a healthy adult. But the presence of vitamins is necessary in our food to prevent **deficiency diseases**. Plants and fish liver oils furnish many vitamins, but most vitamins can now be manufactured in the laboratory. Rats, mice, and birds have been used a great deal for experimental work (Figure 16-14). The usual procedure is to feed an animal a diet that is normal in every respect except for the absence of a particular vitamin, and then to observe the results. The results are usually similar to the conditions that appear in a person deprived of the same vitamin. Originally, vitamins were designated only

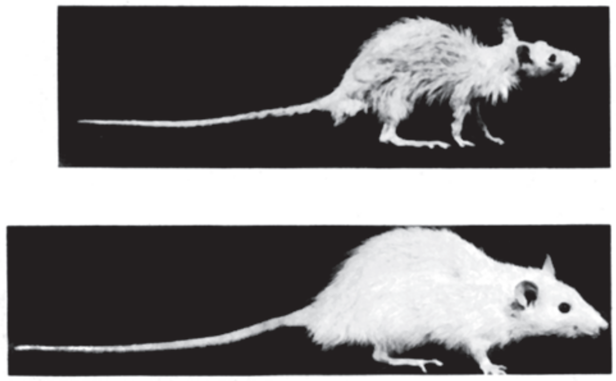


Figure 16-14 A rat's appearance during riboflavin (vitamin B_2) deficiency—sickly, with loss of hair and weight (upper). The same rat is seen six weeks later, after receiving food rich in riboflavin (lower).
USDA

by capital letters; but as their chemical structure became known, they have been given chemical names as well.

Vitamin A has its source in the pigment *carotene* (kâr´ə•tēn´) of plants, which in man is changed into vitamin A. This vitamin is used by the eyes to synthesize the light-sensitive retinal pigments needed by the **rods** for vision. Lack of this vitamin not only interferes with normal vision, but also disturbs the secreting powers of **mucous membranes**; for example, the **tear glands**. When the tear glands do not keep the eye moist, the condition called "dry eye" results. The eyesight is impaired, resistance to certain infections decreases, and growth is retarded. **Night blindness** (inability to see in dim light) has been known for centuries. This condition results from insufficient amounts of a substance in the eye known as *visual purple*, which is essential for good vision in dim light. To regenerate visual purple, vitamin A is required. A large number of persons suffer from some degree of night blindness. The chief sources of vitamin A are fresh vegetables such as spinach, asparagus, carrots, and sweet potatoes, and fish-liver oils. Vegetables do not actually contain vitamin A, but the body can form it from them.

Among the vitamin B group, which is primarily associated with nerve, skin, and blood maintenance, **vitamin B_1** or *thiamine* (thī´ə•mən), was the first member to be differentiated. Its absence causes the disease known as *beriberi*, which is prevalent among oriental people who live on a diet consisting largely of polished rice. Beriberi is characterized by loss of appetite and degenerative changes in the nervous system. Thiamine is abundant in brewer's yeast and whole cereal, and in wheat germ and bran. It is also found in peas, beans, nuts, and liver. Lack of thiamine also causes changes in ganglion cells and the sheaths of nerve fibers, often resulting in actual destruction of the cells, or irritation or degeneration of nerves. Frequently, the fibers of nerves become so irritated that a condition called *polyneuritis* (pä´lē•nū•rī´təs) results, which manifests itself by excruciating pain along the course of the nerves. Anxiety and fear complexes can result from a lack of the vitamin B group.

Vitamin B_3 (*nicotinic acid* [nĭ´kə•tē´nĭk ă´səd] or *niacin* [nī´ə•sən]) prevents *pellagra* (pə•lă´grə), which is characterized by roughened skin on the hands, arms, feet, face, and neck, a sore mouth, pink tongue, diarrhea, and nervous disturbances. Along with this, severe muscular weakness and one or more forms of mental illness often occur. Niacin is found in milk, green vegetables, egg white, and meat.

Vitamin B_6 (*pyridoxine*, pĭr´ə•däk´sēn) has not yet shown a disease due to a deficiency, although this vitamin has proven to be essential for good health. It plays an important role in certain enzyme actions in amino acid metabolism in the cell. It was first found to prevent *dermatitis* (dər´mə•tī´təs) in rats. Yeast, whole cereal grains, milk, and liver are good food sources of pyridoxine.

Biotin (bī´ə•tən), another of the vitamin B complex, is necessary for the growth of birds; but in man it is not a dietary requirement; it is supplied by the intestinal bacteria. Deficiency symptoms are diarrhea, dermatitis, and nervous disorders. Sources of this vitamin are liver, kidney, and yeast.

Vitamin B_{12} was first isolated from liver. It is necessary for the formation of red corpuscles. A deficiency in man causes *pernicious* (pər•nĭ´shəs) *anemia*. B_{12} is also essential for the growth of young animals. Sources of this vitamin are milk, liver, kidney, and lean meat.

The primary function of **vitamin C**, or ascorbic (ə•skôr´bĭk) acid, is to maintain normal intercellular substances throughout the body. These include the connective tissue fibers that hold the cells together, the intercellular cement substances between the cells, the matrix of bone dentine, of the teeth, and other substances secreted by the cells into the intercellular spaces. Deficiency of ascorbic acid in the diet causes a failure of wounds to heal because of failure to deposit new fibers and new cement substances. It causes bone growth to cease and retards the blood-clotting process. Vitamin C is abundant in oranges and other citrus fruit.

A deficiency of **vitamin K** depresses blood coagulation, thus causing excessive bleeding of wounds. Treatment of a newborn baby with this vitamin prevents the tendency to bleed, which often exists. The chief sources of vitamin K are green, leafy vegetables and certain bacteria, such as those living in human intestines.

Vitamin D, found in fish oils, is necessary for bone growth. Its absence leads to a condition called *rickets* (rĭ´kəts), in which the limb bones are weak and bent. This vitamin can be formed by the body in the presence of sunlight.

Vitamins are necessary and essential to life. They do not have to be digested, and they play an important part in enzymatic processes. Cooking may destroy vitamin C, unless it is done in a pressure cooker. Today, bread, cereal, and milk have been fortified with vitamins. Thus, with a well-rounded diet there is no need to take vitamin supplements, unless a doctor so prescribes.

Food Type	Mouth	Esophagus	Stomach	Small Intestine
Carbohy-drates	Salivary amylase	no digestion	Starch digestion stops (pH) gradually.	Pancreatic amylase continues starch digestion; intestinal carbohydrates complete digestion to yield simple sugars.
Fats	none		Gastric juice starts fat digestion.	Liver bile emulsifies fats; pancreatic lipase converts fats to fatty acids and glycerin.
Proteins	none		HCl activates pepsin; pepsin begins protein digestion.	Pancreatic trypsin and intestinal proteinases complete the digestion of proteins into amino acids.

Figure 16-15 This summary of digestion lists the more important enzymes—how and where they work on the carbohydrates, fats, and proteins. The other food requirements (water, minerals, and vitamins) require no digestion but are absorbed by the body as they are.

16-18 Chemistry of Digestion

After food is taken into the mouth and chewed, it is not yet prepared for distribution over the body. All of the organs of the alimentary canal are lined with membranes through which there are no gates or valves. It is necessary for the food to pass through these membranes to get into the body tissues. The membranes of the body allow passage of some substances but exclude other substances. These membranes are important in keeping out disease-causing bacteria and other harmful substances. It is said that such membranes are *differentially* or *selectively permeable*.

It is easy to see that many food particles are too large to pass through a membrane; therefore, the food must be digested. Thus, complex sugar, such as *sucrose* (found in cane and beets), is broken down into simple sugar, such as *glucose* (found in fruit). Likewise, the giant molecules of proteins are broken down into their component amino acids; starch is changed to simple sugars, such as glucose.

Fats are digested in the small intestine, where most of the digestion takes place, by the enzyme *lipase* (lī′pāz) furnished by the pancreas. Fats are broken down into glycerin and fatty acids. This process is aided by **bile** from the liver.

Other properties of particles, in addition to size, seem to determine whether they pass through membranes or are detained by them. Such processes are not entirely explained by **diffusion** (which has been studied in chapter 4). An example is the absorption of digested food into the blood vessels in the small intestine. In ordinary diffusion, the glucose and amino acids would be absorbed into the blood until the concentration in the blood equals the concentration in the intestine, and then they cease. But the absorption goes on to completion. This is an example of *active transport*, where the cells use their stores of ATP to increase the transport against the **concentration gradient** (the difference in concentration of ions across a membrane, which drives diffusion). However, more research is needed to fully understand the process.

16-19 Assimilation

When digested food has been transported to the various cells of the body, it is either oxidized or assimilated. (Oxidation in the muscles has been studied earlier in this chapter.) **Assimilation** is the changing of food so that it becomes a real part of the cells of the body. The amino acids may have been derived from the protein of beef or of beans, but in the human body they are built into human protein. Not only is the chemical formula different, but now it is part of a living cell.

Questions: Digestive System

1. What type of muscle tissue aids in most of the digestive process?
2. Describe the path of food through the digestive system.
3. What is the function of the liver in digestion?
4. List the vitamins mentioned necessary to human diets and what they are thought to influence.
5. What are the main functions of the digestive system?

Taking it Further: Digestive System

1. List the other systems that are necessary for the proper functioning of the digestive system and why.

EXCRETORY SYSTEM

16-20 Removal of Wastes

Carbon dioxide, one of the chief products of metabolism, passes out of the body by way of the lungs. Other waste products, mostly compounds containing nitrogen, such as *urea* (yū′rē•ə), *uric* (yûr′ĭk) *acid*, and *creatinine* (krē•ă′tən•ēn′), must be carried out of the body in solution. The composition of the blood cannot be allowed to vary beyond narrow limits lest the conditions within the tissues necessary for the life of the cells be lost. Regulation of the composition of the blood involves not only the removal of harmful waste products, but also the conservation or excretion, as conditions demand, of such normal components as water, sugar, and salts. In this double process the kidneys are very important.

16-21 Organs of Excretion

The urinary system consists of two large glands called the *kidneys*, which excrete **urine** (yŭr´ən); the ducts leading from them, the *ureters* (yū•rē´tərs); a large urinary reservoir, the *bladder*; and the tube leading from it to the surface of the body, the *urethra* (yū•rē´thrə).

The **kidneys** are surrounded by a layer of fat and lie on the posterior abdominal wall opposite the last thoracic and the first three lumbar vertebrae. The shape of the kidneys, that of an elongated oval with a notch on one side, is so well known as to give rise to the descriptive term "kidney-shaped." The region of the notch is called the *hilum* (hī´ləm), and here the ureter and blood vessels attach to the organ. The surface of the kidney is relatively smooth and is covered with a thin membrane of connective tissue.

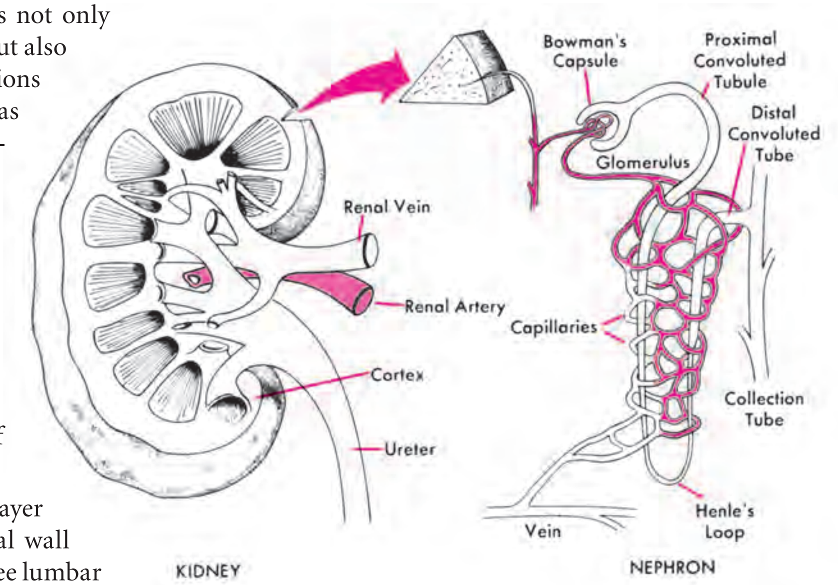


Figure 16-17 The internal structure of a kidney as revealed by dissection (right). In the cortex are found about a million microscopic structures called nephrons. These nephrons remove substances from the blood and from the urine.

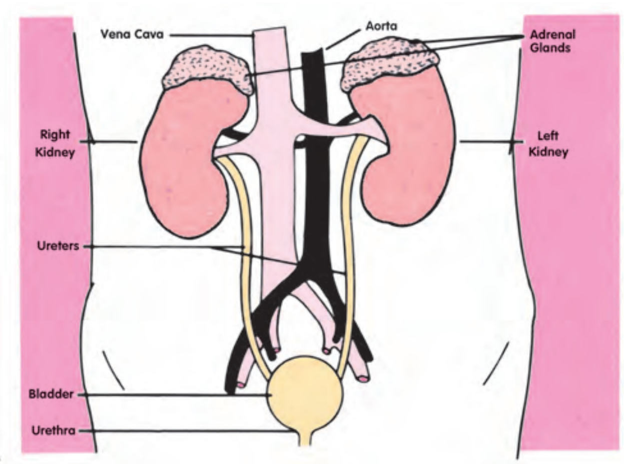


Figure 16-16 The kidneys and associated organs. The adrenal glands, situated on top of the kidneys, have nothing to do with excretion, but secrete hormones.

Each kidney contains many thousands of filtering units called **nephrons** (nĕ´fräns´). A blood vessel enters the nephron and forms a bed of capillaries called a **glomerulus** (glō•mĕr´yə•ləs). Surrounding this is a cup-shaped structure known as the **Bowman's capsule**, which collects water, minerals, and waste products from the blood and passes them into a coiled tubule surrounded by a capillary bed. Water and minerals are reabsorbed into the bloodstream as they pass through this tubule. The tubule empties into larger collecting tubules, which finally lead to the **ureter**. One ureter from each kidney carries urine to the urinary bladder for temporary storage.

The **urinary bladder** is a large, muscular bag that lies in the pelvic cavity behind the pubic bones (or *pubes*). The interior of the bladder is lined with a membrane that is smooth when the organ is full and distended, and thrown into folds when it is empty and collapsed.

The filtering action of the kidneys can be better appreciated if a person examines its work. It has been estimated that 1,700 liters of blood pass through the kidneys in one day. Of this, 170 liters are absorbed into the Bowman's capsule, but 168 liters of this are reabsorbed into the capillaries. Hence, only about two liters of concentrated urine are passed out each day, conserving great quantities of water at the same time that it rids the body of poisonous wastes.

The **large intestine** throws off some of the products of metabolism such as certain liver secretions. Most of the material eliminated consists of indigestible components of food.

The **skin** also functions to excrete some water and salts through the *sweat glands*.

Questions: Excretory System

1. What organs are used by the excretory system?
2. Draw and label the different sections of a nephron.
3. What is the benefit of eliminating only highly concentrated urine.
4. What is the purpose of the excretory system?

Taking It Further: Excretory System

1. What would happen to a human body if the excretory system ceased to function?

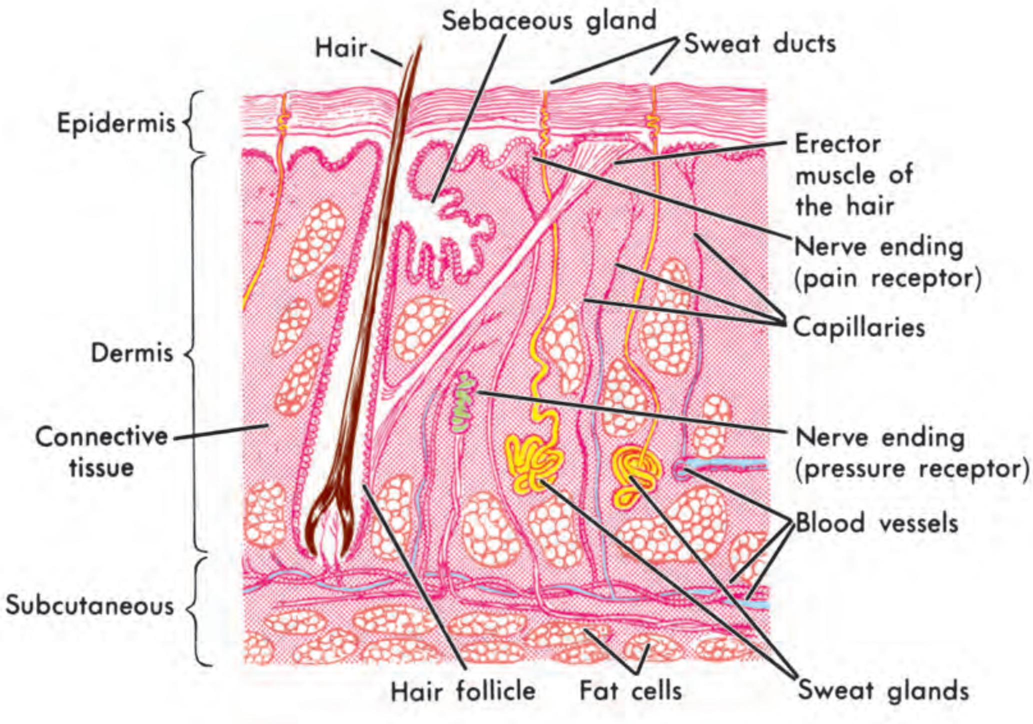


Figure 16-18 Vertical section of the skin

INTEGUMENTARY SYSTEM

16-22 The Integument

The **integumentary** (ĭn•tĕg´yə•mĕn´tə•rē) **system** is the outer covering of the body, which includes *skin* (or **cutis**), *hair*, and *nails*. It functions to a limited extent as an excretory organ, using the sweat glands, as just mentioned. It also is the location of nerves for the sense of touch. The prime function of the **integument** (ĭn•tĕg´yə•mənt´), however, is to protect the body. Its surface may not seem to be very tough, but it is sufficient to keep out infectious organisms, protect the body from harmful *ultraviolet radiation*, and prevent the body from drying out. The skin also helps to control body temperature. (See the section on "Homeostasis" [hō´mē•ō•stā´səs] in the following chapter.)

Examine Figure 16-18, which shows a vertical section of skin. Skin has two major layers—the **epidermis** (ĕ´pə•dər´məs) on the surface and the **dermis** (dər´məs) underneath. The dermis is where all active skin functions take place. It contains the hair follicles, the muscles that are attached to them, the oil glands, fat cells, blood vessels, and nerve endings.

At the very top of the dermis is a layer of cells that produce the epidermis. These cells push towards the surface but become flattened and dried out as they do it. For the most part then, the epidermis is a thin layer of tough, dry cells that are no longer living. A tough waterproof protein called **keratin** (kâr´ə•tən) has replaced the cytoplasm of the cell. These epidermal cells are continually rubbed off by friction and replaced from below. Where friction is more common, the irritation causes growth to be faster. This produces a thicker layer of epidermis called a **callus** (kă´ləs).

Fingernails and toenails are also a part of the integument. They originate between the epidermis and the dermis and are not part of the skeleton as many people think. Most of the nail is dead, but the **base** (or *root*) below the skin is living and continually growing.

Although one normally thinks of humans as having very little hair in comparison with mammals, people actually have fine hair over all of their bodies except the soles of their feet, the palms of their hands, and a few other small areas. Much of this fine hair aids them in their sense of touch. Each hair follicle has an oil gland (called a **sebaceous** [sĭ•bā´shəs] **gland**) near the root, which continually secretes oil onto the hair. This provides for the natural "grooming" and maintenance of the hair and of the skin.

Many young people have trouble with **acne** (ăk´nē). This condition results when the sebaceous glands fail to discharge their secretions, and they collect into semisolid masses, or "blackheads." When they become infected with bacteria and filled with pus, they are called *pimples*. The cause of acne is not completely clear. Some **dermatologists** (dər´mə•tä´lə•jĭsts, skin specialists) attribute the basic cause to a hereditary tendency, which is activated by hormones, nervous tension, or certain foods. Acne usually lasts for only a few years during adolescence.

Skin color is due to several factors. In the lower layer of the epidermis are granules of a pigment called **melanin** (mĕ´lə•nən). This brown pigment is found in all races of man, but to varying degrees. In *Caucasoids*, there is very little of this pigment, so that most of the skin color comes from the blood vessels as they appear through the skin. In *Negroids*, however, there is a lot of brown pigment. The apparent differences in color are merely differences in the amount of the melanin found in the skin, not differences in the type of color.

As mentioned above, the skin protects the body from ultraviolet radiation, but the skin itself can be affected by UV rays. In gradually increasing small dosages, the ultraviolet light from the sun increases the amount of pigment in the skin, or "tans" it. However, in large dosages, the sun will destroy the cells of the skin and produce a *sunburn*. It is interesting to note that ultraviolet radiation cannot pass through clear glass (if it has a high **ferric** [fâr´ĭk, iron] content), but it does penetrate dense clouds. A person with little pigmentation can get severe sunburn even on a cloudy, windy, cool summer day.

Questions: Integumentary System

1. What is the main organ of the integumentary system?
2. What gland is the main source of acne problems?
3. Why is it important for people with little melanin to wear suntan lotion on a cloudy day?
4. What are the main functions of the integumentary system?

Taking It Further: Integumentary System

1. What basic substance of the cell are the UV rays changing to produce more melanin?

Questions: Chapter Review

1. What is the function of a tendon? Of a ligament?
2. How is the stimulation of smooth muscles different from that of striated muscles?
3. How must muscles be attached to bones to flex a limb?
4. Using your knowledge of muscle contraction, explain how an outstretched arm can be held in one position.
5. Trace the route of blood from the heart, through the head, and back to the heart. Do the same for blood going through a foot.
6. Why is the pulse felt only in the arteries?
7. When a wound is bleeding, how can you tell whether an artery or a vein has been severed?
8. Why are more valves needed in the veins of the legs than in the veins of the arms?
9. What protective "devices" are found in the respiratory system?
10. Discuss several reasons why the body needs food.
11. What structure of the body keeps undigested food from being transported by the bloodstream?
12. Name three areas of the body that function in excreting waste products.
13. Why is it necessary to have a capillary bed surrounding the tubules in the kidney?

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[1] See page 42 of chapter 5 for this same chemical equation, which represents the process of cellular respiration.

CHAPTER 24

PROBLEMS FOR EVOLUTIONISTS

MECHANISM AND EVOLUTION

24-1 Problem of Mechanism

A basic problem facing evolutionists is finding some means, or *mechanism*, that might produce the changes of plant and animal forms, or kinds, required by the doctrine of evolution. **No satisfactory mechanism has yet been found**. Many mechanisms have been suggested through the years, but careful investigation has shown difficulties with each one of them. The mechanism most seriously considered today is the *accumulation of successive random mutations*.

Remember from the study of chapter 7 that **mutations** are changes in the genes that result in changes in the organism. According to the evolutionary point of view, occasionally mutations will occur that aid survival of the organism in its environment; and supposedly a succession of such mutations produces evolution. The first difficulty with this idea is that it is not substantiated by scientific evidence. *No known mutation is beneficial*, if the net effect is taken into account. For example, it is well known that mutations reduce the viability of the organism.

Most evolutionists agree that the vast majority of mutations are harmful but hold to the belief that some mutations, although an extremely small proportion, are beneficial and that an accumulation of a succession of these mutations results in evolution. Supposedly, one animal form, or kind, will change into another animal form, or kind, over long periods of time.

The problem of justifying evolution by such a process seems insurmountable. It may be compared to a climber on the side of an icy hill who in attempting to climb upward actually slips downward 999 times to just 1 movement upward (Figure 24-1). His net progress is downward, not upward. Similarly, the changes produced by mutations are in the wrong direction to support evolution; but there may be only one beneficial mutation in a thousand examples. Furthermore, gene mutations do not result in the appearance of new traits but only *degenerative* or modified variational characteristics of already existing traits, as will be discussed in a later section.

Even supposition of the minute chance that one organism might "evolve" by this improbable process is

Figure 24-1 If this man slips backward 999 times to just one step up, how will he ever climb the icy cliff?
© Corey Hochachka, DesignPics

not sufficient. The dependency of organisms on a balance in nature must be considered. If great emergent changes in living organisms did occur, it would involve the whole biosphere. The living world with its decomposers, producers, herbivores, and carnivores is very complex and interrelated (Figure 24-2). For instance, many plants depend upon insects for pollination. *Mutations in all these organisms filling the various niches would have to be timed so that the entire ecosystem would evolve as a unit*. This suggestion goes beyond all reason, and therefore mutation is not a satisfactory mechanism for evolution.

Clues to the problems associated with mutations can also be seen by considering **artificial mutations** produced by man-made changes in environment. For example, a strong dosage of X-rays may produce mutations in a

Figure 24-2 Clockwise, from top left—goldenrod spider on large blazing star with its prey; highly destructive tentworms (moth larvae); greenbottle fly on milkweed; and nine-spotted ladybug beetle hunting aphids. The living world with its decomposers, producers, herbivores, and carnivores is very complex and interrelated.

living organism; but those mutations are harmful. Spraying with DDT kills houseflies, but after DDT has been used a long time, some flies are not killed. Some of the flies are apparently naturally mutated and can live in the presence of DDT, which functions as a naturally selective agent such that these mutant flies survive and reproduce.

Is the net result beneficial beyond the state of the original housefly? There is evidence that this type of mutation has a detrimental by-product, because the fly population soon returns to the predominantly nonresistant type again after the spraying has been discontinued. The few flies of the original strain that were not killed produced more offspring than the mutant, resistant type. This example shows that the mutant fly does not have the viability of the original organism.

It is well known that high-energy radiation from man-made nuclear explosions or from natural nuclear processes of the sun produces harmful mutations. International treaties banning nuclear tests are based on this scientific knowledge. No one expects these mutations to be beneficial.

24-2 Problem of Establishing a New Trait

For many years, critics of evolution have pointed out the difficulty for a new and useful structure of an animal or plant to become established by natural selection. All the leading theories of the method of evolution include natural selection, already described. Proponents of the mechanism of natural selection claim that a plant or animal succeeds because it has useful structures or organs. This seems reasonable and persuasive. Supposedly, if organs become better, the organism succeeds better and produces more offspring, presumably starting a new and improved kind.

The difficulty is that if a new structure is started but not well enough formed to be functional, that structure is a hindrance rather than a help. Wings not large enough for use in flight would hinder a bird in running and dodging among the bushes. The stubs of wings might even enable the bird's predators to hold it more readily.

Establishment of life processes is even harder to visualize by chance variation. Chapter 6 explained how the nucleus of a cell divides by such a precise process that each daughter nucleus has a copy of each chromosome. If mitosis had started by a cell being broken in two by accident, the result would have been far from an improvement. As mentioned before, chromosome number is important because, in humans, an extra chromosome causes **Down syndrome** (mental and physical retardation). Suppose the cells developing into eggs are accidentally broken in two. If they did not die at once, they would develop into organisms with an incomplete set of genes; and they would not develop properly.

The *vertebrate eye*, with the lens through which light passes to the retina, the pupil that regulates the amount of light, and the nerves and brain that somehow interpret the image, is a marvelous mechanism. The function of the camera is patterned after it. The only explanation "natural selectionists" can give is that the eye was built up through accumulation of chance changes, one at a time. But each of the mentioned aspects of the eye, which supposedly occurred as new additions, would not help an animal in the struggle for existence until the eye was complete enough for the animal to see clearly (Figure 24-3).

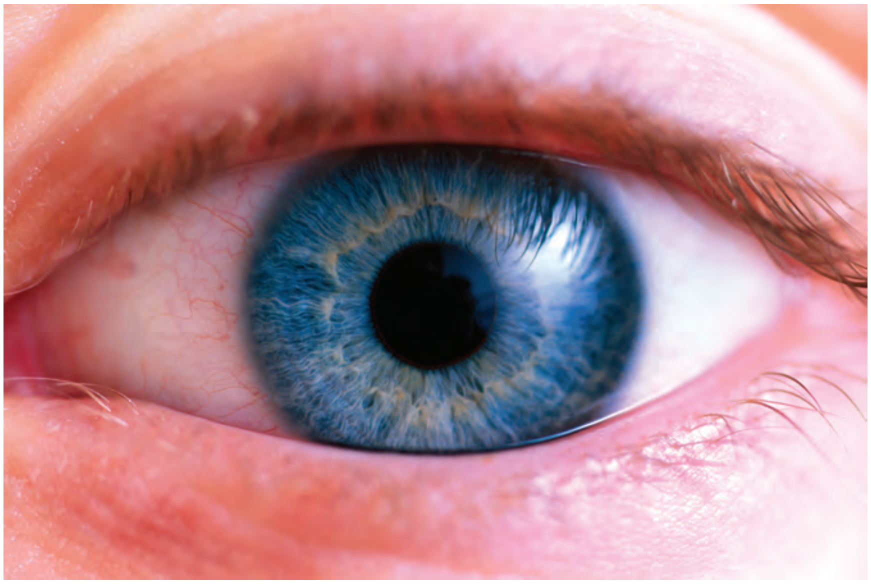

Figure 24-3 The vertebrate eye is a marvelous mechanism. The only explanation that natural selectionists can give is that the eye was built up through accumulation of chance changes, one at a time. But the process would be useless to the organism for survival until the eye was complete enough for seeing clearly.
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Creationists do not deny that natural selection occurs, but they explain results of natural selection processes differently from the evolutionists. The arrangement of chromosomes, genes, and DNA codons is so complex and so well structured that a person cannot visualize any improvement from chance accidental changes.

Any student of nature observes an occasional abnormal plant or animal. To expect all organisms to be perfect or even manifest normal structure and function is unreasonable. Conceivably, natural selection processes function to remove defective and abnormal organisms before they reproduce. Thus, natural selection sets a limit and a standard is maintained generation after generation.

Questions: Mechanism and Evolution

1. What does the current evidence imply about mutations being the mechanism of evolution?
2. List the different problems with intermediate stages. Give examples.

Taking It Further: Mechanism and Evolution

1. Can you think of an intermediate stage between two species that would be beneficial to the organism?
2. What are the benefits of natural selection?

ORIGIN AND EVOLUTION

24-3 Problem of the Origin of Life

Evolutionary theorists have the burden of accounting for the progressive emergence of life from non-living matter at one extreme to the highly unique human being at the other extreme. No satisfactory mechanism has been found for the phases of evolutionary change required in living organisms. A still greater hurdle precedes that phase: it is the problem of how life originated. Some proponents extend the evolutionary theory and hold the position that the origin of life occurred through mechanistic processes, following physical laws; but no one knows any physical processes that can produce life.

Many mechanistic theories of the origin of life have been advanced, but difficulties abound for each of them. One obvious difficulty is that any mechanistic theory of the origin of life violates the **law of biogenesis**. The long investigation, ending in the experiments of **Louis Pasteur** (1822–1895, see chapter 6), overthrew the primitive notions of spontaneous generation of microscopic life, just as the investigations of **Francesco Redi** (1626–1697) denied primitive notions of spontaneous generation of whole, or complete, plants or animals. Nevertheless, evolutionary theorists are forced to abandon the law of biogenesis and advocate some theory of spontaneous generation of life. In these days, they imagine spontaneous generation of life at the submicroscopic level of organization of life, as will be demonstrated soon. This is indeed an awkward position for a scientist, to abandon a basic law that has been so universally validated and for which there is *no known* exception.

Evolutionary theories on the origin of life have been changed from time to time, but the most widely accepted theory in the last thirty years is based on the hypothesis of **Aleksandr I. Oparin** (1894–1980), a Russian scientist. According to Oparin, the early atmosphere was composed of four gases: methane (CH_4), ammonia (NH_3), hydrogen (H_2), and water vapor (H_2O). Supposedly, lightning caused the gases to break up and form molecules of amino acids. Presumably, these acids, occurring in an ocean, formed proteins and eventually formed living matter.

An experiment by **Stanley L. Miller** (1930–) was designed to test the chemistry involved in Oparin's theory. He put the necessary gases in a closed system where water vapor was produced by boiling and electrical energy was supplied in the form of electrical sparks. After a week, he found, among other compounds, some amino acids. This is not a remarkable experiment from the point of view of chemistry, for it changes no one's concepts in chemistry. The reason it gained prominence is that evolutionists consider it to be a significant link in evolutionary thought.

Sydney W. Fox (1912–) performed another experiment that he believed would extend the results of the Miller experiment. He heated a mixture of amino acids until they melted. Some of the amino acid molecules united into larger molecules resembling proteins. Fox did not produce living protoplasm, of course, nor did he even produce true proteins; but the **synthesis** of larger molecules is considered a triumph by many evolutionists.

Especially noteworthy regarding the work of Drs. Miller and Fox is the fact that they tried to **synthesize** living material; *they did not try to create life*. They started with chemical materials available in their laboratories, and by certain formulae, under certain conditions, they attempted to put the chemical materials together to perform a synthesis in such a manner as to yield living substance. They did not create life, nor will any scientist ever create life. If a scientist is ever successful in forming living substance, he will have *synthesized* life but will *not* have *created* life. And such a scientist will have accomplished that presently impossible feat according to certain repeatable formulae and not at all by chance or accident. As a scientist, he will have to be able to repeat the feat and to use his intelligence. Dependence upon chance or accident would make any success or progress impossible in an attempt to synthesize life; yet chance or accident is the very foundation of the thinking of evolutionists. They believe all matter and all life came about and evolved through an extensive series of chance occurrences or accidents.

24-4 Difficulty in Oparin's Theory

Anyone examining Oparin's theory carefully, as was done by geophysicists **Lloyd V. Berkner** (1905–1967) and **L. C. Marshall**, will find great difficulty in the theory. Under the same conditions postulated by Oparin for an ancient atmosphere, there would have been no protection against excessive ultraviolet radiation. Oxygen, primarily in the form of **ozone** (ō′zōn, O_3), in the present earth's atmosphere shields the earth from lethal dosages of ultraviolet light. If the Oparin process were successful in generating life, ultraviolet radiation would have killed it. Note that it was necessary for Oparin to omit oxygen from his theoretical atmosphere. In the absence of oxygen, however, lethal dosages of ultraviolet light from the sun would have reached the earth's surface, where any spontaneous generation of life according to Oparin's imagined processes supposedly occurred. The very cells would have been destroyed that supposedly were produced according to his theory.

Berkner and Marshall point out this difficulty with Oparin's theory as follows:

> Cell absorption in these bands is highly lethal to cell function in all forms, disorganizing chemical function, and bringing growth, reproduction, and survival to a halt. Only atmospheric ozone can provide protection by shielding the lethal radiation in these bands.… Here it is seen that in the primitive atmosphere, lethal radiation penetrates to a depth of approximately 10 meters of water.… In particular, life in the oceans seems unlikely.[1]

Oparin theorized that this synthesis took place on the surface of the ocean because, according to the evolutionary theory to which he subscribed, life first began in the ocean. Berkner and Marshall show that Oparin's own postulated conditions would prevent life from beginning in the ocean by the imagined process.

Had Oparin postulated oxygen in the atmosphere, his theory would still have been in trouble because oxygen can be toxic to some cells. But the enzymes would not have "evolved" before the cells. Either way, with or without oxygen, this theory of the origin of life cannot survive the tests of scientific analysis.

The origin of life is a big problem to those who will not consider divine creation, or intelligent design. Therefore, they divide the problem into many small parts: a very simple cell that added parts one at a time; parts so small that they seem trivial. But the sum of these parts is still the problem of origins.

Questions: Origin and Evolution

1. Describe the currently widely held theory of evolutionary origin.
2. Describe the problems with Oparin's theory.

Taking It Further: Origin and Evolution

1. Besides lacking a protective atmosphere, what other problems would life have in an atmosphere without oxygen? Given the chemicals present in Oparin's described early atmosphere, is there any way to accommodate these problems?

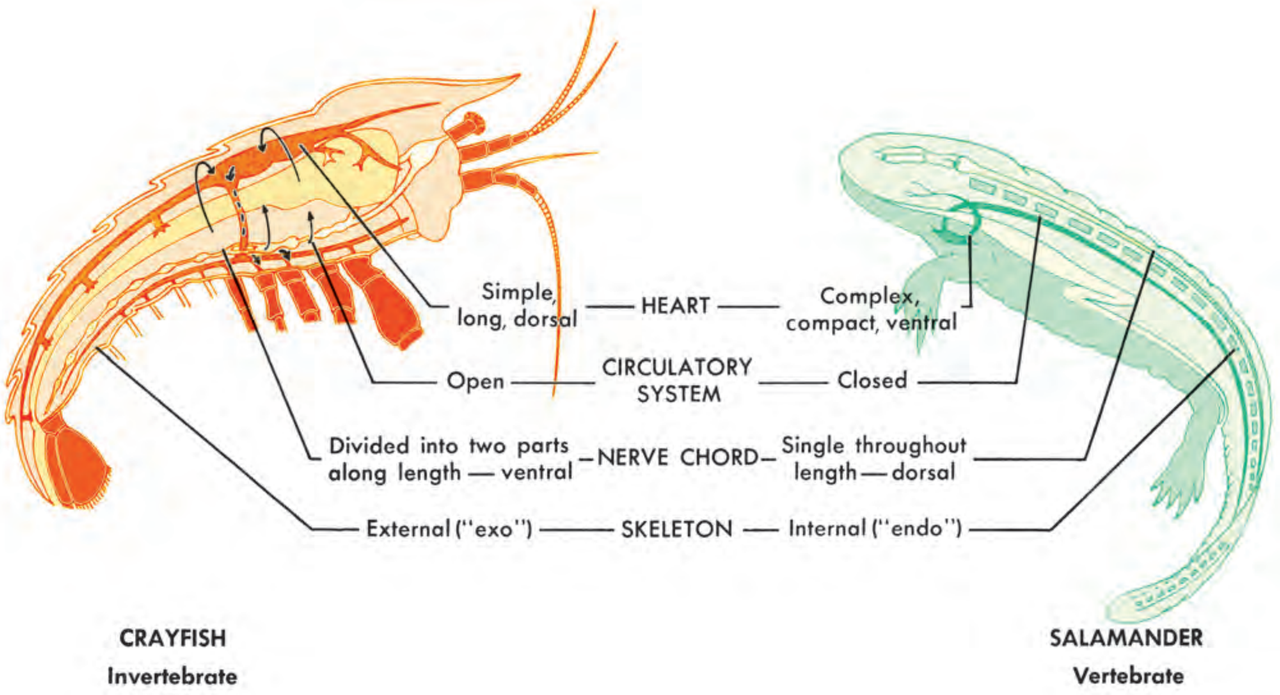

Figure 24-4 A comparison between the arrangements of the circulatory system, nervous system, and skeleton of the crayfish (an invertebrate) and a salamander (a vertebrate). Note the reverse arrangements of the heart and nerve cord and the differences in arrangement of the exoskeleton and endoskeleton.

TRANSITION AND EVOLUTION

24-5 Problem of Structural Evolution

Evolutionary theorists assume that the vertebrate body pattern "evolved" out of the invertebrate body pattern. Such a transition presents another real hurdle. The chief invertebrates have an exoskeleton, dorsal circulatory system, ventral nervous system, and muscles *inside the skeleton*. In vertebrates, the arrangement is reversed with an endoskeleton, ventral circulatory system, dorsal nervous system, and muscles *outside the skeleton*. One can hardly imagine *how* a transition could be made from the one form into such a different structure (Figure 24-4).

There are *no known transitions* across divisions of fossil forms or divisions of living organisms, as was stated in chapter 21. Specialists in paleontology and genetics have recognized that gaps, **systematic gaps**, are present in the fossil record; "links" are **missing**, and groups of organisms are showing up suddenly and without transitions. Rather than supporting the theory of evolution, the historical record of the fossils is actually incompatible with the theory because of:

(1) the absence, which is total absence, of types considered to be most primitive and ancestral to animals without backbones,

(2) the sudden appearance of the major divisions of organisms, and

(3) an amazing absence of any transitional forms.

In addition, results of controlled experiments with animals and plants in the laboratory and in the field confirm the conclusion that different degrees of variation occur *within* possible basic forms, or kinds, of organisms but *never across* these basic divisions of plants or animals. Bacteria give rise only to bacteria, moss to moss, ferns to ferns, protozoa to protozoa, earthworms to earthworms, and dogs to dogs. From these experiments come observations that are in total agreement with the **law of biogenesis** (life begets life) and in total disagreement with the theory of evolution.

24-6 Uniqueness of Man as a Problem in Evolution

As interesting and varied as the animal kingdom is, no other organism is truly comparable to man. This uniqueness of man presents further problems for application of evolutionary theory to include the human being. Although man's body has similarities to an animal's body, there are many differences. It is man's **human attributes**, however, that place him in a group entirely separate from the animals. He is capable of *abstract reasoning* and uses a complex *language*. He accumulates knowledge and transmits it to his children (i.e., *pedagogy* [pĕ′də•gō′jē]). He invents tools (i.e., *inventiveness*). Although some animals may use crude tools such as twigs or sticks, they do not invent and perfect new tools. Man appreciates beauty, composes music, and paints pictures (i.e., *aesthetics* [ĕs•thĕ′tĭks]). He is able to weep and to laugh (i.e., *emotivity* [ē′mō•tĭ′və•tē]). That such a being evolved from animals is extremely difficult to imagine.

Man has a characteristic attitude toward a standard for his behavior that he considers his duty. By an inward prompting, which is called **conscience**, he is led to do what he considers to be right (i.e., *morality* [mə•ră′lə•tē]). This gives him a feeling of responsibility for his actions and for conditions of his environment that he is able to influence. Due to his **sinful nature** (Romans 3:10–23), however, man does not always do what is right, or even what he mistakenly thinks is right. He may even commit crimes more heinous and brutal than the deeds of any animal. But unless he has been wrongly taught, has repeatedly disregarded the promptings of his conscience, or has a mental disorder, a wrongdoer may find that his conscience makes him uncomfortable after performing a wrong act; this is especially true of one who has been converted to Christ by the gospel (John 3).

Man looks in vain for any real development of such attitudes or behavior in animals, even in those most similar to man in physical structure. A chimpanzee may care for its offspring, but it will never develop a written language or a moral code. A dog may seem to show fear of punishment after doing something his master disapproves, but this is not conscience. Aside from caring for their offspring while they are immature and, in some cases, helping their own group, animals do not manifest a sense of responsibility.

Questions: Transition and Evolution

1. Why does the fossil record seem not to support the theory of evolution?
2. In what ways does the theory of evolution contradict the law of biogenesis?

Taking It Further: Transition and Evolution

1. Is it more logical to believe that there is no transition fossil in existence or that it simply has not been found yet? Which idea requires more faith? Support your answer.
2. Studies done with primates to teach them sign language have raised questions about possible "human" characteristics being present in these mammals. Find an article pertaining to this subject and summarize the findings.

Questions: Chapter Review

1. What was the result of Johannsen's selection of beans (chapter 7)?
2. In any group of organisms, if all the genes of one individual were just like the genes of the others, what changes could natural selection produce?
3. From chapter 7, recall several mutations of plants and animals that are helpful to man and see if you can find any that are helpful to the organism itself.
4. In a certain textbook, the following examples of mutations were mentioned: rabbits that could run faster and could see hawks more quickly than other rabbits. What is wrong with such examples?
5. Does a shift in the average by selection make a biological change?
6. Which of the following statements is most logical regarding *natural selection*:

   (1) claim it is illogical and does not exist;

   (2) claim it tends to change amoeba to man; or

   (3) claim it maintains a standard limit?
7. Does or does not the theory of evolution (or natural selection) explain *altruism* in man?

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[1] Berkner, Lloyd V. and L. C. Marshall, in *The Origin and Evolution of Atmospheres and Oceans*, eds. Peter J. Brancazio and A. G. W. Cameron (New York: John Wiley and Sons, 1964), pp. 113–115. This is a publication of the proceedings of a conference held at the Goddard Institute for Space Studies, National Aeronautics and Space Administration, New York, April 8–9, 1963.