Unit 9

VERTEBRATES

CHAPTERS

"Nature discloses the secrets of her past with the greatest reluctance. We paleontologists weave our tales from fossil fragments poorly preserved in incomplete sequences of sedimentary rocks. Most fossil mammals are known only from teeth—the hardest substance in our bodies—and a few scattered bones."

Opossums are the only North American marsupial mammals.

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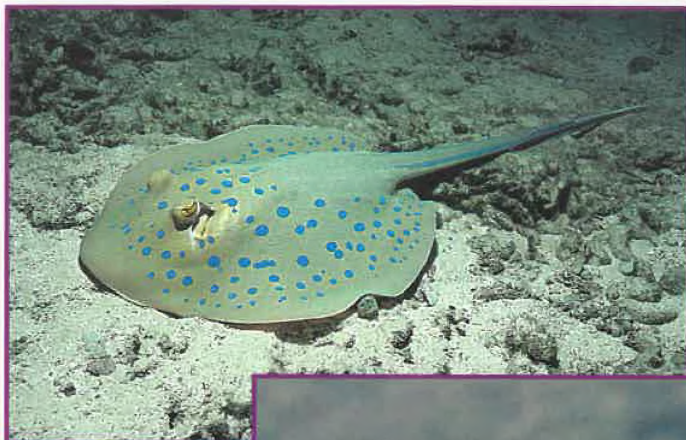
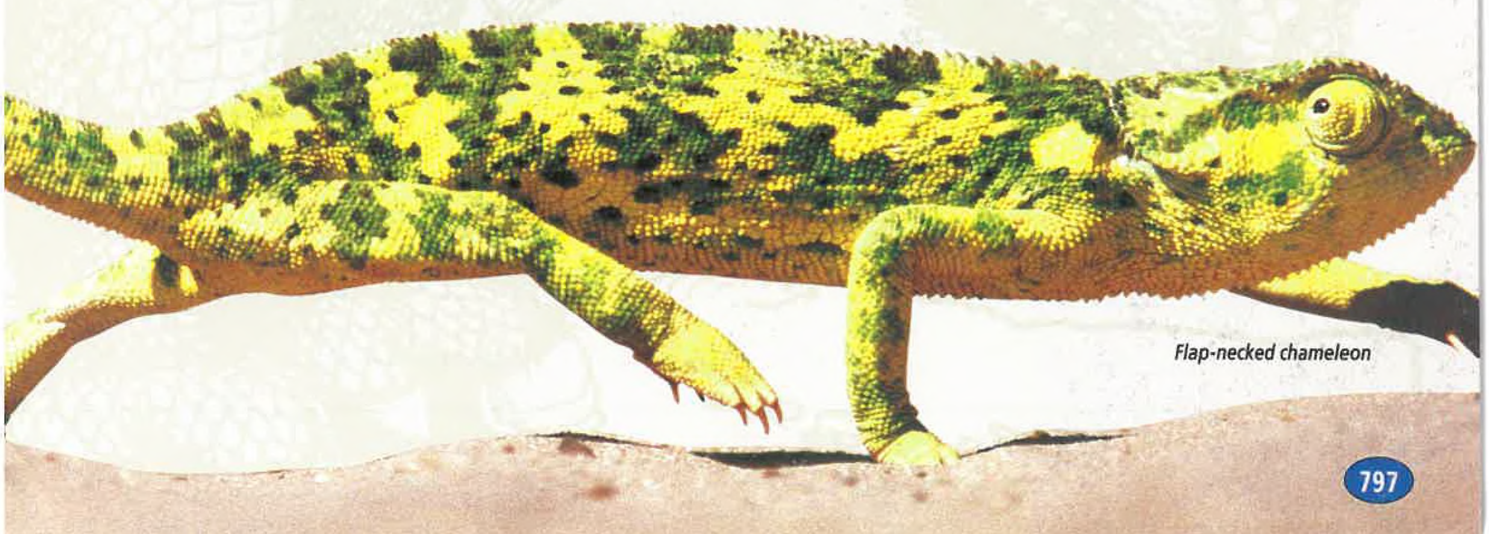
National Science Teachers Association sciLINKS Internet resources are located throughout this unit.



This blue-spotted stingray, Taeniura lymna, *is one of about 100 species of stingrays that belong in the class Chondrichthyes.*

Antlers, such as those on this caribou, are bony outgrowths that are shed each winter.

These colorful rainbow lorikeets, also known as brush-tongued parrots, can be found in eastern Australia, where they feed on eucalyptus flowers.



Flap-necked chameleon

CHAPTER 41

FISHES

The whale shark lives in a saltwater environment, for which it has special organs and biochemical adaptations.

FOCUS CONCEPT: *Structure and Function*

As you read the chapter, focus on the adaptations that allow fishes to survive and reproduce in aquatic environments.

INTRODUCTION TO VERTEBRATES

Although the vertebrates are not the largest or most abundant group of animals, they are the most familiar to us. This is partly because we are vertebrates. Vertebrates are an important part of our diet. In many parts of the world, vertebrates, not machines, perform the hard work of pulling plows and hauling heavy loads. We have also taken vertebrates into our homes as pets.

SECTION 41-1

OBJECTIVES

▲ Identify the distinguishing characteristics of vertebrates.

● List the seven major groups of vertebrates, and give an example of each.

■ Describe the characteristics of the early vertebrates.

◆ Explain the importance of jaws and paired fins for fishes.

CHARACTERISTICS

Vertebrates are one subphylum within the phylum Chordata. Like other chordates, vertebrates have, at some stage of life, a notochord, a dorsal hollow nerve cord, pharyngeal pouches, and a post-anal tail. Vertebrates are a distinct group because they have three characteristics that distinguish them from other chordates. First, vertebrates have vertebrae, bones or cartilage that surround and protect the dorsal nerve cord. The vertebrae form the **vertebral column,** or spine. Second, vertebrates have a **cranium,** or skull, that protects the brain. Third, all vertebrates have an endoskeleton composed of bone or cartilage.

Classification

Today there are about 45,000 species of vertebrates. They occupy all but the most extreme terrestrial habitats. More than 24,000 vertebrate species are fishes. Fishes are found in a wide range of water habitats. The major groups of vertebrates are summarized below.

- **Lampreys and Hagfishes** (class Agnatha)—These fishes have elongated, eel-like bodies, and they lack jaws, paired fins, and bone. There are about 80 species.
- **Sharks, Rays, and Skates** (class Chondrichthyes)—These predatory fishes have jaws and paired fins. Their skeleton is made of cartilage, not bone, and their skin is covered by a unique kind of scale. There are about 800 species.
- **Bony Fishes** (class Osteichthyes)—Most familiar fishes, such as guppies, salmon, bass, and catfish, are bony fishes. All have jaws, and most species have a skeleton composed of bone. This group comprises two main lineages: the ray-finned fishes and the lobe-finned fishes. There are over 23,000 species of bony fishes.

Word Roots and Origins

vertebra

from the Latin *vertebra,* meaning "a joint"

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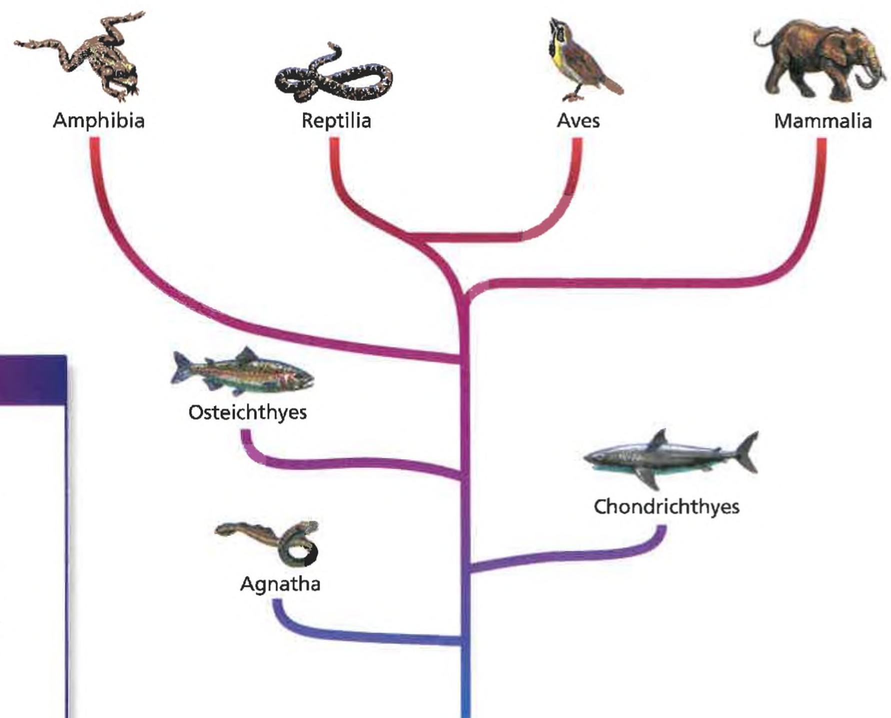
TOPIC: Fish
GO TO: www.scilinks.org
KEYWORD: HM799

FIGURE 41-1

This phylogenetic tree shows the evolutionary relationships among vertebrates.



Quick Lab

Analyzing a Phylogenetic Tree

Materials paper, pencil

Procedure

1. Draw the phylogenetic tree shown on this page on your paper.
2. Using the information on pp. 799 and 800, determine the key characteristics that distinguish each vertebrate group. Indicate these evolutionary changes on the branches of the tree to make a diagram of the relationship that exists among vertebrates. Begin at the bottom of the tree with the key characteristics that distinguish vertebrates from other chordates.

Analysis What characteristics are shared by all vertebrates? What key characteristic separates the classes Chondrichthyes and Osteichthyes? What adaptations lead to the divergence of mammals? Which two groups of vertebrates share the most recent common ancestor?

- **Amphibians** (class Amphibia)—Frogs, toads, and salamanders belong to this group. Their skin is thin and is permeable to gases and water. Most species lay their eggs in water and pass through an aquatic larval stage.
- **Reptiles** (class Reptilia)—This group includes turtles, crocodiles, alligators, lizards, and snakes. The skin of reptiles is dry and scaly. The eggs of reptiles protect the embryo from drying out and can be laid on land. There are about 6,000 species.
- **Birds** (class Aves)—Birds are characterized by adaptations that enable flight, including feathers, hollow bones, and a unique respiratory system. There are over 10,000 species.
- **Mammals** (class Mammalia)—Humans, cats, mice, and horses are among the members of this group. All mammals have hair and nurse their young with milk. There are about 4,400 species. Figure 41-1 shows the relationships among the major groups of living vertebrates.

EVOLUTION

Most biologists think that vertebrates originated about 550 million years ago, shortly after the first chordates appear in the fossil record. The oldest known vertebrate fossils are those of jawless fishes. They appear in the fossil record starting a little over 500 million years ago. Most early jawless fishes did not have paired fins. Their bodies were covered with heavy, bony scales, but their skeletons were composed of cartilage. Figure 41-2 shows an artist's reconstruction of one of these fishes.

Jawless fishes were the only vertebrates for more than 50 million years, and they diversified into many evolutionary lines. By about 350 million years ago, most of these lines had become extinct. The survivors became the ancestors of today's jawless fishes (class Agnatha).

FIGURE 41-2

Early jawless fishes, such as this *Pharyngolepis,* lacked paired fins and probably fed on small invertebrates. Most species of early jawless fishes were less than 15 cm (6 in.) in length.

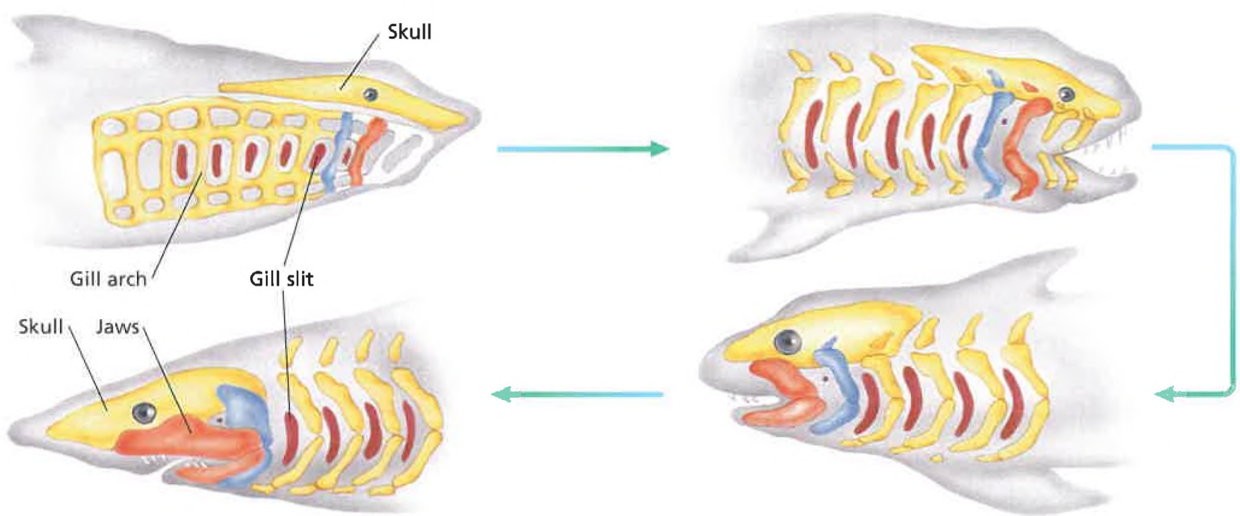
Origin of Jaws

About 440 million years ago, the first fishes with jaws and paired fins appeared. Paired fins increased their stability and maneuverability, and jaws allowed them to seize and manipulate prey. Jaws are thought to have evolved from the first pair of **gill arches,** the skeletal elements that support the pharynx. Figure 41-3 shows three possible stages in this transformation.

The first fishes to have paired fins and jaws were the acanthodians (AY-kan-THOH-dee-uhnz), or spiny fishes, in the class Acanthodii. Acanthodians became extinct about 270 million years ago. Modern fishes—the sharks and rays (class Chondrichthyes) and the bony fishes (class Osteichthyes)—make their first appearance in the fossil record about 400 million years ago.

FIGURE 41-3

Jaws are thought to have developed from the gill arches of early jawless fishes. These figures represent hypothesized stages of evolution.



SECTION 41-1 REVIEW

1. What are three characteristics of vertebrates?
2. Which group of modern vertebrates contains the jawless fishes?
3. Name two differences between the first fishes and modern bony fishes.
4. Explain why scientists think that the early jawless fishes were probably awkward swimmers.
5. List the function of jaws.
6. CRITICAL THINKING Explain why scientists think that the vertebrates evolved from chordates in the sea.

SECTION

41-2

OBJECTIVES

▲ Identify three problems faced by all fishes.

● Describe the feeding behavior of lampreys and hagfishes.

■ Identify two characteristics of cartilaginous fishes.

◆ Describe how sharks detect prey.

▲ Describe reproduction in cartilaginous fishes, and contrast it with reproduction in jawless fishes.

JAWLESS FISHES, SHARKS, AND RAYS

The term fish *generally refers to three distinct classes of living vertebrates: Agnatha, jawless fishes; Chondrichthyes, cartilaginous fishes; and Osteichthyes, bony fishes. Fishes are the most numerous and widespread of all vertebrates.*

LIFE IN THE WATER

The body plan of a fish makes it well-suited to live in a water environment. A streamlined shape and a muscular tail enable most fishes to move rapidly through the water. Paired fins allow fishes to maneuver right or left, up or down, and backward or forward. Unpaired fins on the back and belly increase stability. In addition, most fishes secrete a mucus that reduces friction as they swim.

Most of the tissues in a fish's body are denser than water. By controlling the amount of gas in their bodies, many fishes can regulate their vertical position in the water. Some fishes also store lipids, which are less dense than water and therefore help them to float.

Fishes need to absorb oxygen and rid themselves of carbon dioxide. However, scales on fishes limit diffusion through the skin. Instead, most exchanges between water and blood take place across the membranes of gills—the internal respiratory organs of fishes.

Homeostasis

The concentration of solutes in a fish's body usually differs from the concentration of solutes in the water in which the fish swims. The body of a freshwater fish has a higher concentration of solutes than the surrounding water does, so the fish tends to gain water through osmosis and lose ions, such as sodium and chloride ions, through diffusion. Most saltwater fishes contain lower concentrations of solutes than their surroundings do. Thus, saltwater fishes tend to lose water and gain ions.

Like all organisms, fishes must also rid themselves of the waste products produced by metabolism. The kidneys and gills play important roles in maintaining homeostasis in the tissues and in getting rid of metabolic wastes. The kidneys filter the blood and help regulate the concentration of ions in the body. The gills release wastes, such as carbon dioxide and ammonia, and either absorb or release ions, depending on whether the fish lives in fresh water or in salt water.

Eco Connection

Hagfish Depletion

Hagfishes have recently become economically important. Most "eel-skin" products, such as wallets, are actually made from the tanned skin of hagfishes. The demand for these products is so high that hagfish populations in some parts of the world have been almost wiped out by overfishing.

Sensory Functions

A prominent adaptation present in nearly all fishes is the **lateral line system.** This system consists of a row of sensory structures that run the length of the fish's body on each side and that are connected by nerves to the brain. The lateral line system detects vibrations in the water, such as those caused by a fish swimming nearby. Most fishes also have highly developed senses of smell and sight. Hearing is an important sense for some fishes, and some species can detect electrical currents.

Word Roots and Origins

agnatha

from the Greek *gnathus,* meaning "jaws," and *a,* meaning "without"

CLASS AGNATHA

The only existing jawless fishes are the 80 species of hagfishes and lampreys that compose the class Agnatha. Figure 41-4 shows an example of both types of jawless fishes. Their skin has neither plates nor scales. Hagfishes and lampreys have an eel-like body, a cartilaginous skeleton, and unpaired fins. The notochord remains throughout life. Hagfishes have small eyes that are beneath the skin, while lampreys have large eyes. Hagfishes lack vertebrae and are unique among vertebrates in that their body fluids have nearly the same ion concentration as sea water. Hagfishes live only in the oceans. Many lampreys live permanently in fresh water, and all species reproduce in fresh water.

Hagfishes

Hagfishes are bottom dwellers in cold marine waters. They feed on small invertebrates or on dead and dying fish. Because the hagfish lacks jaws, it cannot bite, but within its mouth are two movable plates and a rough tonguelike structure that it uses to pinch off chunks of flesh. Hagfishes often burrow into the body of a dead fish through the gills, skin, or anus. Once inside, they eat the internal organs. Hagfishes can tie their bodies into knots to evade capture. They also secrete bad-tasting slime to discourage predators. Hagfishes usually remain hidden in mud burrows on the ocean floor.

Lampreys

About half the species of lampreys are free-living and do not feed as adults. The other half are parasites as adults and feed on the blood and body fluids of other fishes. Once a suitable host is located, a lamprey uses its disk-shaped mouth to attach to the host. Then it scrapes a hole in the host with its rough tongue and secretes a chemical that keeps the host's blood from clotting. The lamprey feeds on the blood and fluids that leak from the wound. After feeding, the lamprey drops off. The host may recover, bleed to death, or die from an infection.

Some lamprey species spend most of their adult lives in the ocean. Others live in rivers or lakes and never enter salt water. All lampreys breed in fresh water, usually choosing a shallow stream

FIGURE 41-4

Hagfishes (a) and lampreys (b) are modern jawless fishes. What feature can you see on the lamprey and hagfish that would prevent them from swimming as well as bony fishes and sharks?

(a)

(b)

with a gravel bottom. They scrape out a small nest in the gravel, and the female releases eggs while the male releases sperm. Fertilization occurs outside the body of either parent. This type of fertilization is known as **external fertilization.** The eggs hatch into small larvae that closely resemble an amphioxus, or lancelet. The larvae eventually transform into adults.

CLASS CHONDRICHTHYES

Sharks, skates, and rays belong to the class Chondrichthyes. Because the fishes in this class have skeletons composed of cartilage, they are also called cartilaginous fishes. **Cartilage** is a flexible, lightweight material made of cells surrounded by tough fibers of protein. Sharks, skates, and rays differ from lampreys and hagfishes in that they have movable jaws, skeletons, and paired fins. Almost all of the approximately 800 species of sharks, skates, and rays live in salt water. All species are carnivores and some are scavengers. They eat many different kinds of foods, including fishes, seals, aquatic invertebrates, and plankton. The skin of cartilaginous fishes is covered with **placoid** (PLA-koyd) **scales**—small, toothlike spines that feel like sandpaper. Placoid scales, shown in Figure 41-5, probably reduce turbulence of the water flow and thus increase swimming efficiency.

Sharks

The largest sharks, the whale shark (up to 18 m, or 59 ft, long) and the basking shark (up to 15 m, or 49 ft, long), feed on plankton. Sharks swim in a side-to-side pattern created by the motion of their asymmetrical tail fin. Just behind a shark's head are paired **pectoral** (PEK-tuh-ruhl) **fins,** which jut out from the body like the wings of a plane. Figure 41-6 shows the external structure and internal anatomy of a shark.

The mouth of a typical shark has 6 to 20 rows of teeth that point inward. When a tooth in one of the front rows breaks or wears down, a replacement moves forward to take its place. One shark may use more than 20,000 teeth over its lifetime. The structure of each species' teeth is adapted to that species' feeding habits. Sharks that feed primarily on large fish or mammals have big, triangular teeth with sawlike edges that hook and tear flesh.

Sharks use several senses to locate prey. Their ability to detect chemicals—that is, their sense of smell—is particularly acute. Paired nostrils on the snout have specialized nerve cells that connect with the **olfactory** (awl-FAK-tuh-ree) **bulbs** of the brain, where the information from the nostrils is analyzed. Water entering the nostrils is continuously monitored for chemicals. Sharks also have a well-developed lateral line system. Their vision is keen, even at low levels of light. They are also extremely sensitive to electrical fields, such as those generated by the muscular contractions of animals.

Quick Lab

Modeling a Shark Adaptation

Materials 8 cm dialysis tubing, 8 cm length of string (2), 100 mL salt solution (5 percent), 250 mL beaker, 10 mL distilled water, scale, graduated cylinder

Procedure

1. Tightly tie one end of the dialysis tubing with string. Place 10 mL of distilled water inside the dialysis tubing, and tie the other end of the tube tightly with string.
2. Record the initial weight of the filled tube.
3. Add the filled dialysis tubing to a beaker filled with 100 mL of salt solution.
4. After 10 minutes, remove the tubing from the beaker, blot the outside, and reweigh it. Record your observations.

Analysis Explain the reason for the change in the weight of the tube, if any. Are sharks likely to lose or gain ions? What physical structures of a shark play a key role in maintaining ionic homeostasis in sharks?

FIGURE 41-5

These teethlike placoid scales are found on the skin of cartilaginous fishes. What advantage might they give a shark in swimming?

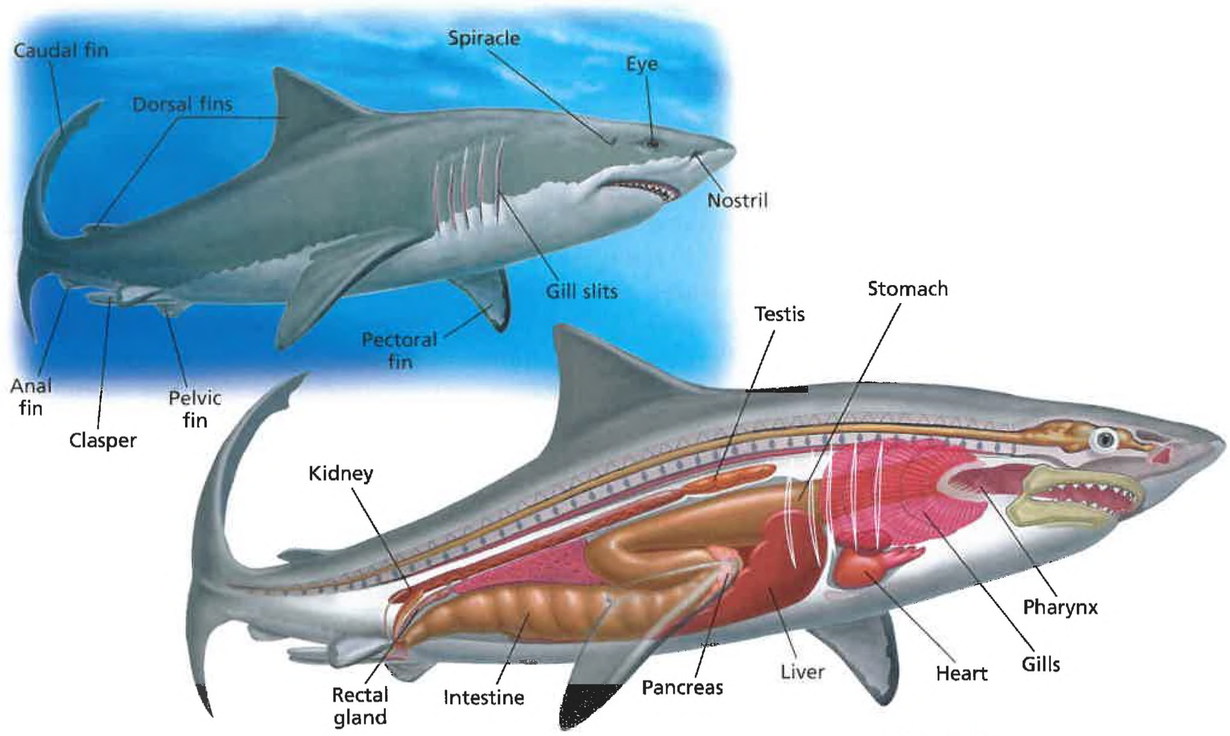


FIGURE 41-6

A streamlined shape allows the shark to slip through the water with little resistance. The shark's powerful caudal fin propels it forward, and the paired fins help steer and stabilize it. The shark's internal anatomy includes organs for digestion, reproduction, and maintaining homeostasis. Note how the rectal gland is connected to the lower part of the intestine. This makes the disposal of excess salts easier.

Sharks detect these fields by means of sensitive receptors located in small pits scattered over their head. Tests have shown that sharks can find and capture prey using only their sensitivity to electrical fields. Evaluating and integrating information from all these different senses requires a large and complex brain. Sharks have the largest brain—for their body size—of any fishes.

Rays and Skates

Rays and skates have flattened bodies with paired winglike pectoral fins and, in some species, whiplike tails. Rays have diamond- or disk-shaped bodies, while most skates have triangular bodies. Most rays and skates are less than 1 m (3.3 ft) long. Rays and skates are primarily bottom dwellers. Their flat shape and coloration camouflage them on the ocean floor. Most rays and skates feed on mollusks and crustaceans. Figure 41-7 shows an example of a ray.

Adaptations of Cartilaginous Fishes

In cartilaginous fishes, gas exchange occurs in the gills, which lie behind the head. Efficient gas exchange requires a continuous flow of water across the gills. Some fast-swimming sharks are able to push water through their mouth, over their gills, and out of their gill slits by swimming alone. However, most sharks and rays pump water over their gills by expanding and contracting their mouth cavity and pharynx. When lying on the bottom, rays and skates cannot bring in water through their mouth, which is located on the ventral surface of their body, so instead, they draw water in through their spiracles, which are two large openings on the top of the head, just behind the eyes.

FIGURE 41-7

This blue-spotted stingray, *Taeniura lymna,* is an example of a bottom dweller. This stingray was photographed in the Red Sea near Egypt.

Instead of releasing ammonia, cartilaginous fishes use energy to convert ammonia into a compound called urea, which is much less toxic. Sharks retain large amounts of urea in their blood and tissues, thus raising the concentration of solutes in their body to at least the same level as that found in sea water. As a result, sharks do not need to drink. Because the concentration of sodium and chloride in the body of a shark is less than the concentration found in sea water, these ions still diffuse into the body across the gills and are absorbed with food. The **rectal gland,** located in the posterior portion of the intestine, removes excess sodium and chloride ions from the blood and releases them into the rectum for elimination.

Cartilaginous fishes maintain their position in the water in two ways. First, because a fish generates lift, or upward force, as it swims, it can remain at the same level in the water, counteracting the tendency to sink, as long as it keeps moving. Some open-water sharks rely entirely on this method, but it does use up a lot of energy. Second, many cartilaginous fishes store large amounts of low-density lipids, usually in the liver. A shark's lipid-filled liver may account for 25 percent of its mass. Lipids give sharks buoyancy by reducing the overall density of the body. Because continuous swimming is not necessary, less energy is used.

Reproduction in Cartilaginous Fishes

Cartilaginous fishes differ from jawless fishes in that fertilization occurs inside the body of the female. This type of fertilization is called **internal fertilization.** During mating, the male transfers sperm into the female's body with modified pelvic fins called **claspers.** In a few species of sharks and rays, the females lay large yolky eggs right after fertilization. The young develop within the egg, are nourished by the yolk, and hatch as miniature versions of the adults. The eggs of many species develop in the female's body, and the young are born live. In some of these species, the mother nourishes the developing sharks while they are in her body. No cartilaginous fishes provide parental care for their young after birth or hatching.

SECTION 41-2 REVIEW

1. What is the function of the lateral line in fishes?
2. How do parasitic lampreys feed?
3. Name two characteristics shared by all cartilaginous fishes.
4. A shark can locate and capture a fish buried in the gravel at the bottom of its tank. Describe at least two senses that the shark might be using to find the fish.
5. Define the terms *internal fertilization* and *external fertilization.*
6. **CRITICAL THINKING** When sea lampreys invaded the Great Lakes, they devastated populations of their hosts. In lakes where sea lampreys have lived for a long time, host populations have not declined. Using what you know about coevolution, explain this difference.

Bony Fishes

Of the 24,000 known species of fishes, about 95 percent are in the class Osteichthyes—the bony fishes. Bony fishes account for most of the vertebrates living in fresh water and in salt water. In this section you will study some of the adaptations of this very large and successful group.

CHARACTERISTICS

The bony fishes are characterized by three key features:

- **Bone**—This material is typically harder and heavier than cartilage. The skeletons of most bony fishes contain bone.
- **Lungs or swim bladder**—Early bony fishes had **lungs,** internal respiratory organs in which gas is exchanged between the air and blood. Only a few species of bony fishes have lungs today. Most bony fishes have a **swim bladder,** a gas-filled sac that is used to control buoyancy. The swim bladder is thought to have evolved from the lungs of the early bony fishes.
- **Scales**—The body of a bony fish is usually covered with scales. Scales protect the fish and help reduce water resistance.

Biologists divide the bony fishes into two main groups: lobe-finned fishes and ray-finned fishes.

Lobe-Finned Fishes

The **lobe-finned fishes** have fleshy fins that are supported by a series of bones. Only seven species of lobe-finned fishes exist today, six species of lungfishes and one species of coelacanth. Lungfishes, which exchange gases through lungs and gills, live in shallow tropical ponds that periodically dry up. They burrow into the mud and cover themselves with mucus to stay moist until the pond refills. Lobe-finned fishes are important because extinct lobe-finned fishes are ancestors of amphibians and all other terrestrial vertebrates.

Ray-Finned Fishes

Ray-finned fishes have fins that are supported by long, segmented, flexible bony elements called rays. Rays probably evolved from scales. In contrast to lobe-finned fishes, ray-finned fishes do not have fins with a central bony axis. Ray-finned fishes are diverse in appearance, behavior, and habitat. Ray-finned fishes include most familiar fishes, such as eels, yellow perch, trout, salmon, guppies, bass, herring, and darters.

SECTION

41-3

OBJECTIVES

▲ List three characteristics of bony fishes.

● Distinguish between ray-finned fishes and lobe-finned fishes.

■ Trace the flow of blood through a fish's heart.

◆ Explain how gills function in respiration.

▲ Describe the function of the swim bladder.

● Compare and contrast reproduction in bony fishes with reproduction in cartilaginous fishes.

Word Roots and Origins

operculum

from the Latin *operculum*, meaning "cover"

EXTERNAL ANATOMY

Figure 41-8 shows the external anatomy of a yellow perch, a bony fish that is common in the Great Lakes and in other freshwater lakes of the eastern United States and Canada. The yellow perch, like all bony fishes, has distinct head, trunk, and tail regions. On each side of the head is the **operculum** (oh-PERK-yoo-LUHM), a hard plate that opens at the rear and covers and protects the gills.

Fins

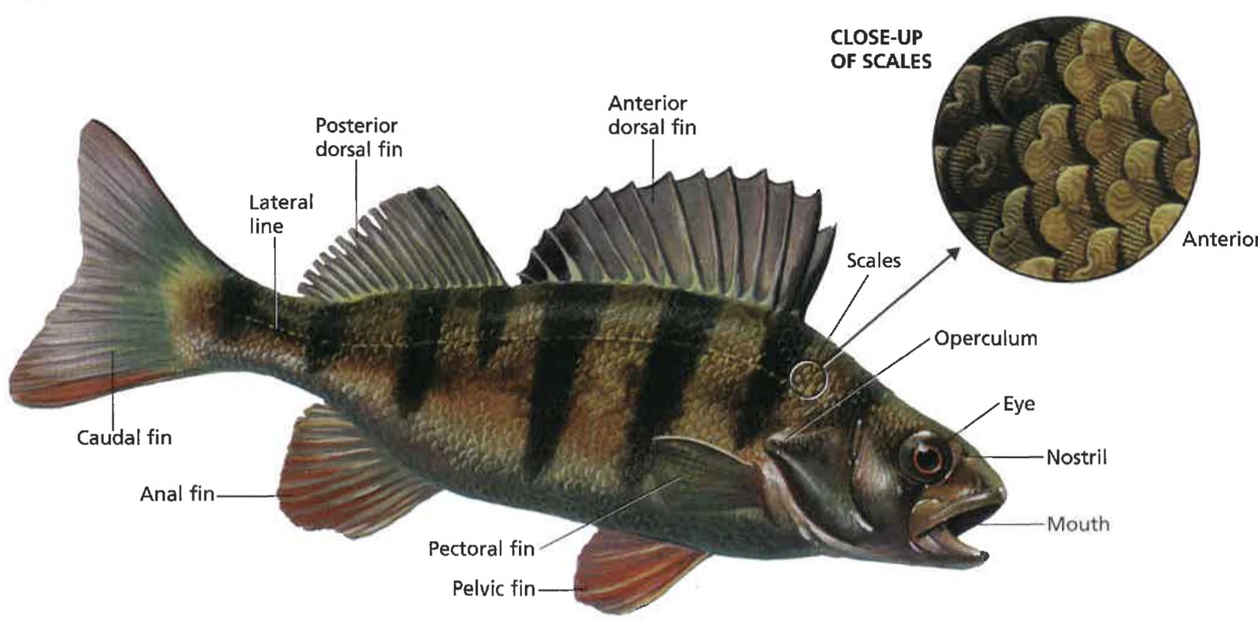
The fins of the yellow perch are adapted for swimming and navigating through the water. The **caudal fin** extends from the tail. It moves from side to side and amplifies the swimming motion of the body. Two **dorsal fins,** one anterior and one posterior, and a ventral **anal fin** help keep the fish upright and moving in a straight line. The fish uses paired **pelvic fins** and pectoral fins to navigate, stop, move up and down, and even back up. The pelvic fins also orient the body when the fish is at rest. The fins are supported by either rays or spines. Rays are bony yet flexible, while spines are bony and rigid.

Skin

The skin of the yellow perch is covered with scales. Scales are thin, round disks of a bonelike material that grow from pockets in the skin. As Figure 41-8 shows, scales overlap like roof shingles. They all point toward the tail to minimize friction as the fish swims. Scales grow throughout the life of the fish, adjusting their growth pattern to the food supply. The scales grow quickly when food is abundant and slowly when it is scarce. In fishes that live in habitats with annual variations in food availability, the resulting growth rings give a good approximation of the fish's age.

FIGURE 41-8

The external features of the yellow perch, *Perca flavescens,* are representative of bony fishes. Note the growth rings on the scales shown in the inset. They indicate the fish's approximate age.



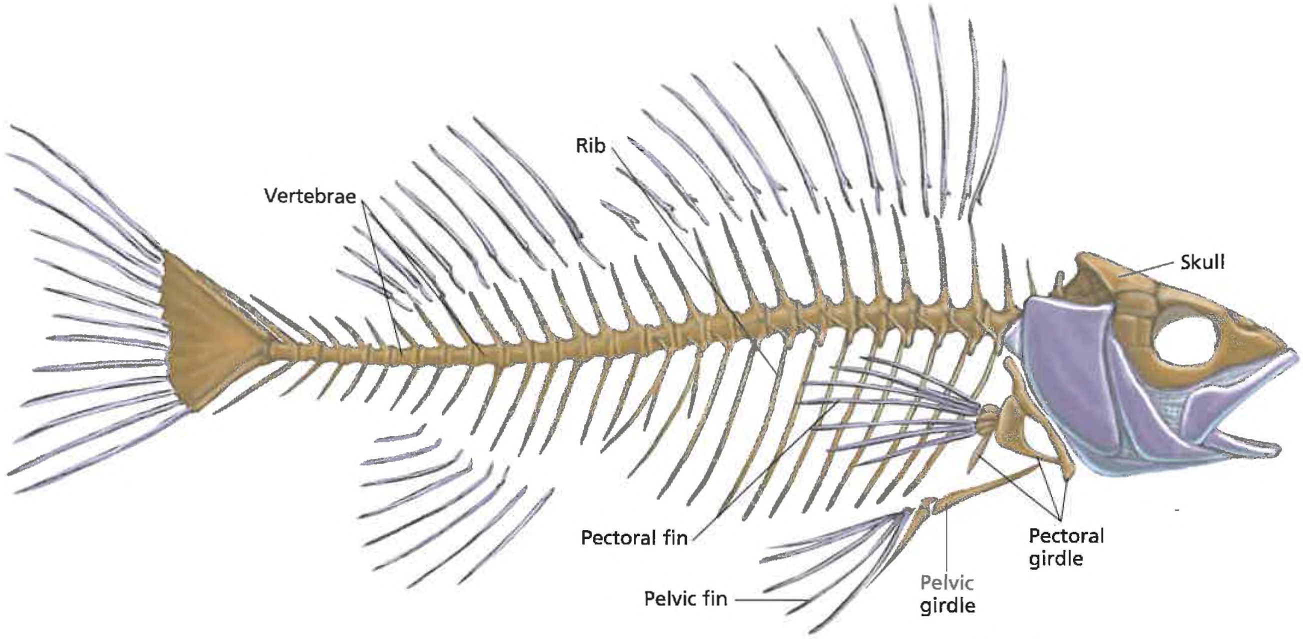


FIGURE 41-9

The skeleton of *Perca flavescens* is similar to that of other bony fishes. The general structure of the vertebrae, rib cage, and fins is found in many fishes.

INTERNAL ANATOMY

The major parts of a fish's skeleton, shown in Figure 41-9, are the skull, spinal column, pectoral girdle, pelvic girdle, and ribs. The spinal column is made up of many bones, called the vertebrae, with cartilage pads between each. The spinal column also partly encloses and protects the spinal cord. The **pectoral girdle** is the attachment point for the pectoral fins. The **pelvic girdle** is the attachment point for the pelvic fins. In a human skeleton, the pectoral girdle is the shoulder and its supporting bones, while the pelvic girdle is the hips. A fish's skull is composed of a large number of bones (far more than are in the human skull) and is capable of a wide range of movements. Figure 41-9 shows the skeleton of a bony fish.

Digestive System

Most bony fishes are generalized carnivores. The jaws of predatory fishes are lined with many sharp teeth that point inward to keep prey from escaping. Strong muscles operate the jaws, which are hinged to allow the mouth to open wide.

Figure 41-10 shows the internal anatomy of a bony fish. Food passes from the mouth into the pharynx, or throat cavity, and then moves through the **esophagus** to the stomach. The **stomach** secretes acid and digestive enzymes that begin to break down food. From the stomach, food passes into the **intestine,** where digestion is completed and nutrients are absorbed. The **liver,** located near the stomach, secretes **bile,** which helps break down fats. The **gallbladder** stores bile and releases it into the intestine. The **pancreas,** also located near the stomach, releases digestive enzymes into the intestine. The lining of the intestine is covered with fingerlike extensions called villi that increase the surface area for absorption of digested foods. Undigested material is then eliminated through the **anus.**

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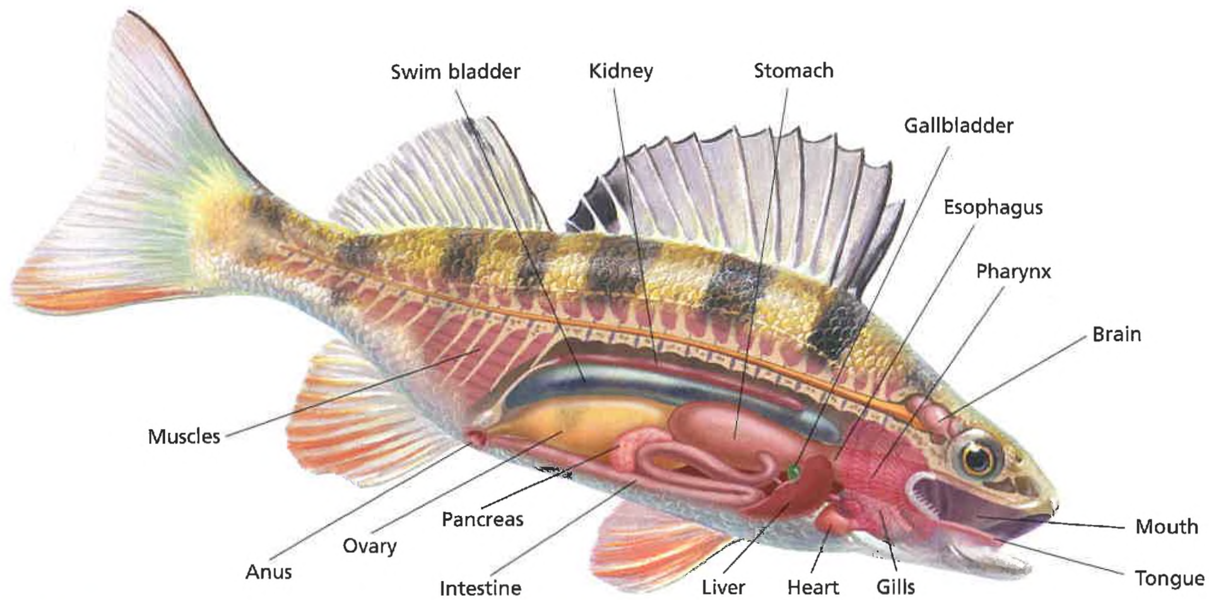


FIGURE 41-10

The internal anatomy of a bony fish, such as this perch, is a model for the arrangement of organs in all vertebrate descendants of fish. Food passes first from the mouth through the esophagus, then to the stomach and intestines. Finally, undigested waste is eliminated through the anus. Digestion of protein occurs in the stomach, and absorption of nutrients occurs in the intestine.

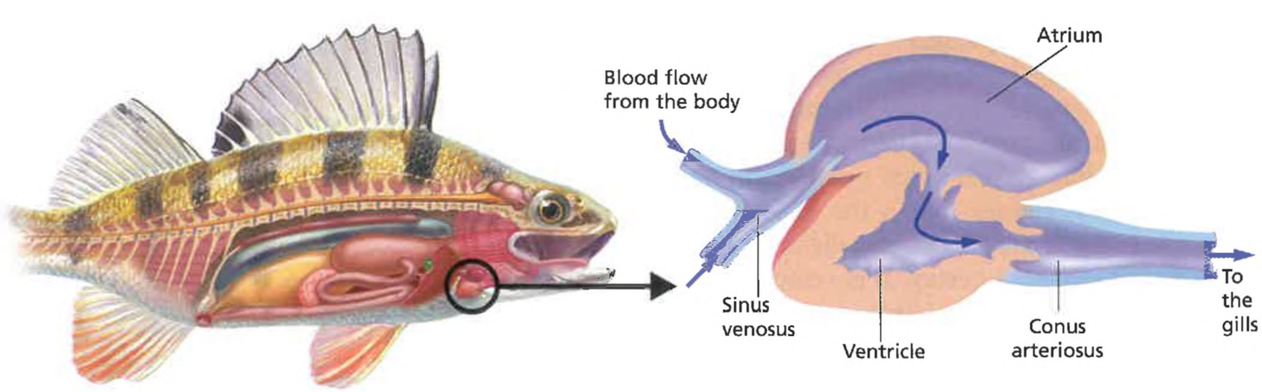
Circulatory System

The circulatory system of a fish delivers oxygen and nutrients to the cells of the body. It also transports wastes produced by metabolism—carbon dioxide and ammonia—to the gills and kidneys for elimination. The circulatory system consists of a heart, blood vessels, and blood. The heart pumps blood through **arteries** to small, thin-walled vessels, called **capillaries,** in the gills. There the blood picks up oxygen and releases carbon dioxide. From the gills, the blood then travels to the body tissues, where nutrients and wastes are exchanged. The blood returns to the heart through **veins.**

The heart of a bony fish has four chambers in a row, as you can see in Figure 41-11. Deoxygenated blood from the body empties into a collecting chamber called the **sinus venosus.** Next, blood moves into the larger **atrium.** Contraction of the atrium speeds up the blood and drives it into the muscular **ventricle,** the main pumping chamber of the heart. Contraction of the ventricle provides most of the force that drives the blood through the circulatory system. The final chamber is the **conus arteriosus.** It has an elastic wall and usually contains valves to prevent blood from flowing back into the ventricle. The conus arteriosus smooths the flow of blood from the heart.

FIGURE 41-11

A fish's heart is a series of four chambers that act in sequence to move blood through the body, transporting oxygen to the cells and wastes to organs for elimination. Note the thickness of the muscle in the ventricle. Why would the ventricle muscle be so much thicker than the other muscles of the heart?



Respiratory and Excretory Systems

The large surface area of a fish's gills allows for rapid gas exchange. Gills are supported by four sets of curved bones on each side of the fish's head. Each gill has a double row of thin projections, called gill filaments. In most bony fishes, water is taken into the mouth and pumped over the gills, where it flows across the gill filaments before exiting behind the operculum. As you can see in Figure 41-12, water flows away from the head while blood flows toward the head. This arrangement is known as **countercurrent flow.** Countercurrent flow allows more oxygen to diffuse into the gills than would be possible if blood and water flowed in the same direction.

A fish's kidneys filter dissolved chemical wastes from the blood. The resulting solution, called **urine,** contains ammonia, ions such as sodium and chloride, and water. Urine is carried from the kidneys through a system of ducts to the **urinary bladder,** where it is stored and later expelled. By varying the amount of water and salts in the urine, the kidneys help regulate the water and the ion balance.

As blood flows through the gill filaments, ammonia generated by metabolism diffuses from the blood into the water passing over the gills and is removed from the body. The gills also regulate the concentration of ions in the body. Recall that saltwater fishes have lower ion concentrations than sea water has. Therefore, they lose water through osmosis and gain ions, such as sodium and chloride ions. Saltwater fishes make up for this water loss by excreting very little urine and by drinking sea water, but this increases their internal concentration of sodium and chloride ions. Both kinds of ions are actively transported out through the gills. Freshwater fishes tend to gain water and lose ions. They respond by producing large amounts of urine and actively transporting sodium and chloride ions in through the gills.

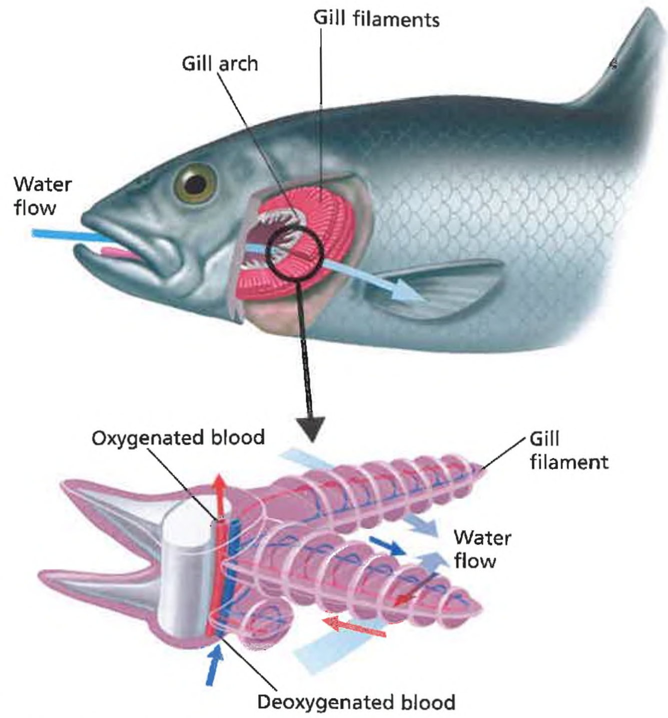


FIGURE 41-12

The gills are located directly behind the head and beneath the operculum. The gill filaments provide the organism with a large surface area, thus enabling gas exchange to occur quickly.

Swim Bladder

Most bony fishes have a swim bladder. This thin-walled sac in the abdominal cavity contains a mixture of oxygen, carbon dioxide, and nitrogen obtained from the bloodstream. Fish adjust their overall density by regulating the amount of gas in the swim bladder, enabling them to move up or down in the water.

Nervous System

The nervous system of a bony fish includes the brain and spinal cord, nerves that lead to and from all parts of the body, and various sensory organs. The major sensory organs are connected directly

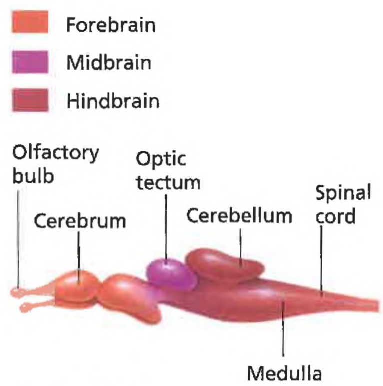


FIGURE 41-13

The fish brain, like the shark brain, has a well-developed medulla to coordinate muscle control.

with the brain via **cranial nerves.** The fish brain is illustrated in Figure 41-13. The most anterior part of the brain, the forebrain, contains the very prominent olfactory bulbs, which process information on smell. The forebrain, which includes the **cerebrum,** has areas that integrate sensory and other types of information from other areas of the brain. Behind the forebrain lies the midbrain, which is dominated by the **optic tectum.** The optic tectum receives and processes information from the fish's visual, auditory, and lateral line systems. The optic tectum is also involved in turning an animal's body toward or away from a stimulus. The most posterior division of the brain is the hindbrain, which contains the **cerebellum** (SER-uh-BEL-uhm) and the **medulla oblongata** (muh-DUL-uh AHB-lawn-GAHT-uh). The cerebellum helps coordinate motor output. The medulla oblongata helps control some body functions and acts as a relay station for stimuli from sensory receptors throughout the fish's body.

From the medulla oblongata, the spinal cord extends the length of the body and carries nerve impulses to and from the brain. **Spinal nerves** connect the spinal cord with the internal organs, muscles, and sense organs.

REPRODUCTION

Eggs are produced by ovaries in the female, and sperm are produced by the testes in the male. Eggs and sperm are released through an opening behind the anus. Fertilization in most species takes place externally. Mortality among the eggs and young fishes is often very high. Many species of fishes lay large numbers of eggs to ensure that at least a few individuals survive to become adult fish.

Some bony fishes bear live young. Using a modified anal fin, the male inserts sperm into the female, and fertilization is internal. The female carries the eggs in her body until the young are born. Other species care for the young as shown in Figure 41-14.

The reproductive, or **spawning,** behavior of bony fishes varies widely. Some species build crude nests from plants, sticks, and shells. Many species migrate to warm, protected shallow water to spawn. For example, adult salmon migrate back to fresh water to spawn.

FIGURE 41-14

This male ringtailed cardinal fish, *Apogon aureus,* is carrying fertilized eggs in its mouth. This behavior lowers losses of eggs to predators and contributes to the success of the species.

SECTION 41-3 REVIEW

1. Describe two characteristics of bony fishes.
2. Identify the two kinds of lobe-finned fishes.
3. What is the function of the ventricle in the fish's heart?
4. What is countercurrent flow, and how does it relate to respiration in fishes?
5. Why is laying a large number of eggs an adaptation of some fishes?
6. CRITICAL THINKING Bottom-dwelling fish often lack a swim bladder. Explain the adaptive advantage of this.

CHAPTER 41 REVIEW

SUMMARY/VOCABULARY

41-1

- Vertebrates are chordates and have a notochord, pharyngeal pouches, a dorsal nerve cord, and a post-anal tail at some stage of life.
- Vertebrates have vertebrae, a cranium, and an endoskeleton.
- Vertebrates are classified into seven classes: jawless fishes (class Agnatha); sharks and rays (class Chondrichthyes); bony fishes (class Osteichthyes); amphibians (class Amphibia); reptiles (class Reptilia); birds (class Aves); and mammals (class Mammalia).
- The oldest known vertebrates are jawless fishes.

Vocabulary

cranium (799)
gill arch (801)
vertebral column (799)

41-2

- Fishes have streamlined bodies and most have paired fins. Fishes float by means of a swim bladder or lipids in the body.
- Fishes use gills for respiration in water. The kidney and the gills help them maintain homeostasis.
- Living jawless fishes lack paired fins and jaws and have a notochord throughout life.
- Many lampreys are external parasites that feed on other fishes. Hagfishes feed on invertebrates or on dead or dying fishes.
- Sharks, rays, and skates are cartilaginous fishes.
- Sharks can smell, see, and detect electrical fields to detect prey. Rays and skates are flattened bottom-dwellers.

Vocabulary

cartilage (804)
clasper (806)
external fertilization (804)
internal fertilization (806)
lateral line system (803)
olfactory bulb (804)
pectoral fins (804)
placoid scale (804)
rectal gland (806)

41-3

- The characteristics of bony fishes are scales on the body, lungs or a swim bladder, and bone in the skeleton.
- Fishes use their fins for propulsion, maneuvering, and stability.
- The digestive system of a fish consists of a mouth, pharynx, esophagus, stomach, intestine, liver, gallbladder, pancreas, and anus.
- The fish heart has a sinus venosus, atrium, ventricle, and conus arteriosus.
- The main parts of a fish's brain are optic tectum, olfactory bulbs, the cerebrum, the medulla oblongata, and the cerebellum.
- Fertilization is external in most bony fishes and is internal in some species.

Vocabulary

anal fin (808)
anus (809)
artery (810)
atrium (810)
bile (809)
capillary (810)
caudal fin (808)
cerebellum (812)
cerebrum (812)
conus arteriosus (810)
countercurrent flow (811)
cranial nerve (812)
dorsal fin (808)
esophagus (809)
gallbladder (809)
intestine (809)
liver (809)
lobe-finned fish (807)
lung (807)
medulla oblongata (812)
operculum (808)
optic tectum (812)
pancreas (809)
pectoral girdle (809)
pelvic fin (808)
pelvic girdle (809)
ray-finned fish (807)
sinus venosus (810)
spawning (812)
spinal nerves (812)
stomach (809)
swim bladder (807)
urinary bladder (811)
urine (811)
vein (810)
ventricle (810)

Review

Vocabulary

In each set of terms below, choose the term that does not belong, and explain why it does not belong.

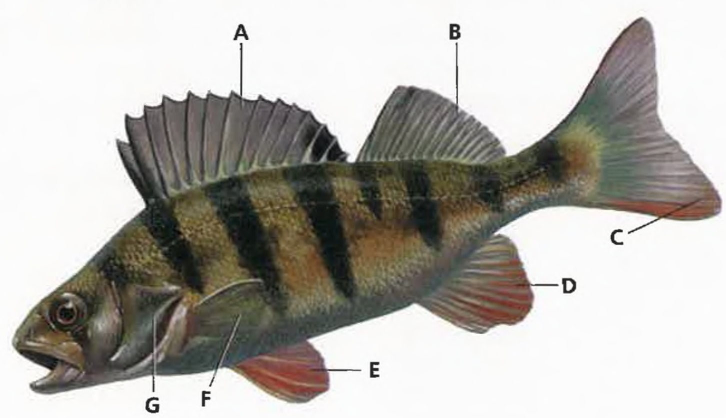
1. atrium, ventricle, sinus venosus, gill
2. cerebrum, cerebellum, operculum, optic tectum
3. internal fertilization, lung, placoid scale, rectal gland
4. cranium, vein, capillary, artery
5. stomach, liver, pancreas, swim bladder

Multiple Choice

6. Which of the following is *not* a characteristic of the first fishes? (a) bony plates on body (b) jaws (c) no paired fins (d) cartilaginous skeleton
7. The spinal column (a) protects the spinal cord (b) anchors limb muscles (c) protects the lateral line (d) collects sensory information.
8. One characteristic found in lampreys but not in hagfishes is (a) a notochord (b) paired fins (c) vertebrae (d) a cranium.
9. Which of the following is true of sharks and rays? (a) They have placoid scales. (b) Most species live in fresh water. (c) They have lungs. (d) They do not have a lateral line system.
10. Which of the following is not a way to control buoyancy? (a) the swim bladder (b) a fat-filled liver (c) continuous swimming (d) the rectal gland
11. The lateral line system (a) keeps fish moving in a straight line (b) initiates migration (c) detects vibrations (d) acts as camouflage.
12. Sharks use claspers to (a) increase maneuverability (b) startle other fish (c) transfer sperm while mating (d) hold on to prey while feeding.
13. The esophagus of a fish (a) creates buoyancy (b) fertilizes eggs (c) carries food from the mouth to the stomach (d) holds wastes moving from the stomach to the anus.
14. A fish's ventricle (a) pumps blood through the body (b) collects blood returning to the heart (c) facilitates gas exchange through diffusion (d) carries oxygen through the capillaries.
15. Bony fishes that live in fresh water (a) lose water (b) gain sodium and chloride ions (c) store urea (d) produce large amounts of urine.

Short Answer

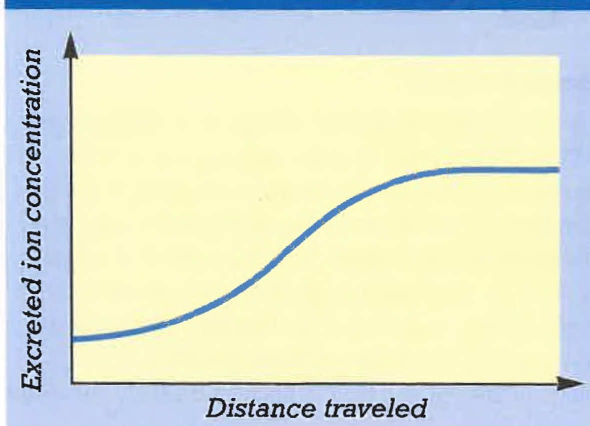
16. Name the three classes of fishes, and give a representative of each.
17. What is the advantage to lungfishes of having both lungs and gills?
18. Why do all scales point toward a fish's tail?
19. Explain how bony fishes living in salt water and fresh water maintain their salt and water balance. How do sharks and rays prevent water loss?
20. What is the function of the rectal gland in sharks and rays?
21. Trace the flow of blood through the heart of a fish.
22. Many female sharks and rays retain the eggs inside their body, and some may even provide nutrition for the developing young. Explain why natural selection might have favored this behavior.
23. A shark replaces lost and worn teeth throughout its life. Why is this ability advantageous? How is this pattern of tooth replacement different from that of humans?
24. Describe as many functions of gills as possible. Be sure to include respiratory and excretory functions in your answer.
25. Identify each lettered structure in the figure below.



CRITICAL THINKING

1. Neoteny is a phenomenon in which larvae become sexually mature but still retain larval characteristics. The term has been used to explain in part the evolution of vertebrates from ancestral chordates. Use what you know about tunicates to test this hypothesis.
2. Sharks have a large corkscrew-shaped structure in the intestine called a spiral valve. How might this organ function in digestion?
3. In a famous set of experiments, A. J. Kalmijn studied the ability of sharks to find prey. He showed that a shark could locate and capture a stationary fish buried in the sand at the bottom of its tank. When the fish was enclosed in electrical insulation and then buried, however, the shark could not locate it. From this information alone, can you conclude that the shark is using only its electrical sense to locate the buried fish? Explain your answer.
4. Saltwater fishes drink more water and produce much less urine than freshwater fishes do. How do you account for this difference?
5. Cod and many other ocean fishes lay eggs near the surface of the water. The male largemouth bass scoops out a nest in a lake or river bottom and waits for a female to deposit her eggs. What hypothesis would you make regarding the relative number of cod and bass eggs? Explain your answer.
6. Many species of fishes that live deep in the ocean, where there is little or no light, are luminescent. What might be the advantages of such an adaptation?
7. Many fish are able to regulate their internal ion concentration as they go from a saltwater environment to a freshwater environment. Study the chart below, which shows the excreted ion concentration of a fish as it travels from one body of water to another. Is the fish traveling from fresh water to salt water or salt water to fresh water? Explain your reasoning.

Effect of Environment on Ion Excretion



EXTENSION

1. Scientists are investigating an unexplained aspect of shark biology: sharks rarely get cancer. Use library resources or an on-line database to research this phenomenon. Gather information on how scientists are studying sharks' resistance to cancer. Also gather information on shark-cartilage dietary supplements. How has the popularity of shark-cartilage affected shark populations?
2. Read "Relax, It's Only a Piranha" in *Smithsonian,* July 1999, on page 42. Why does the author believe that the piranha has an undeserved and mistaken reputation for viciousness? How do piranhas usually feed? Describe the environmental conditions that led to the legendary voracious reputation that piranhas have.
3. Study the anatomy of any fish other than a yellow perch. Identify the operculum, vertebral column, and each fin. Label the internal organs. Compare the internal anatomy of your fish with that of the fish shown in Figure 41-10. What conclusions can you draw about habitat and behavior on the basis of the fish's structure?

CHAPTER 41

INTERACTIVE EXPLORATION

Exploring the Fish Heart

OBJECTIVES

- Simulate the action of a fish heart.
- Compare the structure and efficiency of a fish heart with those of the hearts of other vertebrates.

MATERIALS

- computer with CD-ROM drive
- CD-ROM *Interactive Explorations in Biology: Human Biology*

Background

This Interactive Investigation allows you to examine the action of a fish heart. Complex animals such as fishes require a uniform system of oxygen and nutrient distribution throughout their body. They also require a way to rid themselves of waste products, such as urea and carbon dioxide. The heart and the system of veins and arteries work together to provide these functions. The fish heart is a muscular tube with valves and chambers. It pumps blood to the gills and then throughout the body. The blood travels in a single loop, so that only deoxygenated blood enters the heart. Because the fish heart must pump blood through the fish's body in one cycle, it is less efficient than a human heart, which pumps blood first to the lungs, then to the heart, and finally to the rest of the body. Single-cycle pumping is considered to be less efficient than double-cycle pumping because it does not deliver as much oxygen and nutrients to the body's tissues.

Prelab Preparation

1. Start up the program Evolution of the Heart. Click the Topic Information button. Read the focus questions and review the three key concepts: the circulatory system, the heart, and the pulmonary vein.
2. Click the word *File* at the top left of the screen, and select Interactive Exploration Help. Listen to the instructions for operating the exploration. Click the Exploration button at the bottom right of the screen to begin the exploration. You will see an animated drawing like the one below.

VARIABLE

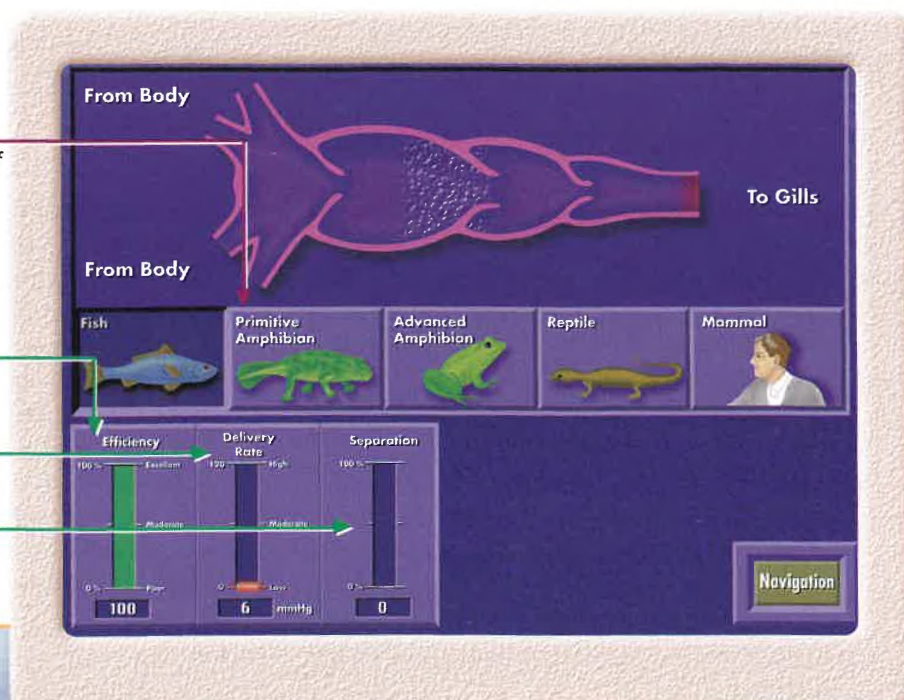
Type of heart: *allows you to select one of five hearts: fish, primitive amphibian, advanced amphibian, reptile, or mammal*

FEEDBACK METERS

Efficiency: *the efficiency with which the heart delivers oxygen and nutrients to the body's tissues*

Delivery Rate: *how rapidly the blood is pumped*

Separation: *the degree of separation of oxygenated blood and deoxygenated blood*



Procedure

Create a table like the one below for recording your data.

PART A The Fish Heart

First you will investigate the shape of the fish heart and its efficiency in pumping blood through the fish body.

1. Click the Interactive Explorations button (the one with the "magnifying glass" icon) at the top right of the screen. A fish heart is displayed with its efficiency, delivery rate, and separation in the feedback meters on the bottom left of the screen.
2. Note the route that blood travels through the fish heart. How does the blood complete the circuit? What is the efficiency of the fish heart? What is the delivery rate? Record this information in your data table.
3. Why is the separation in the feedback meter so low? Why does the lack of separation not matter in a single-cycle heart? Would this affect a two-cycle heart?

PART B The Primitive Amphibian Heart

4. Move the pointer to the primitive amphibian icon and click it. Has the shape of the heart changed significantly? How has the route of blood flow through the body changed?
5. How have the feedback meters changed? Did the amount of separation change from the fish heart?

PART C The Advanced Amphibian Heart

6. Move the pointer to the advanced amphibian icon and click it. What significant change occurs that separates it from the primitive amphibian heart?
7. Note the changes in the feedback meters. How did the change in the heart architecture change the readings on the feedback meters?

PART D The Reptile Heart

8. Move the pointer to the reptile icon and click it. What changes did you see take place?
9. Do the changes in the feedback meter indicate an improvement for the reptile's heart over the advanced amphibian's heart? Explain your answer.
10. Compare the reptile data with the fish heart data. Is the reptile heart better than the fish heart? Are the reptile data uniformly better than the fish heart data? Explain any inconsistencies.

PART E The Mammal Heart

11. Move the pointer to the mammal icon and click it. Record the feedback meter readings in the table you made. How do these changes compare with the readings from the other hearts?
12. What is the major advancement in the structure of the mammalian heart over the other animal hearts?

Analysis and Conclusions

1. What advantage does the fish's heart have over the reptilian and amphibian hearts? Explain the reason for the difference.
2. What advantage do the reptilian and amphibian hearts have over a fish's heart? How is this advantage improved on in the mammalian heart?

Further Investigation

Click the Navigation button and then click the Readings button. Click the "book" icon to the left of the article titled "The Beat Goes On." Prepare a report summarizing how successful scientists have been in producing artificial hearts.

COMPARISON OF VERTEBRATE HEARTS

Animal	Efficiency rate	Delivery rate	Separation

CHAPTER 42

AMPHIBIANS

Amphibians, such as this southern leopard frog (Rana pipiens), *are thought to have been the first vertebrates on land. Many amphibians still live part or all of their life in water.*

FOCUS CONCEPT: *Structure and Function*

As you read, note the adaptations of amphibians that enable them to live on land and in water.

SECTION

42-1

Origin and Evolution of Amphibians

About 370 million years ago, the first amphibians evolved from lobe-finned bony fishes and became the first vertebrates to live on land. The name amphibian *comes from the Greek words meaning "double" and "life" and reflects the fact that many amphibians spend part of their life on land and part in water.*

OBJECTIVES

- Describe two similarities between amphibians and lobe-finned fishes.
- List three characteristics of *Ichthyostega.*
- List the major characteristics of living amphibians.
- Name the three orders of living amphibians, and give an example of each.

ADAPTATION TO LAND

According to one hypothesis, aquatic vertebrates first moved onto land as shallow pools of water began drying up, leaving these amphibian ancestors without water. Vertebrates adapted to land, according to this hypothesis, as a way to escape shrinking pools and move to those that still contained water. This hypothesis is no longer widely accepted because, as many critics have pointed out, it is unlikely that all the complex land-dwelling adaptations shown by amphibians would have evolved merely for short periods of overland travel. It is more likely that the ancestors of amphibians left the water to escape predation and competition and to gain access to the resources that were becoming abundant on land. At that time, oceans, lakes, rivers, and ponds supported a tremendous number and variety of fishes. Food and space were limited, and the numerous species of fishes competed intensely for them. On land, however, there were no vertebrates, and terrestrial invertebrates such as insects, a promising food source, were beginning to diversify.

Characteristics of Early Amphibians

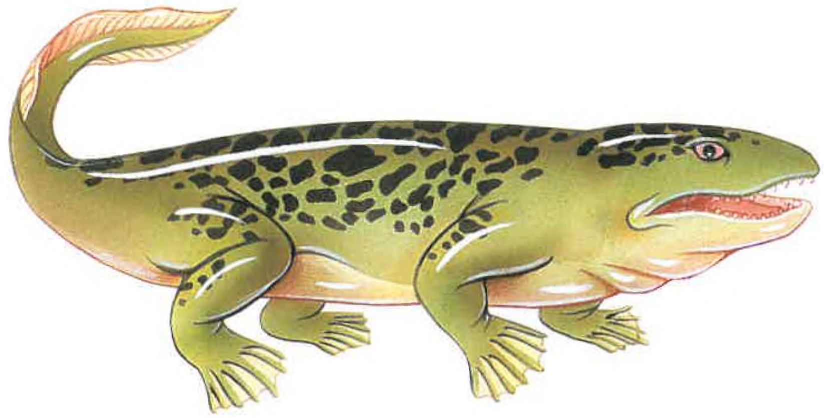
Scientists have long recognized that amphibians evolved from lobe-finned fishes. The groups share many anatomical similarities, including features of the skull and vertebral column. Also, the bones in the fin of a lobe-finned fish are similar in shape and position to the bones in the limb of an amphibian. Figure 42-1 shows a crossopterygian (kraw-SEP-te-RIJ-ee-uhn), an extinct lobe-finned fish that is thought to be closely related to amphibians. This fish probably lived in shallow water and used its sturdy pelvic and pectoral fins to move along the bottom and to support its body while resting.

The oldest known amphibian fossils date from about 370 million years ago. *Ichthyostega* is the best known early amphibian. Like

FIGURE 42-1
Early lobe-finned fishes, such as this crossopterygian, are thought to be the immediate ancestors of the first land vertebrates.

FIGURE 42-2

Ichthyostega had well-developed limbs and is thought to have been a crawler on land, but it still had an overall fishlike body.



Quick Lab

Comparing Fish and Amphibian Skin

Materials disposable gloves, lab apron, safety goggles, paper, colored pencils, living or preserved specimens of a fish and a frog

Procedure

1. Put on your disposable gloves, lab apron, and safety goggles.
2. Touch and examine the skin of the specimens provided by your teacher. Record your observations. Handle living animals gently.
3. When you are finished with your observations, remove your disposable gloves, lab apron, and safety goggles. Wash your hands with soap and water.

Analysis Why can a frog use its skin as a respiratory membrane, while a fish cannot? Using your colored pencils, draw a diagram to illustrate how a frog's skin functions as a respiratory membrane. What is this type of respiration called? How does the excretory system help to maintain moisture by conserving water? What behaviors in amphibians enable them to maintain moist skin?

Ichthyostega, which is shown in Figure 42-2, all of the early amphibians had four strong limbs, which developed from the fins of their fish ancestors. The forelimbs of amphibians (and all other terrestrial vertebrates) are homologous to the pectoral fins of fishes, and the hind limbs are homologous to the pelvic fins. The early amphibians also breathed air with lungs. As you learned in Chapter 41, lungs arose early in the history of fishes and are found in the descendants of these early fishes—including terrestrial vertebrates.

Although the early amphibians showed several adaptations for life on land, such as sense organs for detecting airborne scents and sounds, they probably spent most of their time in the water. For example, *Ichthyostega* had a large tail fin and lateral-line canals on its head. Its teeth were large and sharp, indicating a diet of fish, not insects. In addition, some of the early amphibians appear to have had gills like those of fishes. An unusual characteristic of the early amphibians is the number of toes on their feet. Most present-day terrestrial vertebrates have five toes on each foot. However, *Ichthyostega* had seven toes on each hind foot (no fossils of its front feet have been discovered), while *Acanthostega,* another early amphibian, had eight toes per foot. Apparently, the five-toed characteristic had not yet occurred.

Diversification of Amphibians

During the late Devonian period and the Carboniferous period (360 million to 286 million years ago), amphibians split into two main evolutionary lines. One line included the ancestors of modern amphibians, and the other line included the ancestors of reptiles. Amphibians have been a diverse, widespread, and abundant group since this early diversification.

Today there are about 4,500 species of amphibians, belonging to three orders. The largest order, with more than 3,900 species, is Anura, which comprises the frogs and toads. The order Urodela contains about 400 species of salamanders. And the third order, Apoda, consists of about 160 species of caecilians, which are legless, wormlike, tropical amphibians. Figure 42-3 shows the phylogenetic relationships between these three groups.

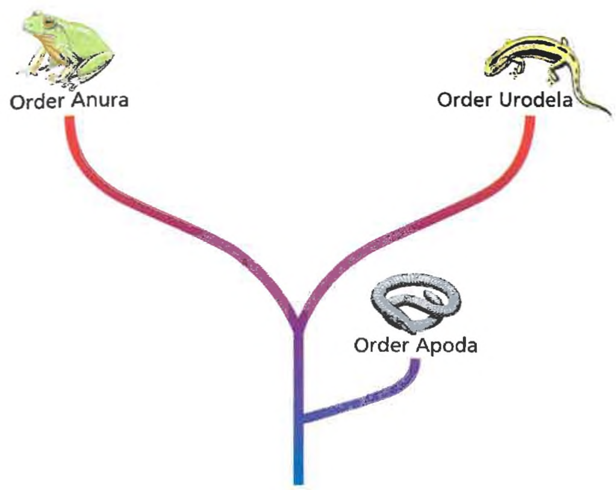


FIGURE 42-3
This phylogenetic tree represents the evolutionary relationships among the amphibians.

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MODERN AMPHIBIANS

Modern amphibians share several key characteristics:

- Most change from an aquatic larval stage to a terrestrial adult form. This transformation is called metamorphosis.
- Most have moist, thin skin with no scales.
- Feet, if present, lack claws and often are webbed.
- Most use gills, lungs, and skin in respiration.
- Eggs lack multicellular membranes or shells. They are usually laid in water or in moist places and are usually fertilized externally.

Order Anura

Anurans (frogs and toads) are found worldwide except in polar climates and a few isolated oceanic islands. They live in a variety of habitats, from deserts and tundra to tropical rain forests. Figure 42-4 shows two examples of anurans. The term *toad* is commonly used for any anuran that has rough, bumpy skin, while the term *frog* commonly refers to anurans having smooth, moist skin. These

FIGURE 42-4
Anurans include toads and frogs such as the plains spadefoot toad (a), *Scaphiopus bombifrons,* which can be found throughout the United States, and the White's tree frog (b), *Litoria caerulea,* which is common in Australia.


(a)


(b)

Word Roots and Origins

Urodela

from the Latin *Ur,* meaning "tail," and the Greek *dēlos,* meaning "visible"

terms are general descriptions, however, and do not refer to any specific groups of anurans. Many anurans spend at least part of their life in water, and some species are permanently aquatic. However, many other species live and reproduce on land.

Anurans are characterized by a body adapted for jumping. Long, muscular legs provide power for the jump. The anuran body is compact, with a short, rigid spine and strong forelimbs that help absorb the shock of landing. The word *anuran* means "tailless" and reflects the fact that no adult anuran has a tail.

Adult anurans are carnivores that feed on any animal they can capture. Some frogs have a sticky tongue that can be extended to catch prey. Many species of anurans return to water to reproduce. In nearly all species, eggs are fertilized externally. The fertilized eggs hatch into swimming, tailed larvae called **tadpoles.**

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Order Urodela

Salamanders have elongated bodies, long tails, and moist skin. Except for a few aquatic species, they have four limbs. The smallest salamanders are only a few centimeters long, while the largest reach lengths of 1.5 m (4.5 ft). Like anurans, salamander species range from fully aquatic to permanently terrestrial. Terrestrial salamanders usually live in moist places, such as under logs and stones. Larval and adult salamanders are carnivores. They are active mainly at night. Figure 42-5 shows two representative salamanders.

Most salamander species live in North America and Central America. There are very few species in Africa and South America, several species are found in Asia and in Europe, and there are no species found in Australia. With more than 300 species, the lungless salamanders (family Plethodontidae) are the largest group of salamanders. As their name suggests, these salamanders lack lungs. They absorb oxygen and release carbon dioxide through their skin.

Like most anurans, many salamanders lay their eggs in water, and the eggs hatch into swimming larval forms. Other species can reproduce in moist land environments. Eggs laid on land usually hatch into miniature adult salamanders and do not pass through a

FIGURE 42-5

The flatwoods salamander (a), *Ambystoma cingulatum,* and the spotted salamander (b), *Ambystoma maculatum,* are members of the order Urodela. *A. cingulatum,* which lives only in Florida, is an endangered species; *A. maculatum* can be found from eastern Canada to eastern Texas.

(a)

(b)

(a) (b)

FIGURE 42-6

Caecilians, such as *Ichthyophis kohtaoensis* (a) and *Caecilia nigricans* (b), are primarily carnivores. They are burrowing amphibians that are usually blind, and a few species have scales embedded in their skin.

free-living larval stage. Most salamander species have a type of internal fertilization by which females pick up sperm packets deposited by males. In some terrestrial species, the female stays with the eggs until they hatch, which can take up to several weeks.

Order Apoda

The common name used to refer to members of the order Apoda is caecilian (see-SIL-yuhn). Caecilians are a highly specialized group of legless amphibians that resemble small snakes, as you can see in Figure 42-6. Caecilians average about 30 cm (12 in.) in length, but some species reach lengths of 1.5 m (4.5 ft). Because they have very small eyes that are located beneath the skin or even under bone, caecilians often are blind. Caecilians are rarely seen, and little is known about their ecology and behavior. Most species burrow in the soil, but some species are aquatic. All species have teeth in their jawbones that enable them to catch and consume prey. They eat worms and other invertebrates, which they detect by means of a chemosensory tentacle located on the side of their head. All species are thought to have internal fertilization. Some species lay eggs, which the female guards until they hatch. In a few species, the young are born alive. Caecilians live in tropical areas of Asia, Africa, and South America.

SECTION 42-1 REVIEW

1. **Explain the most likely reason that aquatic vertebrates evolved from an aquatic existence to a land-based existence.**
2. **What characteristics suggest that lobe-finned fishes are the ancestors of amphibians?**
3. **What features of *Ichthyostega* suggest that it spent most of its time in water?**
4. **What is metamorphosis?**
5. **Give two examples of modern amphibians, and name the order to which each belongs.**
6. **CRITICAL THINKING Fossils of *Ichthyostega* and other early amphibians do not indicate the presence of lungs. Explain why scientists think the early amphibians had lungs.**

SECTION

42-2

OBJECTIVES

▲

Relate the structure of amphibian skin to the types of habitats in which amphibians can survive.

●

Identify three adaptations for life on land shown by the skeleton of a frog.

■

Describe the pattern of blood flow through an amphibian's heart.

◆

Describe how a frog fills its lungs with air.

▲

Explain the function of each organ of an amphibian's digestive system.

●

Compare the amphibian's nervous system with that of a bony fish.

CHARACTERISTICS OF AMPHIBIANS

As you have already seen, terrestrial vertebrates face challenges that are far different from those faced by aquatic vertebrates. In this section, you will learn about some of the ways amphibians meet the challenges of living on land.

EXTERNAL COVERING

The skin of an amphibian serves two important functions—respiration and protection. The skin is moist and permeable to gases and water, allowing rapid diffusion of carbon dioxide and water. Numerous **mucous glands** supply a lubricant that keeps the skin moist in air. This mucus is what makes a frog feel slimy. The skin also contains glands that secrete foul-tasting or poisonous substances that provide protection from predators.

However, the same features that allow efficient respiration also make amphibians vulnerable to dehydration, the loss of body water. Therefore, amphibians live mainly in wet or moist areas on land. Many species are active at night, when loss of water through evaporation is reduced. Although some species of frogs and toads survive in deserts, they spend most of their life in moist burrows deep in the soil. Only after heavy rains do these amphibians come to the surface to feed and reproduce.

INTERNAL ANATOMY

While water supports the body of an aquatic vertebrate against the force of gravity, terrestrial vertebrates must rely on the support of their strong internal skeleton. The vertebrae of the spine interlock and form a rigid structure that can bear the weight of the body. Strong limbs support the body during walking or standing. The forelimbs attach to the pectoral girdle (the shoulder and supporting bones), while the hind limbs attach to the pelvic girdle (the "hips"). The pectoral and pelvic girdles transfer the body's weight to the limbs. The cervical vertebra at the anterior end of the spine allows neck movement.

The frog skeleton in Figure 42-7 shows several specializations for absorbing the forces created by jumping and landing. In most terrestrial vertebrates, there are two bones in the lower hind limb, the tibia and the fibula, and two bones in the lower forelimb, the ulna and the radius. In frogs, the bones of the lower forelimb are fused into a single bone, the radio-ulna. The bones of the lower hind limb are fused into the tibiofibula. Frogs have few vertebrae, and the vertebrae at the posterior end of the spine are fused into a singe bone called the urostyle.

Heart and Circulatory System

The circulatory system of an amphibian, illustrated in Figure 42-8, is divided into two separate loops. The **pulmonary circulation** carries deoxygenated blood from the heart to the lungs, then returns the oxygenated blood to the heart. The **systemic circulation** carries oxygenated blood from the heart to the muscles and organs of the body and brings deoxygenated blood back to the heart. All other terrestrial vertebrates also have a "double-loop" circulatory pattern. This pattern of circulation provides a significant advantage over the "single-loop" circulation of a fish—faster blood flow to the body. In a fish, the blood loses some of its force as it passes through the narrow capillaries of the gills, and blood flow slows as a result. The lungs of an amphibian also contain narrow capillaries that slow blood flow. But after passing through the capillaries of the lung, blood returns to the heart to be pumped a second time before circulating to the body.

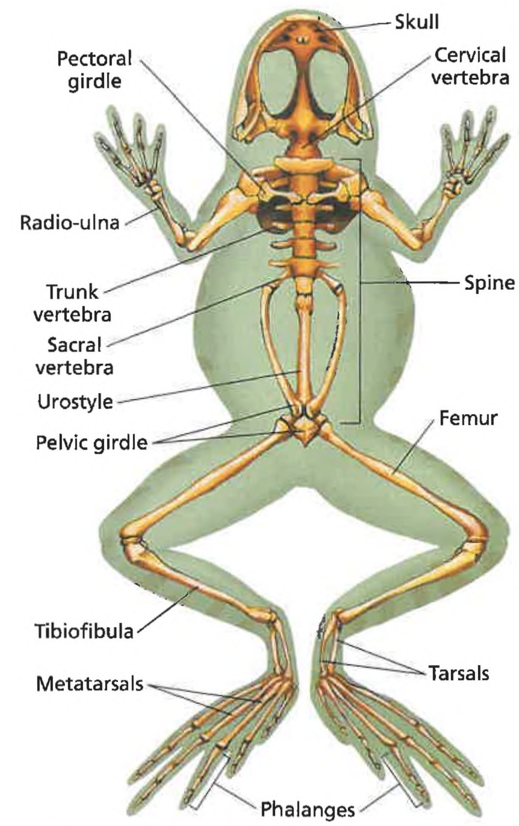


FIGURE 42-7

The skeleton of the frog absorbs shocks when the frog jumps. The urostyle and the two bones of the pelvic girdle extend outward to meet the sacral vertebra. This structure absorbs the shock for the long leg bones when the frog lands.

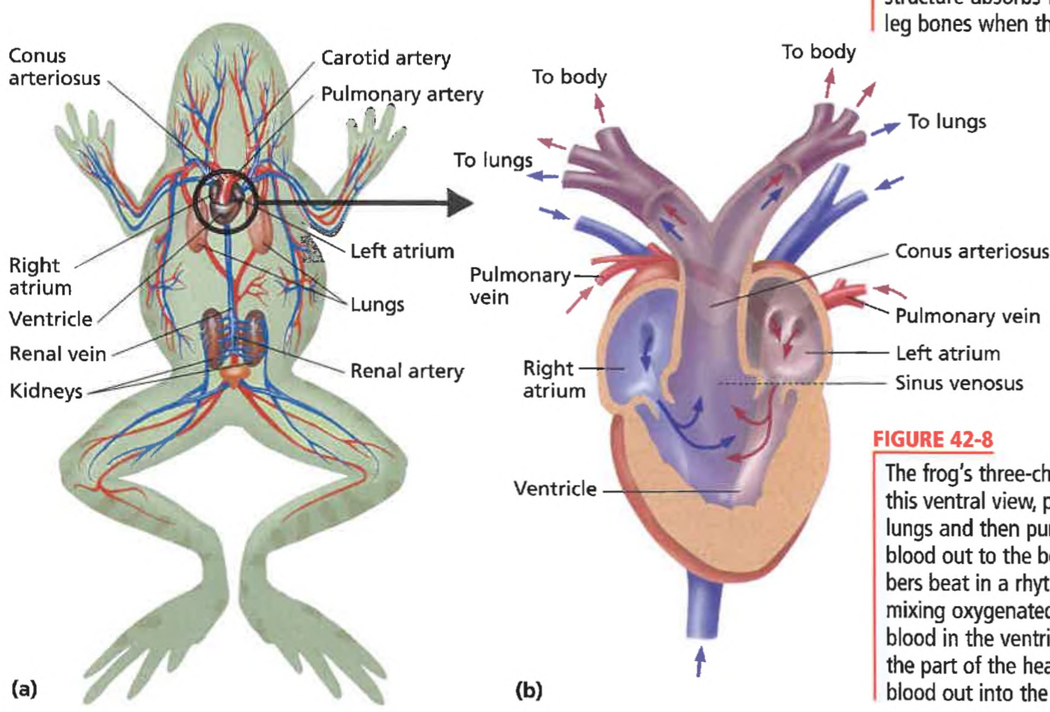
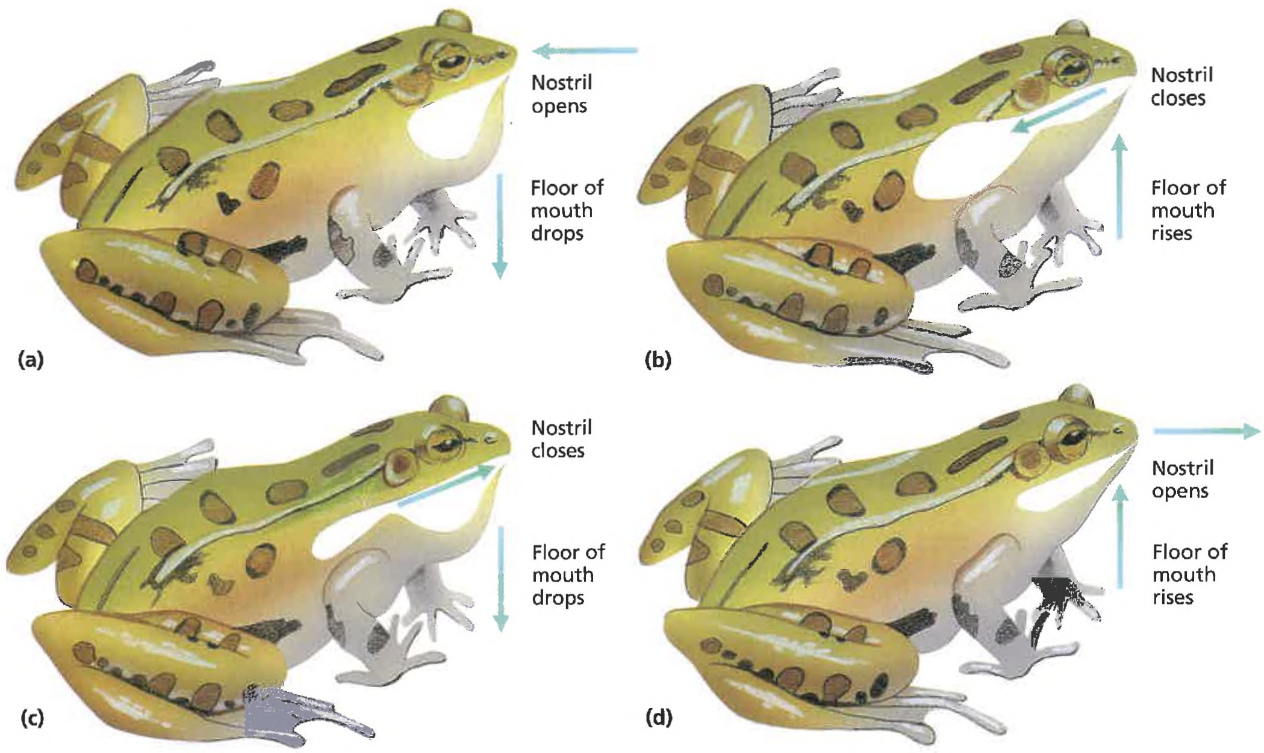


FIGURE 42-8

The frog's three-chambered heart, in this ventral view, pumps blood to the lungs and then pumps the oxygenated blood out to the body. The three chambers beat in a rhythm that minimizes mixing oxygenated and deoxygenated blood in the ventricle. The ventricle is the part of the heart that moves the blood out into the body and lungs.



Frogs breathe by creating pressure that forces air into their lungs. When the floor of the frog's mouth drops, air capacity increases in the frog's mouth (a), and air rushes in. When the nostril is closed and the mouth floor rises, the air is forced into the lungs of the frog (b). The elasticity of the lungs and the use of muscles force the air back out (c). Then the nostril opens and the mouth floor rises again, forcing air out the nostril (d).

The three-chambered heart of an amphibian reflects the division of the circulatory system into pulmonary and systemic circulation. Deoxygenated blood from the body first enters the sinus venosus, a collecting chamber on the dorsal right side of the heart, indicated by the dashed line in Figure 42-8. From the sinus venosus, blood moves into the right atrium. Oxygenated blood from the lungs enters the left atrium, and contraction of the atria forces the deoxygenated and oxygenated blood into the single ventricle, the main pumping chamber of the heart. Although the ventricle is not divided, its spongy, irregular interior surface and the coordinated contractions of the atria keep the oxygenated and deoxygenated blood from mixing. Ventricular contraction expels both kinds of blood into the conus arteriosus, which directs deoxygenated blood to the lungs and oxygenated blood to the body. A valve within the conus arteriosus prevents mixing of oxygenated and deoxygenated blood.

Respiration

Larval amphibians respire, or exchange carbon dioxide and oxygen, through their gills and skin. Most adult amphibians lose their gills during metamorphosis, but they can respire in two ways: through the lungs and through the skin.

Respiration through the lungs is called **pulmonary respiration.** Amphibians ventilate their lungs with a unique mechanism that pumps air into the lungs; this is called positive-pressure breathing. For example, a frog breathes by changing the volume and pressure of air in its mouth while either opening or closing its nostrils, as shown in Figure 42-9. Both inhalation and exhalation involve a two-step process during which the floor of the frog's mouth is raised and lowered. The frog controls the direction of air flow by opening or closing its nostrils. Because amphibians have a small surface area in the lungs for gas exchange, respiration through the skin, or **cutaneous respiration,** is very important to most aquatic and terrestrial amphibians.

Digestive System

All adult amphibians are carnivorous. Because most amphibians are small, insects and other arthropods are their most commonly consumed prey. Larger amphibians sometimes eat mice, snakes, fish, and other amphibians. Many amphibian larvae, such as those of frogs, are herbivorous, feeding on algae or bacteria. The larvae of some species, such as those of salamanders, are carnivorous, and some feed on the larvae of other species.

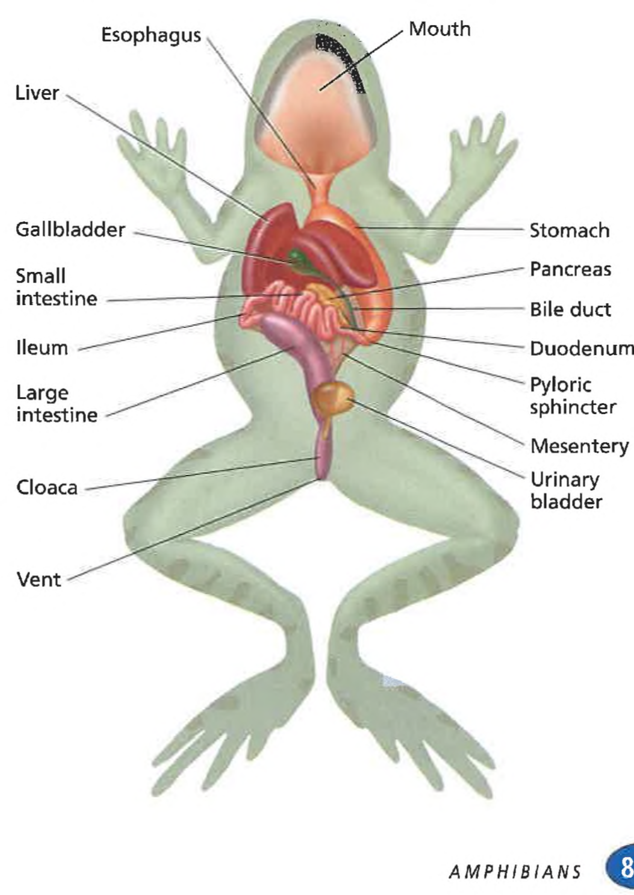
The amphibian digestive system includes the pharynx, esophagus, stomach, liver, gallbladder, small intestine, large intestine, and cloaca. Figure 42-10 shows the digestive system of a frog. The elastic esophagus and stomach allow an amphibian to swallow large amounts of food. Once food reaches the stomach, tiny glands in the stomach walls secrete gastric juices that help break down, or digest, the food. A muscle called the pyloric sphincter at the lower end of the stomach relaxes, which allows digested food to move into the small intestine. The upper portion of the small intestine is called the **duodenum** (DOO-oh-DEE-nuhm). The coiled middle portion of the small intestine is the **ileum** (IL-ee-uhm). A membrane resembling plastic wrap, called the **mesentery,** holds the small intestine in place. Inside the small intestine, digestion is completed and the released nutrients pass through capillary walls into the bloodstream, which carries them to all parts of the body.

The lower end of the small intestine leads into the large intestine. Here indigestible wastes are collected and pushed by muscle action into a cavity called the cloaca (kloh-AY-kuh). Waste from the kidneys and urinary bladder, as well as either eggs or sperm from the gonads, also passes into the cloaca. Waste materials exit the body through the **vent.**

Other glands and organs aid in the digestion process. The liver produces bile, which is stored in the gallbladder. Bile helps break down fat into tiny globules that can be further digested and absorbed. A gland called the pancreas, located near the stomach, secretes enzymes that enter the small intestine and help break down food into products that can be absorbed by the blood.

FIGURE 42-10

The frog digestive system is shown in ventral view. Notice how the short small intestine is an adaptation for a carnivorous diet. Recall that the shark and perch also have short intestines.



Excretory System

The kidneys are the primary excretory organs. One kidney lies on either side of the spine against the dorsal body wall. The kidneys filter nitrogenous wastes from the blood. These wastes, flushed from the body with water, are known as urine. Urine flows from the kidneys to the cloaca through tiny tubes called urinary ducts. From the cloaca, it flows into the urinary bladder, which branches from the ventral wall of the cloaca. For many terrestrial amphibians, the urinary bladder serves as a water-storage organ. During dry periods, water can be reabsorbed from the urine in the bladder.

Like the larvae of fishes, most amphibian larvae excrete the nitrogen-containing wastes as ammonia. Because ammonia is very toxic, it must be removed from the body quickly or diluted with large amounts of water in the urine. To conserve water, adult amphibians transform ammonia into urea, a less-toxic substance that can be excreted without using as much water. Although this transformation uses energy, it helps save water. During metamorphosis, larval amphibians change from excreting ammonia to excreting urea.

Nervous System

Use the diagram in Figure 42-11 to find the main components of the amphibian nervous system. An amphibian's brain is about the same size as that of a similarly sized fish. The olfactory lobes, which are the center of the sense of smell, are larger in amphibians than in fish, and they lie at the anterior end of the brain. Notice that behind the

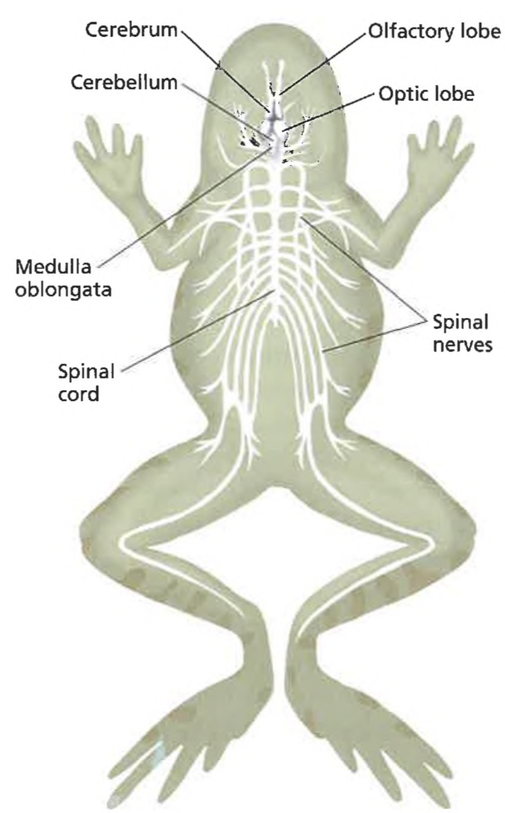


FIGURE 42-11
This diagram shows the frog's nervous system in ventral view. The brain of the frog is sufficiently developed to cope with both land and water environments.

olfactory lobes are the long lobes of the cerebrum, the area of the brain that integrates behavior and is responsible for learning. The optic lobes, which process information from the eyes, lie behind the cerebrum. The cerebellum, a small band of tissue that lies at a right angle to the long axis of the brain, is the center of muscular coordination and is not as well developed in amphibians as it is in other tetrapods. The medulla oblongata lies at the back of the brain and joins the spinal cord. It controls some organ functions, such as heart rate and respiration rate. There is continuous communication among most areas of the brain. Ten pairs of cranial nerves extend directly from the brain. The spinal cord conducts signals from all parts of the body to the brain and from the brain back to the body. Encased in protective bony vertebrae, the spinal cord extends down the back. As in fishes, the spinal nerves branch from the spinal cord to various parts of the body.

Sense Organs

Some sense organs work as well in air as in water, but others do not. For example, the lateral line system, used by fishes to detect disturbances in the water, works only in water. Thus, while larval amphibians have a lateral line, it is usually lost during metamorphosis. Only a few species of aquatic amphibians have a lateral line as adults. The senses of smell, sight, and hearing are well developed in most amphibians. All amphibians have eyes, and visual information is often important in hunting and in avoiding predators. The eyes are covered by a transparent, movable membrane called a **nictitating** (NIK-ti-tayt-eeng) **membrane.** Sound receptors are located in the inner ear, which is embedded within the skull. Sounds are transmitted to this organ by the **tympanic** (tim-PAN-ik) **membrane,** or eardrum, and the **columella** (CAHL-yoo-MEL-uh), a small bone that extends between the tympanic membrane and the inner ear. Sounds first strike the tympanic membrane, which is usually located on the side of the head, just behind the eye. Vibrations of the tympanic membrane cause small movements in the columella that are transmitted to the fluid-filled inner ear. In the inner ear, the sound vibrations are converted to nervous impulses by sensitive hair cells. These nervous impulses are then transmitted to the brain through a nerve.

Word Roots and Origins

nictitating

from the Latin *nictare*, meaning "to wink"

SECTION 42-2 REVIEW

1. **Why do most amphibians live in wet or moist habitats?**
2. **Describe two features of a frog's skeleton that are adaptations for jumping.**
3. **Trace the flow of blood through a frog's heart.**
4. **Explain how a frog moves air into and out of its lungs.**
5. **What is the function of the large intestine in amphibians?**
6. **CRITICAL THINKING Which sense organ of a terrestrial amphibian resembles the fish's lateral line in function? Explain your answer.**

SECTION

42-3

OBJECTIVES

▲

Describe the life cycle of a frog.

●

Describe the changes that occur during metamorphosis in frogs.

■

Identify two examples of parental care in amphibians.

REPRODUCTION IN AMPHIBIANS

One of the biggest differences between aquatic and terrestrial life-forms is their method of reproduction. Most amphibians depend on water for reproduction. They lay their eggs in water and spend the early part of their lives as aquatic larvae.

LIFE CYCLE

Consider the life cycle of a wood frog, illustrated in Figure 42-12. The reproductive system of the male frog includes two bean-shaped testes located near the kidneys. During the breeding season, sperm cells develop in the testes and pass through tubes to the kidneys and urinary ducts. During mating, sperm leave the body through the cloacal opening. In female frogs, a pair of large, lobed ovaries containing thousands of tiny immature eggs lie near the kidneys. During the breeding season, the eggs enlarge, mature, and burst through the thin ovarian walls into the body cavity. Cilia move the eggs forward into the funnel-like openings of the oviducts. As the eggs pass down the oviducts, they are coated with a protective jellylike material. The eggs exit by the cloaca to the external environment, where they are fertilized.

Courtship and Fertilization

In the first warm days of spring in the temperate zones, frogs emerge from hibernation. They migrate in great numbers to ponds and slow-moving streams. Males call to attract females of their own species and to warn off other males. Each species has its own mating call. The frog's croak is produced by air that is driven back and forth between the mouth and the lungs, vibrating the vocal folds. Male frogs have vocal sacs that amplify their calls. The female responds only to the call from a male of the same species.

When a female approaches, the male frog climbs onto her back. He grasps her firmly in an embrace called **amplexus** (am-PLEKS-UHS), which is shown in Figure 42-12a. The male clings to the female, sometimes for days, until she lays her eggs. When the female finally releases her eggs into the water, the male frog discharges his sperm over them, and direct external fertilization takes place. The frogs then separate and resume their solitary lives. Courtship behavior and fertilization often vary from one species to another.

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TOPIC: Life cycle of frogs
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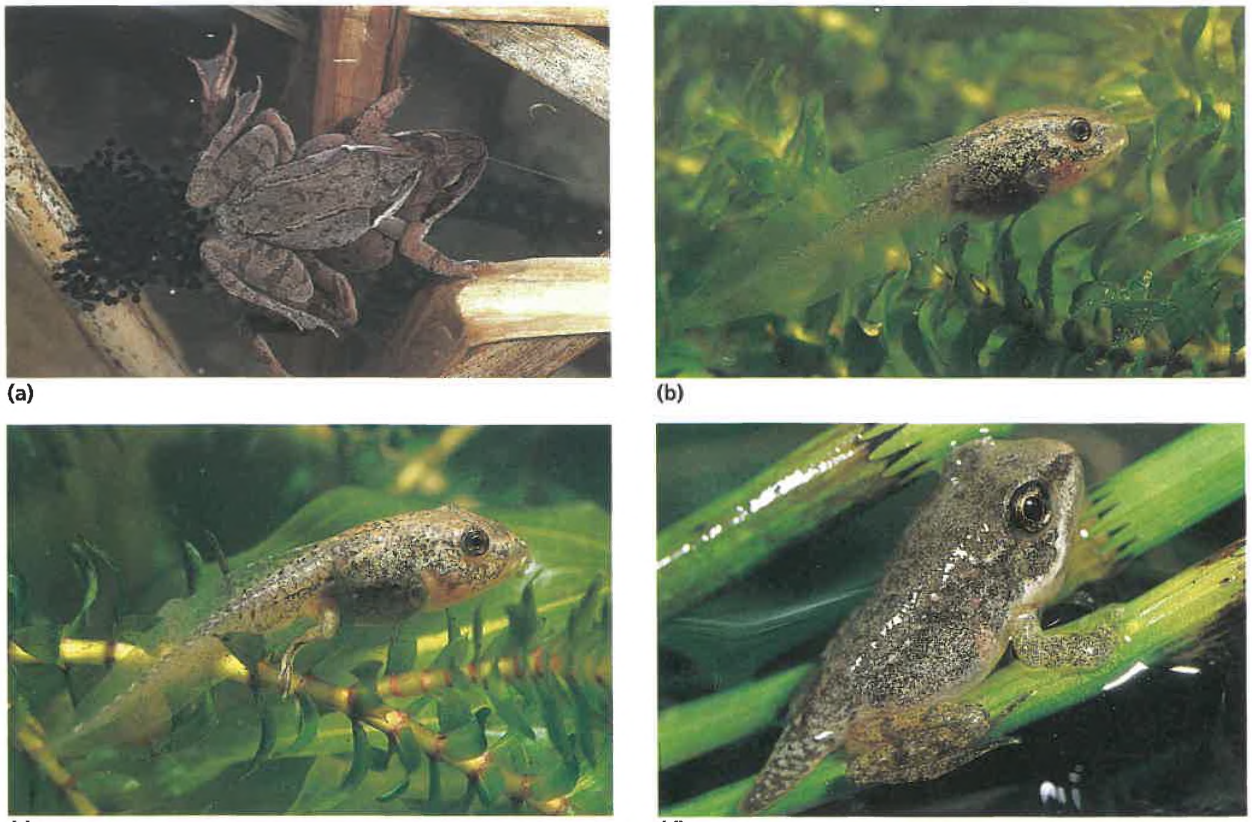
Word Roots and Origins

amplexus

from the Latin *amplexus*, meaning "embrace"



(a) (b) (c) (d)

FIGURE 42-12

The life cycle of the wood frog, *Rana sylvatica,* begins with mating (a). The male frog holds the female frog in amplexus, and when she releases her eggs, he releases his sperm on the eggs. When the eggs hatch, a tadpole is released (b). One of the first developments of metamorphosis is the growth of hind legs (c). When the tadpole completes metamorphosis, a small adult (d) emerges from the water onto the land.

Metamorphosis

Within a few days of fertilization, the eggs hatch into tadpoles. A newly hatched tadpole lives off yolk stored in its body. It gradually grows larger and develops three pairs of gills. Eventually, the tadpole's mouth opens, allowing it to feed. The tadpole grows and slowly changes from an aquatic larva into an adult. This process of change is called metamorphosis. Legs grow from the body, and the tail and gills disappear. The mouth broadens, developing teeth and jaws, and the lungs become functional.

Biologists have long studied the process of metamorphosis and regeneration to learn what controls such dramatic physical changes. Increasing levels of a hormone called thyroxine, which circulates throughout the bloodstream, stimulate metamorphosis.

The life cycles of many amphibians are similar to that of the wood frog. But there are a variety of alternative reproductive patterns among amphibians. For example, many amphibians do not lay their eggs in water. They select a moist place on land, such as under a rock, inside a rotting log, or in a tree. One or both parents may even construct a nest for the eggs. A number of frog species make a nest of mucus, whipping it into a froth by kicking their hind legs. And not all amphibians undergo metamorphosis. Some salamanders remain in the larval stage for their entire life. Other amphibians bypass the free-living larval stage and hatch from the egg as a small version of the adult.

FIGURE 42-13

Rhinoderma darwinii male frogs exhibit parental care by holding the maturing eggs and larvae in their vocal sacs. This frog has already released his offspring, whose tails are still visible. Not all frogs express parental care in this way, and some frogs express no parental behavior at all.

PARENTAL CARE

Parental care is common among amphibians. Eggs and larvae are vulnerable to predators, but parental care helps increase the likelihood that some offspring will survive. Most often, one parent (often the male) remains with the eggs, guarding them from predators and keeping them moist until they hatch. The male Darwin's frog *(Rhinoderma darwinii)* takes the eggs into his vocal sacs, where they hatch and eventually undergo metamorphosis. The young frogs climb out of the vocal sacs and emerge from the male's mouth, as shown in Figure 42-13. Female gastric-brooding frogs of Australia swallow their eggs, which hatch and mature in the stomach. The eggs and tadpoles are not digested because the stomach stops producing acid and digestive enzymes until the young pass through metamorphosis and are released. There are two species of gastric-brooding frogs. Both appear to have become extinct within the last two decades. Females of some species of frogs, such as *Eleutherodactylus,* sit on their eggs until they hatch, not to provide warmth but to prevent the eggs from dessicating. The female normally lays the eggs in the leaves of trees or bushes, where they may dry up.

SECTION 42-3 REVIEW

1. What is the function of the male frog's call?
2. Describe the changes that occur during metamorphosis.
3. What role does thyroxine play in metamorphosis?
4. How does the female gastric-brooding frog care for her eggs?
5. Why is standing water not always required for amphibian reproduction?
6. **CRITICAL THINKING** How does the parental care of a female gastric-brooding frog help her offspring survive? How might her behavior reduce her likelihood of survival?

CHAPTER 42 REVIEW

SUMMARY/VOCABULARY

42-1

- Amphibians evolved from lobe-finned fishes about 370 million years ago.
- *Ichthyostega* and the other early amphibians had lungs and four legs. They were predominantly aquatic, they had a lateral line and a fishlike tail fin, and some had gills.
- Modern amphibians are divided into three orders: Anura (frogs and toads), Urodela (salamanders), and Apoda (caecilians).
- Anurans are found on all continents except Antarctica, and they have large hind legs for jumping and a strong skeleton.
- Salamanders have four legs and a tail. They are found mainly in North America and Central America.
- Caecilians are legless tropical amphibians that resemble earthworms.

Vocabulary

tadpole (822)

42-2

- Amphibians respire through their lungs and skin. Mucous glands produce slimy mucus that helps retain moisture.
- The skeleton of an amphibian supports the body against the pull of gravity. The spine and limbs are strong so that they can bear the body's weight.
- The amphibian pulmonary circuit carries blood between the heart and lungs. The systemic circuit carries blood to the body and returns it to the heart.
- The heart of an amphibian consists of the sinus venosus, two atria, one ventricle, and the conus arteriosus. Although the ventricle is not divided, deoxygenated and oxygenated blood mix little in the heart.
- Larval amphibians respire with gills and through their skin. Adult amphibians respire with the lungs and the skin. Amphibians pump air into their lungs by raising and lowering the floor of their mouth cavity.
- In amphibians, food passes through the mouth, esophagus, stomach, small intestine, large intestine, and cloaca. The kidneys remove wastes from the blood. Adult amphibians eliminate nitrogenous wastes as urea.
- The brain of a frog has large optic lobes that process visual information, large olfactory lobes that control the sense of smell, a cerebrum that integrates behavior and controls learning, a cerebellum that coordinates movement, and a medulla oblongata that controls the heart and respiration rate.

Vocabulary

columella (829)	ileum (827)	nictitating membrane (829)	systemic circulation (825)
cutaneous respiration (827)	mesentery (827)	pulmonary circulation (825)	tympanic membrane (829)
duodenum (827)	mucous gland (824)	pulmonary respiration (826)	vent (827)

42-3

- Most amphibians lay their eggs in water and have an aquatic larval stage.
- Male frogs call to attract females. Females of some species can distinguish the species of the caller and determine his size.
- The male frog grasps the female and fertilizes her eggs as they are released.
- The hormone thyroxine triggers metamorphosis. During metamorphosis, the tadpole loses its tail and gills and grows legs and lungs.
- Many amphibians show parental care, guarding their eggs and keeping them moist, and some take them into their body to develop.

Vocabulary

amplexus (830)

REVIEW

Vocabulary

Explain the difference between each pair of related terms.

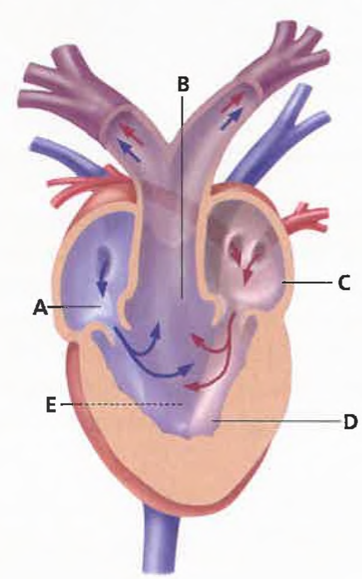
1. systemic circulation, pulmonary circulation
2. amplexus, metamorphosis
3. ileum, cloaca
4. conus arteriosus, sinus venosus
5. pulmonary respiration, cutaneous respiration

Multiple Choice

6. Which of the following is not a characteristic of *Ichthyostega*? (a) tail fin (b) four limbs (c) lungs (d) pelvic fins
7. The forelimbs of vertebrates evolved from which structures in lobe-finned fishes? (a) pelvic fins (b) pectoral fins (c) pectoral girdle (d) anal fin
8. Amphibians must lay eggs in water primarily because the eggs (a) need oxygen from water (b) are not laid in nests (c) do not have multicellular membranes and a shell (d) need protection from predators.
9. Metamorphosis must take place before amphibians are able to (a) swim (b) live on land (c) feed themselves (d) respire with gills.
10. Salamanders differ from frogs in that they have (a) aquatic larvae (b) four limbs (c) a tail (d) moist skin.
11. The frog's ventricle pumps (a) only oxygenated blood (b) only deoxygenated blood (c) only blood returning from the lungs (d) both oxygenated and deoxygenated blood.
12. Adult amphibians release their nitrogenous wastes in the form of (a) urea (b) uric acid (c) guanine (d) ammonia.
13. Bile is a fluid that (a) aids in circulation (b) lubricates skin (c) breaks down fats into globules (d) aids in respiration.
14. The frog's tympanic membranes are (a) eardrums (b) mouth parts (c) eyelids (d) vocal folds.
15. Which of the following is true of reproduction in most frogs? (a) female calls to attract male (b) eggs surrounded by tough shell (c) fertilization is external (d) fertilization is internal

Short Answer

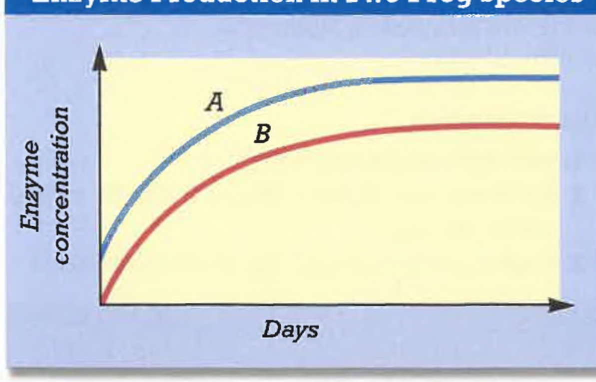
16. Identify and describe the major characteristics of amphibians.
17. Explain why scientists no longer favor one early theory of why vertebrates moved from water to land. What is the most likely reason to explain why vertebrates moved from water to land?
18. Identify two of *Ichthyostega's* adaptations for life on land.
19. Although frogs do not have watertight skin, some species can survive in deserts. Explain how frogs survive such dry conditions.
20. Salamanders in the family Plethodontidae have no lungs. Explain how these salamanders respire.
21. Outline the route of blood flow through the body of a frog, beginning with the ventricle. How does this route differ from the circulatory system of a fish?
22. What functions do the tympanic membrane and columella perform?
23. What kind of information can a female frog get from a male frog's call?
24. Why are the nitrogenous wastes of an adult amphibian and its larvae different?
25. Look at the diagram of a frog's heart shown below. Identify the structures indicated by the letters. In which structures would you find deoxygenated blood? In which structures would you find oxygenated blood?



CRITICAL THINKING

1. There are usually many ecological differences between a frog and its tadpoles. Describe some of these differences. Explain why such differences might have been favored by natural selection.
2. As you learned in Chapter 39, insects also undergo metamorphosis. Compare metamorphosis in insects with metamorphosis in amphibians.
3. Charles Darwin noticed that frogs and toads are often absent from oceanic islands, such as the Galápagos Islands, even though they may be found on the nearby mainland. Darwin conducted some experiments that showed that frogs' eggs cannot tolerate exposure to salt water. What hypothesis do you think Darwin was trying to test? Explain your answer.
4. In the brains of amphibians, the largest parts are the olfactory lobes and the optic lobes, the centers of smell and sight. This is very important to amphibians in hunting prey and avoiding predators. In what other biological process is the capacity for hearing important? Explain why hearing must then be especially distinctive.
5. The female gastric-brooding frogs of Australia do not produce stomach acid or digestive enzymes while brooding their young in their stomachs until the tadpoles have completed metamorphosis and leave. If the mother frog does not eat during this period, from where does she get her energy? What other types of frogs must live off the same energy source during similar periods of fasting?
6. When tadpoles undergo metamorphosis, their bodies begin to produce an enzyme that converts ammonia into urea. The time that a tadpole takes to produce this enzyme varies among species. In the graph below, the rate of enzyme production in metamorphosis is shown for a species that inhabits a desertlike environment and a species that inhabits a forest environment. Which curve represents which frog? Explain your answer.

Enzyme Production in Two Frog Species



EXTENSION

1. Read "Having Their Toxins and Eating Them, Too" in *BioScience,* December 1999, on page 945. Answer the following question from the section titled "A Frog One Doesn't Kiss": Where does the family Dendrobatidae of poison-Dart frogs acquire the toxins found in their skin?
2. Research human uses of the skin secretions of frogs. Find out how South American Indians use the skin secretions of frogs in the family Dendrobatidae. What are some potential medical uses of skin secretions of frogs? Write a report describing what you have learned.
3. Read "Are Pathogens Felling Frogs?" in *Science,* April 30, 1999, on page 728. Frog deformities have been blamed on pollution in the past. What does new data from Australia now suggest may be the real cause of frog deformities and die-offs?

Observing Live Frogs

OBJECTIVES

- Observe the behavior of a frog.
- Explain how a frog is adapted to life on land and in water.

PROCESS SKILLS

- observing
- relating structure to function
- recognizing relationships

MATERIALS

- live frog in a terrarium
- aquarium half-filled with dechlorinated water
- live insects (crickets or mealworms)
- 600 mL beaker

Background

1. What does *amphibious* mean?
2. Describe how amphibians live part of their life on land and part in water.
3. What are some major characteristics of amphibians?

PART A Observing the Frog in a Terrarium

1. Observe a live frog in a terrarium. Closely examine the external features of the frog. Make a drawing of the frog in your lab report. Label the eyes, nostrils, tympanic membranes, front legs, and hind legs. The tympanic membrane, or eardrum, is a disklike membrane behind each eye.
2. In your lab report, make a table similar to the one on the facing page to note all your observations of the frog in this investigation.
3. Watch the frog's movements as it breathes air with its lungs. Record your observations in your data table.
4. Look closely at the frog's eyes, and note their location. Examine the upper and lower eyelids as well as a third transparent eyelid called a nictitating membrane. The upper and lower eyelids do not move. The nictitating membrane moves upward over the eye. This eyelid protects the eye when the frog is underwater and keeps the eye moist when the frog is on land.
5. Study the frog's legs. Note in your data table the difference between the front and hind legs.
6. Place a live insect, such as a cricket or a mealworm, in the terrarium. Observe how the frog reacts.
7. Gently tap the side of the terrarium farthest from the frog, and observe the frog's response.

PART B Observing the Frog in an Aquarium

8. CAUTION **You will be working with a live animal. Handle it gently and follow instructions carefully.** Frogs are slippery. Do not allow the frog to injure itself by jumping from the lab bench to the floor. Place a 600 mL beaker in the terrarium. Carefully pick up the frog and examine its skin. How does it feel? The skin of a frog acts as a respiratory organ, exchanging oxygen and carbon dioxide with the air or water. A frog also takes in and loses water through its skin.
9. Place the frog in the beaker. Cover the beaker with your hand, and carry it to a freshwater aquarium. Tilt the beaker and gently submerge it beneath the surface of the water until the frog swims out of the beaker.

OBSERVATIONS OF A LIVE FROG	
Characteristic	**Observation**
Breathing	
Eyes	
Legs	
Response to food	
Response to noise	
Skin texture	
Swimming behavior	
Skin coloration	

10. Watch the frog float and swim in the aquarium. How does the frog use its legs to swim? Notice the position of the frog's head.

11. As the frog swims, bend down and look up into the aquarium so that you can see the underside of the frog. Then look down on the frog from above. Compare the color on the dorsal and ventral sides of the frog. When you are finished observing the frog, your teacher will remove the frog from the aquarium.

12. Record your observations of the frog's skin texture, swimming behavior, and skin coloration in your data table.

13. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. From the position of the frog's eyes, what can you infer about the frog's field of vision?
2. How does the position of the frog's eyes benefit the frog while it is swimming?
3. How does a frog hear?
4. How can a frog take in oxygen while it is swimming in water?
5. Why must a frog keep its skin moist while it is on land?
6. How are the hind legs of a frog adapted for life on land and in water?
7. What adaptive advantage do frogs have in showing different coloration on their dorsal and ventral sides?
8. What features provide evidence that an adult frog has an aquatic life and a terrestrial life?
9. What adaptations does the frog display in order to eat? What senses are involved in catching prey?
10. What movement does the frog make in order to breathe?

Further Inquiry

Observe other types of amphibians, or do research to find out how they are adapted to life on land and in water. How do the adaptations of other types of amphibians compare with those of the frog you observed in this investigation?

CHAPTER 43

REPTILES

A marine iguana, Amblyrhynchus cristatus, *of the Galápagos Islands warms itself by basking on a rock. These are the only marine lizards in the world, and they feed exclusively on seaweed.*

FOCUS CONCEPT: *Structure and Function*

As you read the chapter, compare reptiles' structural and functional adaptations for living on land with those of amphibians.

SECTION

43-1

OBJECTIVES

▲ Identify and describe three groups of reptiles that lived during the Mesozoic era.

● Describe the asteroid-impact hypothesis to explain the extinction of the dinosaurs.

■ Describe the structure of the amniotic egg, and explain the functions of its parts.

◆ Contrast the skin of reptiles with that of amphibians.

ORIGIN AND EVOLUTION OF REPTILES

The reptiles (class Reptilia) appeared more than 300 million years ago. They are one of the largest and most evolutionarily successful groups of terrestrial vertebrates. In this chapter, you will study the diversity of reptiles and learn about some of the characteristics that make the reptiles a successful group.

HISTORY OF REPTILES

From studies of fossils and comparative anatomy, biologists infer that reptiles arose from amphibians. The oldest known fossils of reptiles were found in deposits from the early Carboniferous period (360 million to 286 million years ago) and are about 350 million years old. The earliest reptiles were small, four-legged vertebrates that resembled lizards and had teeth adapted for eating insects. The abundance of insects at the time may have been one reason the early reptiles flourished.

Age of Reptiles

The reptiles diversified rapidly, and by the Permian period (286 million to 245 million years ago) they had become the dominant land vertebrates. The Mesozoic era (245 million to 65 million years ago) is often called the Age of Reptiles because nearly all of the large vertebrates on Earth were reptiles during that time. On land, the most famous and spectacular reptiles, the **dinosaurs,** appeared and evolved into a great variety of forms during the Mesozoic era. Dinosaurs are known for the great size of some species. One of the largest dinosaurs, *Brachiosaurus,* measured 23 m (75.4 ft) long, stood 12 m (39.4 ft) tall, and weighed more than 77,000 kg (169,400 lb). In other words, *Brachiosaurus* was as long as a tennis court, as tall as a four-story building, and heavier than 10 elephants. Although the size of some dinosaurs has captured our imagination, many species were small, some no larger than a chicken.

Over 300 genera of dinosaurs have been identified. Their fossils have been discovered on all continents, even Antarctica, which had a much milder climate during the Mesozoic era than it does today. Dinosaurs were adapted to a wide range of environments and to different ways of life. Some reconstructions of dinosaurs are shown in Figure 43-1 on the following page.

Word Roots and Origins

dinosaur

from the Greek *deinos,* meaning "terrible," and the Greek *sauros,* meaning "lizard"

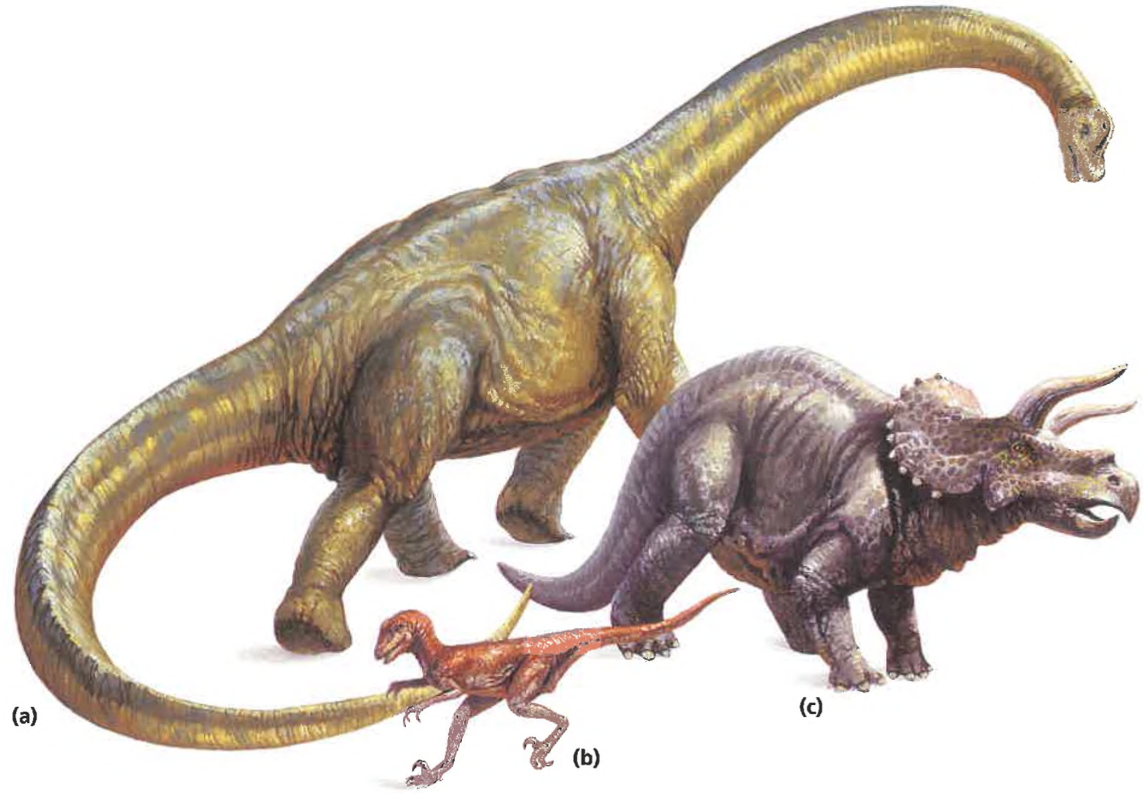


FIGURE 43-1

Brachiosaurus, shown in (a), and related dinosaurs were herbivores that probably used their long necks to reach vegetation in the treetops. *Deinonychus,* shown in (b), and other carnivores walked on their hind legs and used sharp claws to rip apart prey. *Triceratops,* shown in (c), had body armor and horns to defend itself against meat-eating dinosaurs, but it was a plant eater. Scientists believe *Triceratops* may have roamed in great herds across western North America.

Reptilian success during the Mesozoic era was not limited to terrestrial habitats. Several groups of reptiles, including the ichthyosaurs and plesiosaurs, lived in the oceans. Ichthyosaurs, illustrated in 43-2b, were sleek aquatic reptiles that resembled modern bottlenose dolphins. Plesiosaurs had long, flexible necks and compact bodies. Mesozoic reptiles called pterosaurs, shown in Figure 43-2a, evolved the ability to fly. There are no flying reptiles today.

Extinction of Dinosaurs

Although the fossil record provides many clues about what dinosaurs were like, paleontologists who study dinosaurs still have many unanswered questions. For example, why did the dinosaurs become extinct 65 million years ago, at the end of the Cretaceous period? Many species of aquatic and terrestrial organisms besides the dinosaurs became extinct at this time.

Most scientists think that a catastrophic cosmic event was responsible for the mass extinction. Supporters of this hypothesis—called the **asteroid-impact hypothesis**—suggest that a huge asteroid hit the Earth, sending so much dust into the atmosphere that the amount of sunlight reaching the Earth's surface was greatly reduced. The reduced sunlight caused severe climatic changes that led to the mass extinction. According to this hypothesis, the dinosaurs would have become extinct very quickly, perhaps even within a few months.

The asteroid-impact hypothesis was first proposed in 1980 by Luis Alvarez, a Nobel Prize–winning physicist, and his son Walter, a geologist. They noted that sediments from the end of the Cretaceous period contain unusually high concentrations of iridium. Iridium is a metal that is very rare in the Earth's crust but more abundant in asteroids and other extraterrestrial bodies. Other scientists discovered that some sediments from this time contain quartz crystals that have been deformed by a powerful force, such as that resulting from the collision of a large asteroid with Earth. Further evidence for this hypothesis was provided by the discovery of the likely site of impact, a crater located on the Yucatan Peninsula in southern Mexico. The crater dates from the end of the Cretaceous period and is about 180 km (110 mi) across.

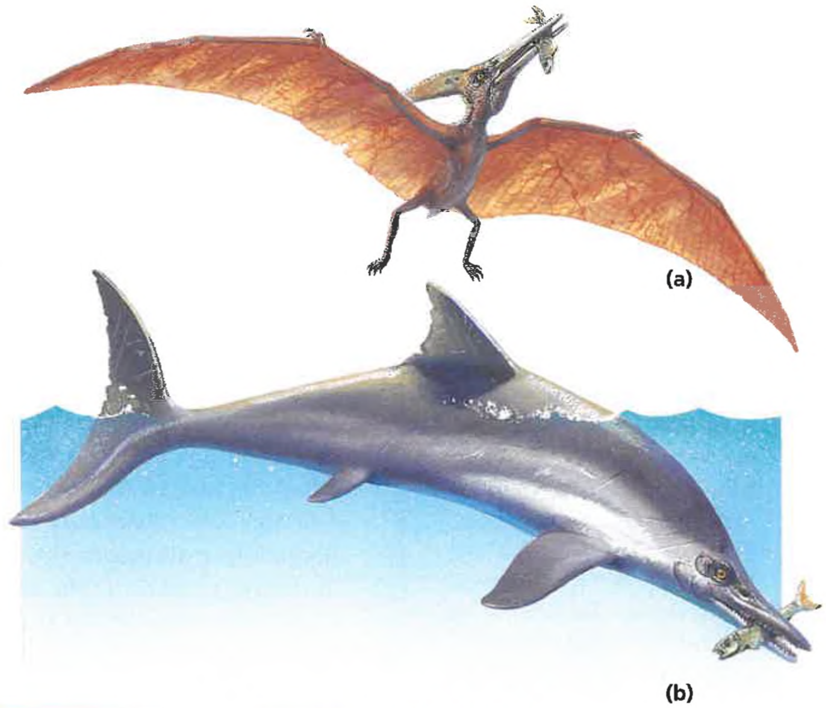


FIGURE 43-2
The smallest pterosaurs, such as the one in (a), were only the size of sparrows, while the largest were about the size of a small airplane, with wingspans of 12 m (about 39 ft). Like dolphins, ichthyosaurs, as in (b), were probably fast swimmers and fed on fish.

SUCCESS OF REPTILES

Representatives of the four modern orders of reptiles—turtles and tortoises, lizards and snakes, tuataras, and crocodilians—survived the mass extinction of the Cretaceous period. These four orders of reptiles have diversified to more than 6,000 species. Reptiles successfully occupy a variety of terrestrial and aquatic habitats on all continents except Antarctica. Figure 43-3 shows the evolutionary relationships between modern reptiles and birds.

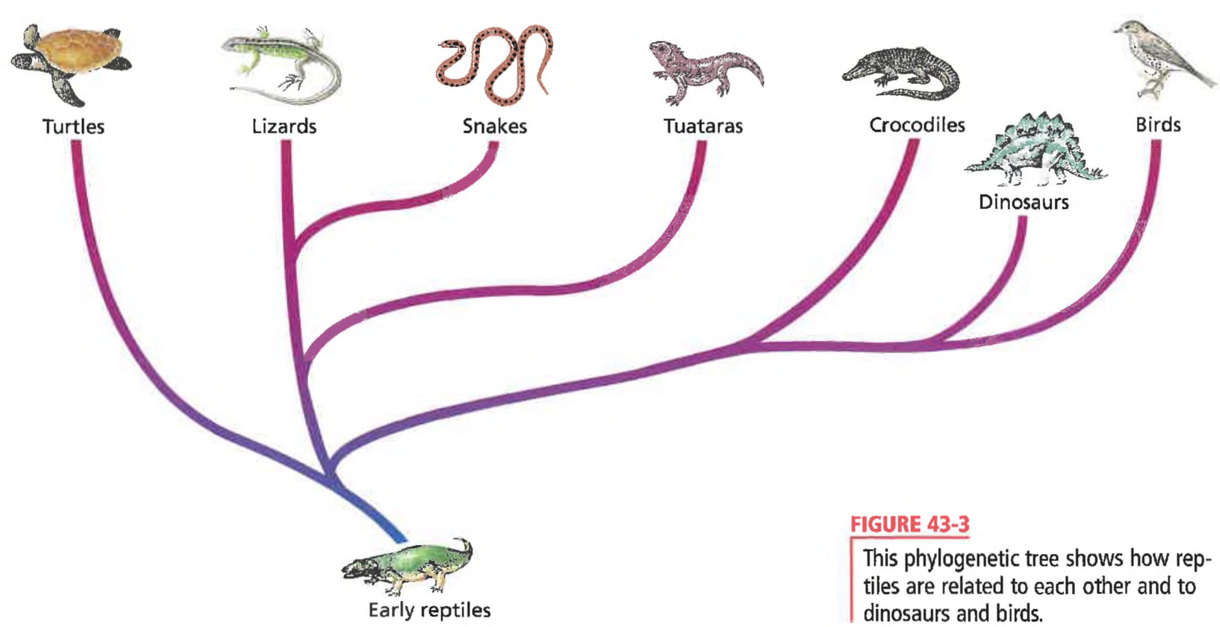


FIGURE 43-3
This phylogenetic tree shows how reptiles are related to each other and to dinosaurs and birds.

Quick Lab

Modeling an Amniotic Egg

Materials paper lunch bag; large, sealable plastic bag; small, sealable plastic bag; modeling clay; yellow balloon; red balloon

Procedure Design an amniotic egg model using the materials provided and the information in Figure 43-4. Use all the materials you have been provided.

Analysis According to your model, how many layers of protection surround the embryo? Why is this structure an important adaptation for reptiles? The amniotic egg links reptiles to what other two groups of organisms?

The Amniotic Egg

Although amphibians were the first vertebrates to successfully invade land, they could not make a full transition to terrestrial life. They still require water in their environment to reproduce. Reptiles are considered the first fully terrestrial vertebrates because they do not need to reproduce in water, as most amphibians do. Reptiles produce **amniotic eggs,** which encase the embryo in a secure, self-contained aquatic environment. Amniotic eggs provide more protection for the developing embryo than the jellylike eggs of amphibians.

Figure 43-4 shows the internal structure of the amniotic egg, including its four specialized membranes: the amnion, yolk sac, allantois, and chorion. The egg is named for the **amnion** (AM-nee-AHN), the thin membrane enclosing the fluid in which the embryo floats. The **yolk sac** encloses the yolk, a fat-rich food supply for the developing embryo. The **allantois** (uh-LAN-toh-wis) stores the nitrogenous wastes produced by the embryo. Because it contains many blood vessels, the allantois also serves as the embryo's "lung," exchanging carbon dioxide for oxygen from the environment. The **chorion** (KOR-ee-AHN) surrounds all the other membranes and helps protect the developing embryo. Protein and water needed by the embryo are contained in the **albumen** (al-BYOO-muhn). You are familiar with albumen as the egg white in a chicken's egg. In most reptiles, the tough outer shell provides protection from physical damage and limits the evaporation of water from the egg.

The amniotic egg first evolved in reptiles, but it also occurs in mammals and birds. The presence of this feature is strong evidence that reptiles, birds, and mammals evolved from a common ancestor. The eggs of some reptiles and nearly all mammals lack shells, and the embryo develops within the mother's body.

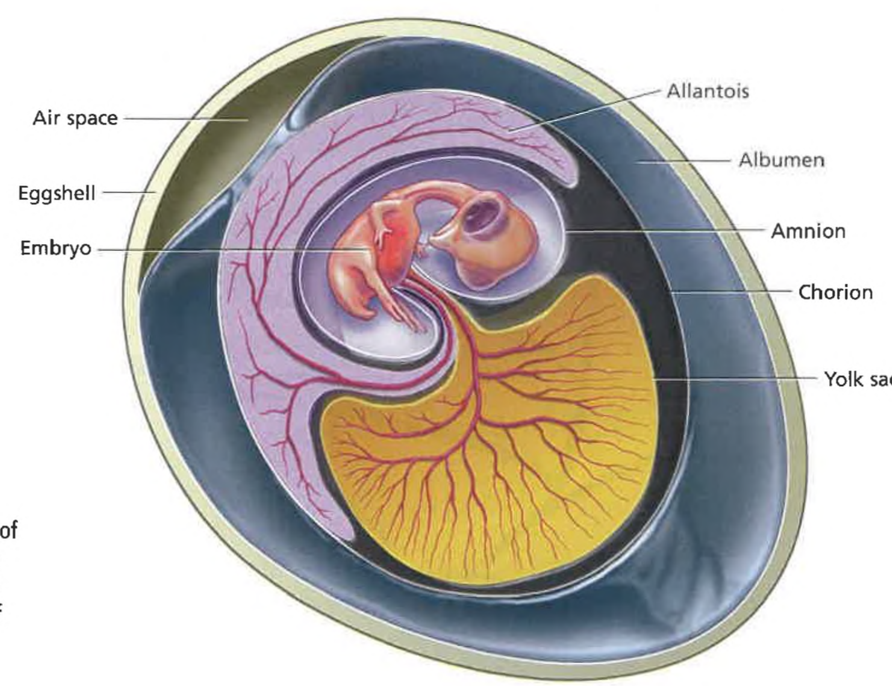


FIGURE 43-4
This amniotic egg at an early stage of development shows a chick embryo and the four major membranes. The porous shell allows the exchange of oxygen and carbon dioxide.

FIGURE 43-5

The skin of the spiny lizard *Sceloporus poinsetti* protects it from the rugged terrestrial environment and from water loss.

Watertight Skin

Because amphibians exchange gases through their skin, the skin must be moist and thin enough to allow rapid diffusion. A drawback of this kind of skin is that it cannot be watertight, and one problem amphibians face on land is the loss of body water through evaporation. Reptiles, like the lizard shown in Figure 43-5, are covered by a thick, dry, scaly skin that prevents water loss. This scaly covering develops as surface cells fill with **keratin,** the same protein that forms your fingernails and hair. Lipids and proteins in the skin help make the skin watertight. The tough skin of a reptile not only helps conserve body water but also protects the animal against infections, injuries, and the wear and tear associated with living in terrestrial environments.

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Respiration and Excretion

All reptiles have lungs for gas exchange. Thus, all of the tissues involved in gas exchange are located inside the body, where they can be kept moist in even the driest environments. The excretory system of reptiles also helps them conserve body water. Snakes, lizards, and other land-dwelling reptiles excrete nitrogenous wastes in the form of uric acid. Uric acid is much less toxic than ammonia or urea. Thus, it requires little water for dilution, and reptiles lose only small amounts of water in their urine.

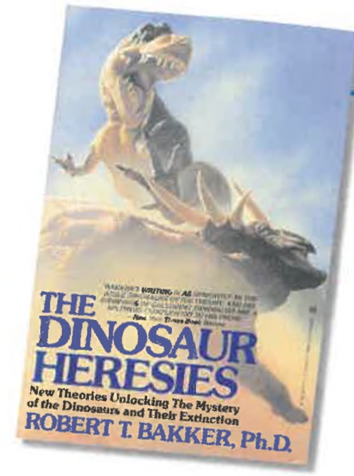
SECTION 43-1 REVIEW

1. Describe three kinds of Mesozoic reptiles, not including dinosaurs.
2. Why is the presence of iridium in sediments from the end of the Cretaceous period an important piece of evidence supporting the asteroid-impact hypothesis?
3. Explain the significance of the amniotic egg for reproduction on land.
4. Describe the functions of the chorion and the allantois in the amniotic egg.
5. What are two differences between the skin of an amphibian and the skin of a reptile?
6. CRITICAL THINKING If it were shown that dinosaurs disappeared slowly over many millions of years, would this contradict or support the asteroid-impact hypothesis? Explain your answer.

Literature & Life

Dinosaurs Are Extinct—But Why?

The following excerpt is from *The Dinosaur Heresies,* by Robert T. Bakker.



A very well-preserved segment of fossil history . . . permits a computation of how long the average species and genus of dinosaur lasted. And that can be compared with the rates of change computed for warm-blooded animals on the one hand and cold-blooded on the other. Rates of evolutionary change must somehow be linked to the metabolic rate of any given organism. When metabolism is very high, the high physical costs of its living must drive the animal to be an aggressive competitor or predator. And the rapid reproduction typical of warm-blooded animals tends to fill habitats to overcrowded levels much more quickly than the more leisurely breeding schedules characteristic of cold-bloods. An ecological community full of warm-blooded species is therefore a tough environment where the resident species jostle one another for food and water, breeding sites and burrows, all year round. In this sort of environment, the average species will not last long in terms of geological time before it is driven to extinction either by a new species, or by a combination of old species, or by an adverse change of climate.

Clams, by contrast, with their low metabolism, move around very little to accomplish the tasks of their adult lives. It is consequently not surprising that species of clams last much longer than warm-blooded species. Crocodiles and turtles are far more active than clams, but are still sluggish compared to the fully warm-blooded mammals. If dinosaurs resembled cold-blooded reptiles metabolically, their rate of evolutionary change would very nearly match that found in crocodiles or large turtles. But if the dinosaurs' metabolism was heated, then the average life span of one of their species or genera would have to be short, like a mammal's.

One of the best places to study the rate of evolutionary changes in dinosaurs is in the Late Cretaceous deltas of Wyoming, Montana, and Alberta. There the changes through the last ten million years of the dinosaurs' history can be followed. As might be expected, the turtles and crocodiles show very little change in these strata. The genera representing these cold-bloods hold on through formation after formation. But what about the dinosaurs here? Their evolutionary pace stands out as quite different. New species and genera kept appearing and eliminating older ones at quite a brisk tempo, geologically speaking. The average genus of dinosaur lasted for only a fraction of the time of that of the average crocodile. . . .

One part of the orthodox story does appear to be unassailable, an ineradicable fact safe from even the wildest heretic: Dinosaurs are indeed all extinct. The fact of their extinction is the cornerstone underlying the orthodox belief that dinosaurs were maladapted failures.

Dinosaurs are incontrovertibly dead. But that does not prove what orthodoxy believes about them. Paradoxically, the extinction of the dinosaurs is strong evidence that their biology was heated to levels far above those of typical reptiles. The basic principle is simple: The higher the metabolic needs of a group of species, the more vulnerable it is to sudden and catastrophic extinction.

Reading for Meaning

What is Bakker's explanation for the extinction of the dinosaurs?

Read Further

Bakker follows the text excerpted here by describing the best natural design for avoiding extinction. Explain what you think that design might be, and name some existing animals that are similar to that design.

CHARACTERISTICS OF REPTILES

SECTION

43-2

OBJECTIVES

▲ Describe the pattern of blood flow through the heart of a lizard.

● Compare the lungs of reptiles with those of amphibians.

■ Identify three senses of reptiles.

◆ Contrast endothermy with ectothermy.

▲ Explain the differences between oviparity, ovoviviparity, and viviparity.

Reptiles live in many different kinds of habitats and show a great deal of diversity in size and shape. Think of the differences between a snake and a turtle or between a lizard and a crocodile. In this section, we will look at some of the anatomical, physiological, and behavioral characteristics of reptiles.

CIRCULATORY SYSTEM

The circulatory system of a reptile, like those of all terrestrial vertebrates, is composed of two loops. The pulmonary loop carries deoxygenated blood from the heart to the lungs and returns oxygenated blood to the heart. The systemic loop transports oxygenated blood to the tissues of the body, where oxygen and nutrients are unloaded and carbon dioxide is picked up, and returns deoxygenated blood to the heart.

Heart Structure and Function

In lizards, snakes, tuataras, and turtles, the heart has two atria and a single ventricle partially divided by a wall of tissue called a **septum.** In crocodiles, there are two atria and two separate ventricles. The sinus venosus and the conus arteriosus, which are major structures in the heart of a fish, are much smaller in reptiles. In fact, the sinus venosus is absent in some species. When it is present, it collects blood from the body and channels it into the right atrium. The conus arteriosus forms the base of the three large arteries exiting from the reptilian heart.

Because the ventricle is not completely divided (except in crocodiles), it might seem that deoxygenated and oxygenated blood would mix. However, recent studies have shown that blood mixing does not occur when a reptile is active. Deoxygenated and oxygenated blood are kept separate during contraction of the heart by the actions of the heart valves and the movement of the septum and ventricular walls.

Pumping blood through lungs requires energy. Under some conditions, it is advantageous for a reptile to divert blood away from the lungs to conserve energy. For example, an inactive reptile needs so little oxygen that it may go a long time without breathing. Similarly, aquatic reptiles do not breathe while they are underwater.

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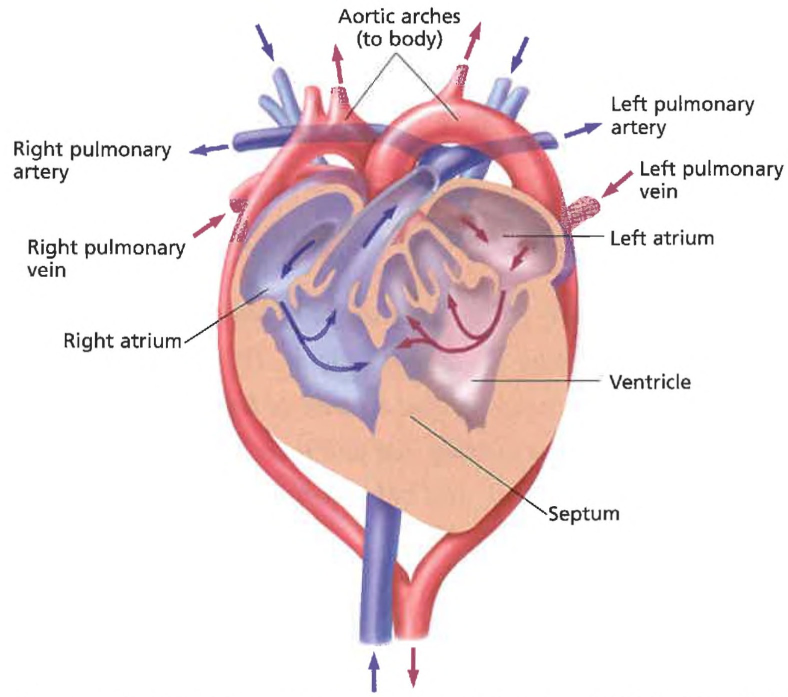
FIGURE 43-6

The turtle's heart, shown in cross section, has a partially divided ventricle, unlike an amphibian's three-chambered heart or a crocodile's four-chambered heart. Because the flow of blood through a turtle's heart is asynchronous, deoxygenated blood and oxygenated blood pass through the upper part of the ventricle at different times and so do not mix.



By constricting the pulmonary arteries, a reptile's blood flow through the heart can be redirected to send some deoxygenated blood back to the body instead of to the lungs. Bypassing the lungs may also help a reptile raise its body temperature quickly—warm blood from the skin can be directed to the organs deep within the body. The reptilian heart has a degree of circulatory flexibility that the hearts of birds and mammals do not. Instead of being a handicap, this flexibility is actually well suited to reptilian physiology and activity patterns. Figure 43-6 shows a schematic diagram of the heart of a turtle. Compare this diagram with the illustrations of the three-chambered heart of a frog (Figure 42-8) and the two-chambered heart of a fish (Figure 41-11).

RESPIRATION

The lungs of reptiles are large, and they are often divided internally into several chambers. The lining of the lungs may be folded into numerous small sacs called **alveoli.** Alveoli greatly increase the internal surface area of the lungs, thus increasing the amount of oxygen that can be absorbed. In most snakes, only the right lung actively functions. It is elongated and may be half as long as the body. The left lung is either reduced to a small nonfunctional sac or absent entirely.

A reptile fills its lungs by expanding its rib cage. This expansion reduces the pressure within the thorax and draws air into the lungs. When the ribs return to their resting position, pressure within the thorax increases and air is forced out of the lungs. Similar movements help you to breathe.

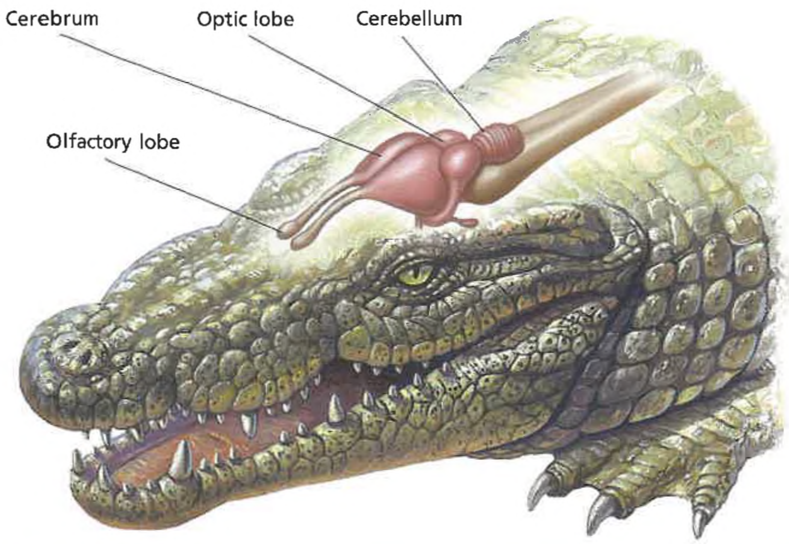


FIGURE 43-7

The crocodile's sense of smell is very important for its survival. The olfactory lobe of the reptile's brain, where the sense of smell is located, is highly developed.

NERVOUS SYSTEM

The brain of a reptile is about the same size as that of an amphibian of the same size. However, the reptilian cerebrum is much larger. This region of the brain is involved in controlling and integrating behavior. Because vision is an important sense for most reptiles, the optic lobes, which receive input from the eyes, are large. Figure 43-7 shows the structure of a crocodile's brain.

Most reptiles rely on their sense of sight to detect predators and prey. The eyes of reptiles are usually large, and many species have keen vision. Hearing is also an important sense. As in amphibians, sound waves first strike the tympanum, or eardrum, and are transmitted to the inner ear through the movements of a small bone called the columella. The inner ear contains the receptors for sound. Snakes lack a tympanum and are sensitive only to low-frequency sounds. They are able to detect ground vibrations, which are transmitted to the columella by the bones of the jaw.

Jacobson's organ is a specialized sense organ located in the roof of the mouth of reptiles. Jacobson's organ is sensitive to odors. Like the snake shown in Figure 43-8, reptiles use their tongue to gather chemicals from the environment. These chemicals are transferred to the Jacobson's organ when the tongue is drawn back into the mouth. Jacobson's organ is found in all reptiles except crocodiles and most turtles, but it is highly developed in lizards and snakes.

Pit vipers, such as rattlesnakes, copperheads, and water moccasins, are able to detect the heat given off by warm-bodied prey, such as mammals and birds. These snakes have one heat-sensitive pit below each eye, as shown in Figure 43-8. Input from these pits allows a snake to determine the direction of and distance to a warm object.

FIGURE 43-8

Some snakes have reduced senses of sight and hearing. They compensate with a sensitive forked tongue that is an organ of touch and smell. As the tongue darts in and out of the mouth, it picks up particles that are taken into the Jacobson's organ inside the snake's mouth, where even extremely low concentrations of odors can be detected.

THERMOREGULATION

The control of body temperature is known as **thermoregulation.** Vertebrates regulate their body temperature in two different ways. An **ectotherm** warms its body by absorbing heat from its surroundings. It has a slow metabolism that produces little heat. Reptiles, fishes, and amphibians are ectotherms. In contrast, **endotherms,** such as mammals and birds, have a rapid metabolism, which generates heat needed to warm the body. Most endotherms have insulation, such as hair, feathers, or fat, to retain the heat. The body temperatures of many aquatic ectotherms, such as fishes and amphibians, remain close to the temperature of their surroundings. When active, however, terrestrial ectotherms, such as lizards and snakes, usually keep their body temperatures about the same as the body temperatures of endotherms.

Reptiles regulate their body temperature by controlling how much heat they absorb. For example, when a lizard emerges from its nest after a cool night, its body temperature is low and must be raised before it can become active. The lizard warms itself by basking in the sun, as shown in Figure 43-9a. The lizard's warm blood is diverted from the skin to the interior of the body. The lizard continues to bask until it is warm enough to become active. As the graph in Figure 43-9b shows, a lizard can maintain its body temperature within a narrow range by using a variety of behaviors and body positions, despite variations in air temperature.

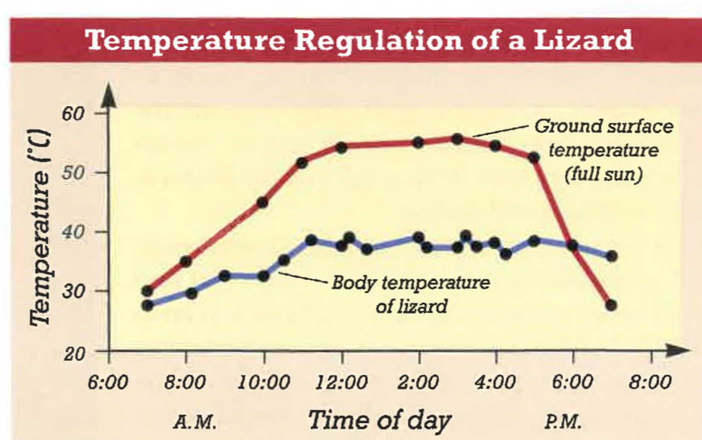
Advantages and Limitations of Ectothermy

Ectotherms require very little energy because their metabolism is very slow, and they also need only about one-tenth as much food as an endotherm of the same size. Ectotherms cannot live in very cold climates, and they can survive temperate climates only by becoming dormant during the coldest months. Furthermore, ectotherms can run or swim at maximum speed only for short periods of time. Ectothermic metabolism cannot provide enough energy for sustained exertion.

FIGURE 43-9

(a) A lizard regulates its body temperature throughout the day, basking to warm and seeking shade to prevent overheating. If its body temperature rises too high, the lizard may pant to accelerate heat loss. The graph in (b) shows an early-morning increase in the lizard's body temperature. The body temperature fluctuates only slightly during the remainder of the day despite wide fluctuations in ground temperature.

(a)



(b)

REPRODUCTION AND PARENTAL CARE

There are three patterns of reproduction among reptiles. The differences between these three patterns lie in how long the eggs remain within the female and in how she provides them with nutrition.

In **oviparity,** the female's reproductive tract encloses each egg in a tough protective shell. The female then deposits the eggs in a favorable place in the environment. Oviparity is characteristic of most reptiles, all birds, and three species of mammals.

Once released from the female's body, an egg is particularly vulnerable to predators and to environmental hazards. One way to reduce exposure to these hazards is to retain the eggs within the female's body for a time. This strategy is called **ovoviviparity.** The eggs may be laid shortly before hatching, or they may hatch within the female's body. The eggs absorb water and oxygen from the female, but they receive no nutrition other than the yolk.

In **viviparity,** a shell does not form around the egg, and the young are retained within the female's body until they are mature enough to be born. Nutrients and oxygen are transferred from mother to embryo through a structure called the **placenta.** The placenta forms from the membranes within the egg, and it brings blood vessels from the embryo near the vessels of the mother. Viviparity is the reproductive pattern shown by most mammals, but it is also found in a few species of lizards and snakes.

Many reptiles provide no care for their eggs or young. However, some species of lizards and snakes guard and warm the eggs until they hatch. Crocodiles and alligators provide the greatest amount of parental care. A female crocodilian, for example, builds a nest for her eggs. She remains nearby while the eggs incubate, guarding against nest-robbing predators. After the young hatch, they produce a high-pitched yelp, which summons the mother. She then breaks open the nest and carries the hatchlings to the water in her mouth, as shown in Figure 43-10. The mother crocodile may protect her young for a year or more.

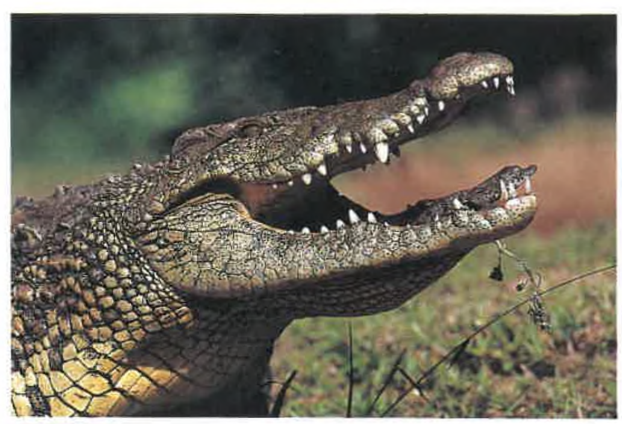
Word Roots and Origins

ovoviviparous

from the Latin *ovum,* meaning "egg," the Latin *vivus,* meaning "alive," and the Latin *parere,* meaning "to bring forth"

FIGURE 43-10

Reptiles generally provide no care for their young, but the hatchlings are usually able to fend for themselves as soon as they emerge from the shell. Crocodiles and alligators, however, care for their young for up to two years. The female crocodile in the photograph is transporting her baby in her mouth.



SECTION 43-2 REVIEW

1. Describe how the heart of a lizard differs from the heart of a crocodile.
2. Explain how a reptile inflates its lungs.
3. What is the function of the Jacobson's organ?
4. Compare ectothermy with endothermy.
5. Contrast oviparity with viviparity.
6. **CRITICAL THINKING** Describe which of the three patterns of reproduction in reptiles best serves to protect the eggs from predators. Explain your answer.

SECTION

43-3

MODERN REPTILES

OBJECTIVES

▲ Compare the anatomy of turtles with that of other reptiles.

● Describe how crocodilians capture prey.

■ Explain two antipredator defenses of lizards.

◆ Describe two ways snakes subdue their prey.

▲ Identify two characteristics of tuataras.

Modern reptiles are classified into four orders: Chelonia, Crocodilia, Squamata, and Rhynchocephalia. As different as two species of reptile—such as a turtle and a snake—appear to be, all species of modern reptiles share the following characteristics: an amniotic egg; internal fertilization of eggs; dry, scaly skin; respiration through lungs; and ectothermic metabolism.

ORDER CHELONIA

The order Chelonia consists of about 250 species of turtles and tortoises. The term *tortoise* is generally reserved for the terrestrial members of the order, such as the Galápagos tortoise shown in Figure 43-11a. *Turtle* usually refers to chelonians that live in water, such as the green sea turtle shown in Figure 43-11b.

The earliest known turtle fossils, which are more than 200 million years old, show that ancient chelonians differed little from today's turtles and tortoises. This evolutionary stability may be the result of the continuous benefit of the basic turtle design—a body covered by a shell. The shell consists of fused bony plates. The **carapace** is the top, or dorsal, part of the shell, and the **plastron** is the lower, or ventral, portion. In most species, the vertebrae and ribs are fused to the inner surface of the carapace. Turtles are also distinctive in that the pelvic and pectoral girdles lie within the ribs instead of outside the ribs, as they do in all other terrestrial vertebrates. Unlike other reptiles, turtles have a sharp beak instead of teeth.

FIGURE 43-11

The Galápagos tortoise, *Geochelone gigantops,* shown in (a), is protected from predators by its high domed carapace. The green sea turtle, *Chelonia mydas,* shown in (b), is streamlined for life in the sea.

(a)

(b)

Turtles and tortoises live in a variety of habitats. Some species are permanently aquatic, some are permanently terrestrial, and some spend time both on land and in the water. The differing demands of these habitats are reflected in the shells and limbs of turtles. For example, water-dwelling turtles usually have a streamlined, disk-shaped shell that permits rapid turning in water, and their feet are webbed for swimming. Many tortoises have a domed carapace into which they can retract their head, legs, and tail as a means of protection from predators. Their limbs are sturdy and covered with thick scales. The limbs of marine turtles, which spend their entire lives in the ocean, have evolved into flippers for swimming and maneuvering.

Reproduction

All turtles and tortoises lay eggs. The female selects an appropriate site on land, scoops out a hole with her hind limbs, deposits the eggs, and covers the nest. She provides no further care for the eggs or the hatchlings. Marine turtles often migrate long distances to lay their eggs on the same beach where they hatched. For example, Atlantic green sea turtles travel from their feeding grounds off the coast of Brazil to Ascension Island in the South Atlantic—a distance of more than 2,000 km (1,242 mi). These turtles probably rely on several environmental cues, possibly even the Earth's magnetic field and the direction of currents, to find this tiny island.

ORDER CROCODILIA

The living reptiles most closely related to the dinosaurs are the crocodilians, order Crocodilia. This group is composed of about 21 species of large, heavy-bodied, aquatic reptiles. In addition to crocodiles and alligators, the order includes the caimans and the gavial. Figure 43-12 shows some examples of crocodilians.

Crocodilians live in many tropical and subtropical regions of the world. Alligators live in China and the southern United States. Caimans are native to Central America and South America, but they have been introduced into Florida.

FIGURE 43-12

Crocodiles, such as genus *Crocodylus,* shown in (a), are found in Africa, Asia, and the Americas. The gavial, *Gavialis gangeticus,* shown in (b), is a crocodilian with an extremely long and slender snout adapted for seizing and eating fish. Gavials live only in India and Burma.

(a)

(b)

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All crocodilians are carnivorous. They feed on fish and turtles, and on land animals that come to the water to feed or drink. Crocodilians capture their prey by lying in wait until an animal approaches and then attacking swiftly. A crocodilian can see and breathe while lying quietly submerged in water. A valve at the back of the throat prevents water from entering the air passage when a crocodilian feeds underwater.

ORDER SQUAMATA

The order Squamata consists of about 5,500 species of lizards and snakes. A distinguishing characteristic of this order is an upper jaw that is loosely joined to the skull. Squamates are the most structurally diverse of the living reptiles, and they are found worldwide.

Lizards

There are about 3,000 species of living lizards. Common lizards include iguanas, chameleons, and geckos. Lizards live on every continent except Antarctica. Figure 43-13 shows some examples of lizards. Most lizards prey on insects or on other small animals. A few of the larger species, such as the chuckwalla and desert iguana of the southwestern United States, feed on plants. The Komodo dragon feeds on prey as large as goats and deer. Only two species of lizards are venomous. They are the Gila monster of the southwestern United States and northern Mexico and the related beaded lizard of southern Mexico.

Most lizards rely on agility, speed, and camouflage to elude predators. If threatened by a predator, some lizards have the ability to detach their tail. This ability is called **autotomy.** The tail continues to twitch and squirm after it detaches, drawing the predator's attention while the lizard escapes. The lizard grows a new tail in several weeks to several months, depending on the species.

Most lizards are small, measuring less than 30 cm (12 in.) in length. The largest lizards belong to the monitor family (Varanidae). Like snakes, monitors have deeply forked tongues that pick up airborne particles and transfer them to the Jacobson's organ in the roof of the mouth.

FIGURE 43-13

The largest of all monitors is the Komodo dragon, *Varanus komodoensis,* of Indonesia, shown in (a). The Komodo dragon can grow to 3 m long (10 ft). A colorful gecko, genus *Phelsuma,* is shown in (b). The gecko has specialized structures on the pads of its fingers and toes that allow it to cling to almost any surface.

(a)

(b)

(a)

(b)

FIGURE 43-14

The Gaboon viper, *Bitis gabonica,* shown in (a), injects a toxic venom to kill its prey before it begins the process of swallowing. The boa constrictor, *Constrictor constrictor,* shown in (b), suffocates its prey.

Snakes

There are about 2,500 species of snakes, and like lizards, they are distributed worldwide. Figure 43-14 shows some examples of snakes. The most obvious characteristic of snakes is the lack of legs, which affects all other aspects of their biology. What was the selective pressure that caused snakes to evolve leglessness? One possibility is that the ancestors of snakes were terrestrial but lived in thick vegetation, where legs were a hindrance to rapid movement.

The graceful movements of snakes are made possible by their unique anatomy. A snake has a backbone of 100 to 400 vertebrae, and a pair of ribs are attached to each vertebra. These bones provide the framework for thousands of muscles. The muscles manipulate not only the skeleton but also the snake's skin, causing the overlapping scales to extend and contract.

Capturing and Consuming Prey

A snake may just seize and swallow its prey. However, many snakes employ one of two methods for killing: constriction or injection of venom. Snakes that are **constrictors** wrap their bodies around prey. A constrictor suffocates its prey by gradually increasing the tension in its coils, squeezing a little tighter each time the prey breathes out. This technique is used both by large snakes, such as boas, pythons, and anacondas, and by smaller snakes, such as gopher snakes and king snakes.

Some snakes inject their prey with a toxic venom in one of three different ways. The snakes with fangs in the back of the mouth, such as the boomslang and twig snakes of Africa, bite the prey and use grooved teeth in the back of the mouth to guide the venom into the puncture. Cobras, kraits, and coral snakes are elapids. **Elapid** snakes inject poisons through two small, fixed fangs in the front of the mouth. **Vipers** inject venom through large, mobile fangs in the front of the mouth. Rattlesnakes, copperheads, and water moccasins are examples of vipers. When a viper strikes, these hinged fangs swing forward from the roof of the mouth and inject venom more deeply than can the fangs of elapids.

Quick Lab

Demonstrating Muscle Contractions

Materials plastic drinking straw, small ball of modeling clay

Procedure Make a small ball of clay slightly smaller than the opening of the drinking straw. Find a way to get the ball of clay into the middle of the straw.

Analysis How is this model similar to the feeding mechanism of a snake? If you used a ball of clay that was larger than the opening of the drinking straw, what problems would you encounter? Why is the size of larger prey not a problem for snakes?

FIGURE 43-15

This series of photographs shows a snake, *Dasypeltis scabra,* swallowing a bird's egg. Prey is often larger than the diameter of the snake's head, so the process of swallowing can take an hour or more.

Once killed, the prey must be swallowed whole because a snake's curved, needlelike teeth are not suited for cutting or chewing. Several features of a snake's skull enable it to swallow an animal larger in diameter than its head, as shown in Figure 43-15. The upper and lower jaws are loosely hinged and move independently, and can open to an angle of 130 degrees. In addition, a snake's lower jaw, palate, and parts of its skull are joined by a flexible, elastic ligament that allows the snake's head to stretch around its prey.

ORDER RHYNCHOCEPHALIA

FIGURE 43-16

Unlike most reptiles, the endangered tuataras, such as the one shown, are most active at low temperatures.

The order Rhynchocephalia (RING-koe-suh-FAY-lee-uh) is an ancient one that contains only two living species, the tuataras of the genus *Sphenodon.* Today tuataras inhabit only a few small islands of New Zealand. The Maoris of New Zealand named the tuataras for the conspicuous spiny crest that runs down the animal's back, which you can see in Figure 43-16. The word *tuatara* means "spiny crest" in the Maori language. Tuataras resemble large lizards and grow to about 60 cm (24 in.) in length. They usually hide in a burrow during the day and feed on insects, worms, and other small animals at night.

Since arriving in New Zealand about 1,000 years ago, humans have radically changed the landscape and introduced predators such as rats and cats, which feed on tuataras and their eggs. As a result, tuataras have disappeared from most of their original range.

SECTION 43-3 REVIEW

1. **Where do tuataras live, and what do they feed on?**
2. **Describe the structure of a turtle's shell.**
3. **How does the position of a crocodile's eyes and nostrils relate to its hunting behavior?**
4. **What is autotomy? How does it help a lizard escape predators?**
5. **How does a constrictor kill its prey?**
6. **CRITICAL THINKING Describe the costs of autotomy for a lizard.**

CHAPTER 43 REVIEW

SUMMARY/VOCABULARY

43-1

- All reptiles produce amniotic eggs in which the embryo is surrounded by two protective membranes, the chorion and the amnion. The yolk sac provides food for the embryo, and the allantois stores its wastes.
- Reptiles conserve water by having a dry, scaly watertight skin and by eliminating their nitrogenous wastes as uric acid.
- During the Mesozoic period, most large vertebrates were reptiles. The dinosaurs lived at this time, as did the aquatic plesiosaurs and ichthyosaurs and the flying pterosaurs.
- Dinosaurs became extinct about 65 million years ago, at the end of the Cretaceous period. Most scientists think that the collision of a large asteroid with Earth caused this extinction.

Vocabulary

albumin (842)	amniotic egg (842)	chorion (842)	yolk sac (842)
allantois (842)	asteroid-impact hypothesis (840)	dinosaur (839)	
amnion (842)		keratin (843)	

43-2

- Lizards, turtles, snakes, and tuataras have a heart with two atria and one partially divided ventricle. Crocodiles have a four-chambered heart, as mammals do.
- Reptiles inflate their lungs by expanding the ribs, drawing in air by decreasing abdominal pressure.
- A reptile's brain is about the same size as the brain of an amphibian, but it has a much larger cerebrum.
- The Jacobson's organ detects chemicals picked up by the tongue.
- All living reptiles are ectotherms. Ectotherms warm their body mainly by absorbing heat from their surroundings.
- Reptiles can keep their body temperature fairly constant by moving into and out of the sun.
- Ectotherms require very little food, but they cannot live in cold climates or be active when temperatures are low.
- Many reptiles lay shelled eggs. This is called oviparity. Some species transfer nutrients and oxygen to the developing embryos through a placenta. This strategy is called viviparity. Some species retain the eggs inside the female's body. This is called ovoviviparity.

Vocabulary

alveolus (846)	Jacobson's organ (847)	placenta (849)	thermoregulation (848)
ectotherm (848)	oviparity (849)	septum (845)	viviparity (849)
endotherm (848)	ovoviviparity (849)		

43-3

- Living reptiles are classified into four orders: Rhynchocephalia, Chelonia, Crocodilia, and Squamata.
- All turtles (order Chelonia) have a shell composed of bony plates. The vertebrae and ribs are fused to the interior surface of the shell. Turtles are mainly aquatic, while tortoises are terrestrial. All species lay eggs.
- Crocodilians (order Crocodilia) are large aquatic or semiaquatic carnivores. This group includes crocodiles, alligators, caimans, and the gavial.
- Lizards and snakes belong to the largest order of reptiles (order Squamata). Most lizards are small, agile, and feed on insects.
- Some snakes kill their prey by constriction, suffocating it with their coiled body. Some species kill by injecting venom. Snakes can swallow objects larger than their head because they have a very flexible skull.

Vocabulary

autotomy (852)	constrictor (853)	plastron (850)	viper (853)
carapace (850)	elapid (853)		

REVIEW

Vocabulary

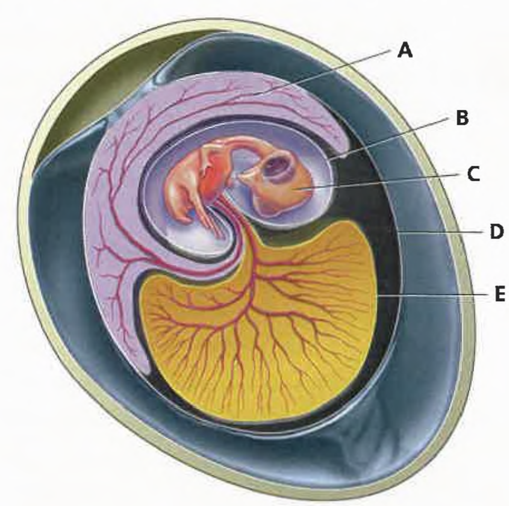
1. Briefly contrast elapids with vipers and give one example of each.
2. What is the function of the septum in the heart?
3. Which reptiles have a carapace and plastron?
4. The term *placenta* is most closely associated with which of the following terms: *oviparity, viviparity, ovoviviparity?* Explain your answer.
5. Use a dictionary to find the meanings of the following Greek roots: *endo-, ecto-, -therm.* Relate these roots to the meaning of the terms *ectotherm* and *endotherm.*

Multiple Choice

6. The membrane that encloses the fluid around a reptilian embryo is the (a) amnion (b) yolk sac (c) allantois (d) chorion.
7. The food supply within the egg is contained within the (a) amnion (b) yolk sac (c) allantois (d) chorion.
8. Which of the following is not true of dinosaurs?
   (a) They lived during the Mesozoic era.
   (b) They became extinct at the end of the Cretaceous period.
   (c) They were all large.
   (d) They lived on all continents.
9. Evidence for the asteroid-impact hypothesis of dinosaur extinction includes all of the following, except (a) sediments rich in iridium from the end of Cretaceous period (b) quartz crystals with blast damage (c) lack of dinosaur fossils from the early Permian period (d) remains of a large impact crater in Mexico.
10. Which of the following is true of the heart of a crocodile?
    (a) It has one ventricle.
    (b) Its atrium is partially divided by a septum.
    (c) It doesn't allow mixing of deoxygenated and oxygenated blood.
    (d) It only pumps deoxygenated blood.
11. The Jacobson's organ is most like our sense of (a) smell (b) hearing (c) sight (d) touch.
12. The two basic parts of a turtle's shell are the (a) septum and amnion (b) carapace and plastron (c) chorion and allantois (d) keratin and columella.
13. All of the following reptiles belong to the order Crocodilia, except (a) alligators (b) tuataras (c) caimans (d) gavial.
14. The ability to lose its tail and grow a new one helps a lizard (a) reduce its need for food (b) hide from predators (c) escape from predators (d) capture prey.
15. Long legless bodies may have arisen as an adaptation that helped snakes (a) absorb oxygen through their skin (b) move through thick vegetation (c) catch prey (d) swallow large animals.

Short Answer

16. What problem of life on land was solved by the evolution of the amniotic egg?
17. Describe how the structure of a turtle's heart allows for flexibility in blood circulation.
18. Explain the purpose of a lizard's ability to lose its tail and grow a new one.
19. Explain why it is inaccurate to call reptiles coldblooded.
20. What is the major benefit of ectothermy?
21. Describe two senses, other than vision and hearing, that reptiles use to find prey.
22. Describe the parental care of crocodilians.
23. Describe three ways snakes inject venom.
24. How has the settling of New Zealand by humans affected the tuataras?
25. The following diagram shows five parts of the amniotic egg, indicated by A, B, C, D, and E. Name and define the function of these parts.



CRITICAL THINKING

1. When a female leatherback turtle comes up on a beach to lay eggs, she first digs a deep hole, lays her eggs, and covers them with sand. Next she crawls about 100 m and digs another hole. This time she lays no eggs but just covers the hole with sand. Suggest a possible explanation for this behavior.
2. Why is it advantageous for a snake to kill its prey, either through constriction or venom, before trying to eat it.
3. The skin of a basking lizard is usually dark. As the lizard warms, the skin lightens. Suggest a functional explanation for this change. (Hint: Consider how this change might affect the lizard's absorption of heat.)
4. Fossil evidence collected in Alaska suggests that some dinosaurs were year-round residents of areas subject to freezing temperatures and long periods of darkness. Does this evidence of arctic dinosaurs support or contradict the hypothesis that the extinction of dinosaurs was due to the intense cold produced by a cloud of debris in the atmosphere? Explain your answer.
5. Many viviparous snakes and lizards live in cold climates. Why might viviparity be advantageous in such environments?
6. Luis and Walter Alvarez first proposed the asteroid-impact hypothesis after the discovery of abnormally high levels of iridium in sediments from the end of the Cretaceous period. According to the Alvarezes, what was the source of the iridium? High iridium levels were initially discovered at one site in Italy. Since then, high levels have been found at more than 100 sites around the world, all dating from the end of the Cretaceous period. Explain how the worldwide distribution of iridium is important evidence for the asteroid-impact hypothesis.
7. Examine the photo of the inside of a turtle's carapace. In cartoons, turtles often crawl out of their shell. Could a real turtle do this? What do you see in the photo that would indicate whether a real turtle could crawl out of its shell?

EXTENSION

1. Read "A Dinosaur with Altitude" in *Time,* November 15, 1999, on page 96. Describe the dinosaur that paleontologists say may be the tallest dinosaur ever. How have they come to this conclusion?
2. Read "Snake Charmer" in *National Wildlife,* February–March 1999, on page 36. Explain why Dr. D. Bruce Means believes we should care about the fate of the eastern diamondback rattlesnake.
3. Use a library or on-line database to research an endangered species of reptile, such as Kemp's ridley turtle. Prepare a report describing the conditions that threaten the survival of the species and the efforts being made to save it (if any).
4. Observe the behavior of a small lizard kept in a terrarium. Keep a log of your observations, noting differences in behavior at various times of day and before and after feeding.

CHAPTER 43 INVESTIGATION

Observing Color Adaptation in Anoles

OBJECTIVES

- Observe live anoles.
- Test whether background color stimulates color change in anoles.

PROCESS SKILLS

- observing
- hypothesizing
- experimenting
- organizing data
- analyzing data

MATERIALS

- glass-marking pencil
- 2 large clear jars with wide mouths and lids with air holes
- 2 live anoles
- 6 shades each of brown and green construction paper, ranging from light to dark (2 swatches of each shade)

Background

1. Anoles include 250–300 species of lizards in the genus *Anolis.*
2. Anoles can change color, ranging from brown to green, and are sometimes mottled.
3. Anoles live in shrubs, grasses, and trees. Describe some ways in which the ability to change color might be an advantage to anoles.
4. Light level, temperature, and other factors, such as whether the anole is frightened or whether it has eaten recently, can affect color. When anoles are frightened, they usually turn a dark grey or brown and are unlikely to respond to other stimuli.
5. Anoles can change color within a few minutes.

Procedure

1. Observe the anoles in two terraria, and discuss the purpose of this investigation with your partners. Develop a hypothesis that describes a relationship between anole skin color and background color. Write your hypothesis in your lab report.
2. Obtain swatches of construction paper in at least six different shades of green and brown. You will need two swatches of paper in each color.
3. Obtain two clear jars. Label one jar "Anole 1," and label the other jar "Anole 2."
4. CAUTION **You will be working with live animals. Handle them gently and follow instructions carefully.** Select two anoles of the same color from the terraria. Plan your actions and cooperate with a partner to transfer one anole into each labeled jar. Anoles will run fast and are easily frightened. Carefully pick them up and place the animals in separate jars. Do not pick up anoles by their tails. Grasp them gently behind the head. Quickly and carefully place a lid with air holes on each jar.
5. Gently place the jar with Anole 1 on a swatch of construction paper that most closely matches the anole's color. Try not to jostle the anole in the jar, and move the jar as little and as gently as possible. Repeat this procedure for Anole 2. Both anoles should closely match the color of the swatch.

6. When you have obtained and matched two anoles to closely matching colors, label the back of the pieces of paper "Initial Color of Anole 1" and "Initial Color of Anole 2," respectively. Replace the swatches underneath the jars after you have labeled them. The anoles should stay in their respective jars until the end of this investigation.
7. Using the given setup and the remaining swatches of colored construction paper, devise a control experiment to test whether background color stimulates color change in the anole.
8. In your lab report, list the independent variable and the dependent variables that you intend to use in your experiment. Describe how you will vary the independent variable and how you will measure changes in your dependent variable.
9. In your lab report, describe the control you will use in your experiment.
10. Create a data table similar to the one below to record your experimental observations for your lab report. For example, the table below is designed to record any change in anole skin color on four different background colors and the time it took for each change to take place. Design your data table to fit your own experiment. Remember to allow plenty of space to write your observations.
11. Have your experiment approved by your teacher before conducting it. As you conduct your experiment, be sure to record all of your data and observations in your lab report.
12. Attach your color swatches to your lab report, or include a color-coded key so that others reading your report will be able to understand how you measured initial color and color changes in your anoles. Be sure the color that most closely represents the initial color of both anoles is clearly indicated in your lab report.
13. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. What effect, if any, did changes in the independent variable have on the dependent variable in your experiment?
2. Do your data support your hypothesis? Explain.
3. Can you think of any sources of error in your experiment?
4. Was your experiment a controlled experiment? If yes, describe your control and why you think a control is necessary for your experiment.
5. Were there any uncontrolled variables in your experiment, such as loud noises, bright light, or sudden movements, that could have affected your experiment? Describe how you might be able to improve your methods.

Further Inquiry

Design an experiment that tests the effects of temperature on anole skin color.

DATA TABLE *OBSERVING ANOLES*

	Color 1		Color 2		Color 3		Color 4	
	Change	**Time**	**Change**	**Time**	**Change**	**Time**	**Change**	**Time**
Anole 1								
Anole 2								

CHAPTER 44

BIRDS

Young birds, such as this owl, depend on their parents for food and protection.

FOCUS CONCEPT: ***Structure and Function***

As you read, note the characteristics of birds that are adaptations for flight.

ORIGIN AND EVOLUTION OF BIRDS

SECTION

44-1

OBJECTIVES

▲ Identify and describe seven characteristics of birds.

● List three similarities between birds and dinosaurs.

■ Describe the characteristics of *Archaeopteryx.*

◆ Summarize the two main hypotheses for the evolution of flight.

Birds belong to the class Aves, which, with about 9,700 species, is the largest class of terrestrial vertebrates. Birds are also the most recently evolved group of vertebrates, having appeared only about 150 million years ago. Among living vertebrates, only birds and bats can fly. The bodies of birds are well adapted to flight.

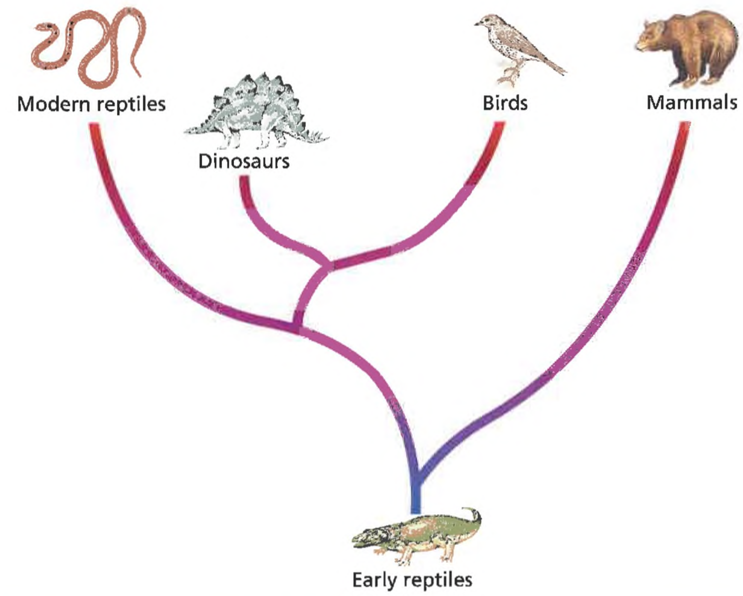
CHARACTERISTICS

Birds are so distinctive that it is difficult to mistake one for any other kind of vertebrate. Seven important characteristics of birds are described below.

- **Feathers**—Feathers are unique to birds, and all birds have them. Like hair, feathers are composed mainly of the versatile protein keratin. Feathers are essential for flight, and they insulate a bird's body against heat loss.
- **Wings**—A bird's forelimbs are modified into a pair of wings. Feathers cover most of the surface area of the wing.
- **Lightweight, rigid skeleton**—The skeleton of a bird reflects the requirements of flight. Many of the bones are thin-walled and hollow, making them lighter than the bones of nonflying animals. Air sacs from the respiratory system penetrate some of the bones. Because many bones are fused, the skeleton is rigid and can resist the forces produced by the strong flight muscles.
- **Endothermic metabolism**—A bird's rapid metabolism supplies the energy needed for flight. Birds maintain a high body temperature of 40–41°C (104–106°F). The body temperature of humans, by contrast, is about 37°C, or 98.6°F.
- **Unique respiratory system**—A rapid metabolism requires an abundant supply of oxygen, and birds have the most efficient respiratory system of any terrestrial vertebrates. The lungs are connected to several sets of air sacs, an arrangement that ensures that oxygen-rich air is always in the lungs.
- **Beak**—No modern bird has teeth, but the jaws are covered by a tough, horny sheath called a beak.
- **Oviparity**—All birds lay amniotic eggs encased in a hard, calcium-containing shell. In most species, the eggs are incubated in a nest by one or both parents.

FIGURE 44-1

This phylogenetic tree shows the phylogenetic relationships between various terrestrial vertebrates. Note how birds, dinosaurs, and crocodiles evolved from a common ancestor, which split off very early from the other terrestrial vertebrates.



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EVOLUTION

Scientists have long recognized the large number of similarities between birds and some dinosaurs. Three of these similarities include a flexible S-shaped neck, a unique ankle joint, and hollow bones. Birds are thought to have evolved from small, fast-running carnivorous dinosaurs during the Jurassic period (208–144 million years ago). Figure 44-1 shows the relationships between birds and other terrestrial vertebrates.

The oldest known bird fossils belong to the species *Archaeopteryx lithographica* and date from the late Jurassic period, about 150 million years ago. In the fossil in Figure 44-2a, the impressions of feathers are clearly visible. Feathers covered *Archaeopteryx*'s forelimbs, forming wings, and covered its body and tail as well. Like modern birds, *Archaeopteryx* had hollow bones and a **furcula** (FUR-kyuh-luh), the fused collarbones commonly called a wishbone. However, *Archaeopteryx* also had several characteristics of its dinosaur ancestors, including teeth, claws on its forelimbs, and a long, bony tail. Figure 44-2b shows an artist's conception of what an *Archaeopteryx* might have looked like.

Based on certain key similarities with modern birds, most scientists think that *Archaeopteryx* could fly. The furcula plays an important role in flight by helping to stabilize the shoulder joint.

Origin of Flight

The evolution of a flying animal from nonflying ancestors entails many changes in anatomy, physiology, and behavior. According to one hypothesis, the ancestors of birds were tree dwellers that ran along branches and occasionally jumped between branches and trees. Wings that allowed these animals to glide from tree to tree evolved. Once gliding was possible, the ability to fly by flapping the wings evolved. Another hypothesis draws on the fact that the

Word Roots and Origins

archaeopteryx

from the Greek *archaios*, meaning "ancient," and *pteryx*, meaning "wing"

(a)

(b)

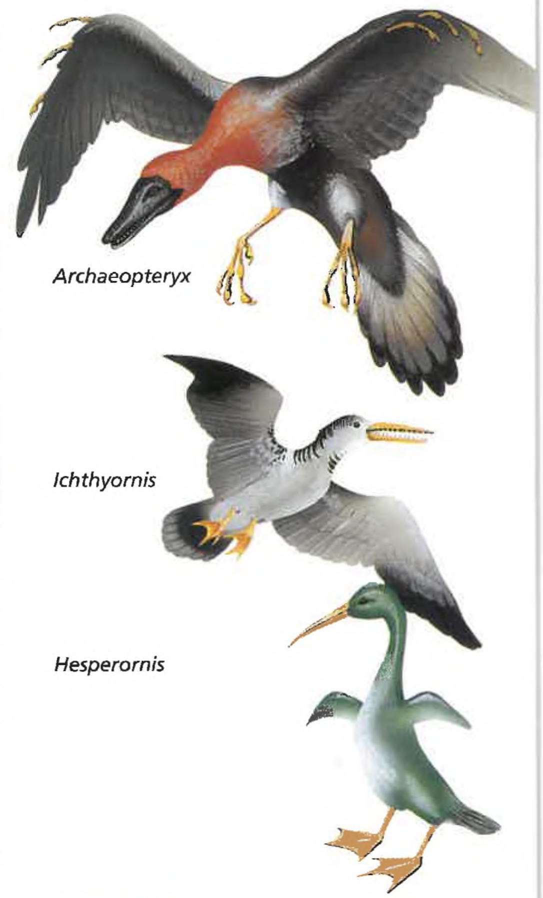


FIGURE 44-2
In this fossil of *Archaeopteryx lithographica* (a), one can see the link between birds and dinosaurs. These artist's renderings (b) of three extinct birds are based on fossil evidence. *Archaeopteryx* is the oldest bird; it still had claws on its wings. *Ichthyornis* had strongly developed wings and was about 21–26 cm (8–10 in.) in length. *Hesperornis* lacked a keel, had small wings, and was considered flightless, but its well-developed legs made it a strong swimmer.

dinosaurs most closely related to birds were terrestrial and states that the evolution of birds must have occurred on the ground, not in the trees. Wings may have originally served to stabilize the animals as they leapt after prey. Or they may have been used for trapping or knocking down insect prey. Over generations, the wings became large enough to allow the animal to become airborne.

Evolution After *Archaeopteryx*

A number of recent discoveries show that by the early Cretaceous period (144–65 million years ago), birds had already begun diversifying. *Sinornis,* a 140-million-year-old specimen discovered in China in 1987, had some key features of modern birds, including a shortened, fused tail and a wrist joint that allowed the wings to be folded against the body. The diversification of birds continued throughout the Cretaceous period. Figure 44-2 shows three birds from the late Cretaceous period.

Only two of the modern orders of birds had appeared by the end of the Cretaceous period. Birds survived the asteroid impact that is thought to have wiped out the dinosaurs and underwent a dramatic and rapid radiation shortly afterward. By about 40 million years ago, most of the modern orders of birds had originated.

SECTION 44-1 REVIEW

1. List two unique features of a bird's skeleton.
2. What are two functions of feathers?
3. Describe two characteristics shared by *Archaeopteryx* and modern birds.
4. Name two differences between *Archaeopteryx* and modern birds.
5. Summarize the two major hypotheses for the evolution of flight.
6. **CRITICAL THINKING** Modern birds lack teeth. Form a hypothesis to explain why this characteristic might have evolved.

SECTION

44-2

OBJECTIVES

▲ Describe the structure of a contour feather.

● Identify two modifications for flight seen in a bird's skeletal system.

■ Contrast the function of the gizzard with that of the crop.

◆ Trace the movement of air through the respiratory system of a bird.

▲ Explain the differences between altricial and precocial young.

CHARACTERISTICS OF BIRDS

A number of unique anatomical, physiological, and behavioral adaptations enable birds to meet the aerodynamic requirements of flight. For example, natural selection has favored a lightweight body and powerful wing muscles that give birds their strength.

FEATHERS

Feathers are modified scales that serve two primary functions: providing lift for flight and conserving body heat. Soft, fluffy **down feathers** cover the body of nestling birds and provide an insulating undercoat in adults. **Contour feathers** give adult birds their streamlined shape and provide coloration and additional insulation. **Flight feathers** are specialized contour feathers on the wings and tail. Birds also have dust-filtering bristles near their nostrils.

The structure of a feather combines maximum strength with minimum weight. Feathers develop from tiny pits in the skin called **follicles.** A **shaft** emerges from the follicle, and two **vanes,** pictured in Figure 44-3a, develop on opposite sides. At maturity, each vane has many branches, called **barbs.** The barbs in turn have many projections, called **barbules,** equipped with microscopic hooks, as shown in Figure 44-3b. The hooks interlock and give the feather its sturdy but flexible shape.

Feathers need care. In a process called **preening,** birds use their beaks to rub their feathers with oil secreted by a **preen gland,** located at the base of the tail. Birds periodically molt, or shed, their feathers. Birds living in temperate climates usually replace their flight feathers (called major molt) during the late summer.

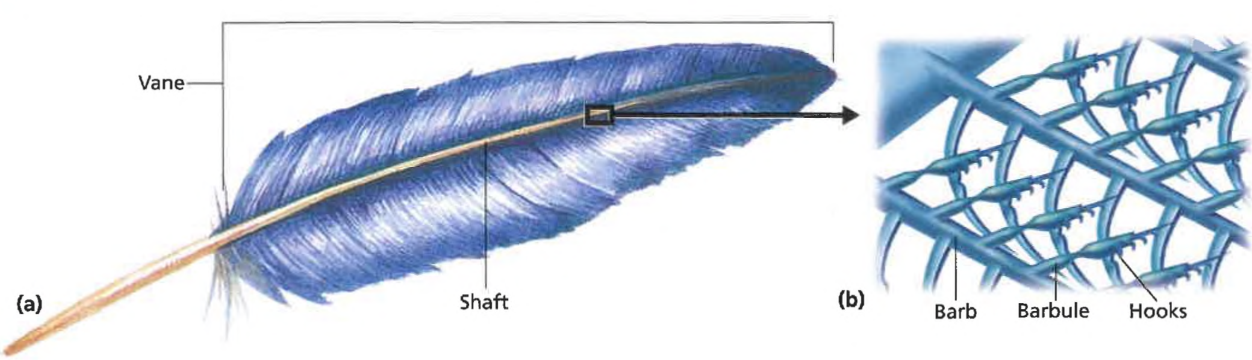


FIGURE 44-3
Bird feathers usually have a shaft, with two vanes growing out either side of the shaft. The vanes consist of barbs and barbules that interlock by means of hooks. Feathers are made of keratin, an insoluble protein that is highly resistant to enzyme digestion by bacteria. Keratin is also the protein that makes up fingernails, claws, hair, and scales.

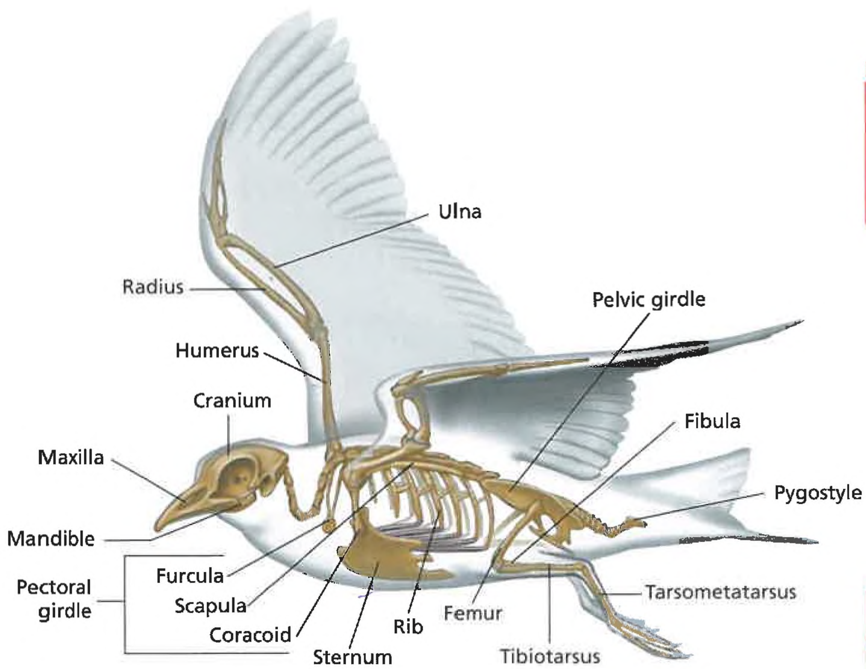


FIGURE 44-4

The avian skeleton is well adapted for flight. The bones are air-filled, making them light but strong. The skeleton is arranged to support the large muscles necessary for flight.

SKELETON AND MUSCLES

The avian skeleton combines lightness with strength. The bones are thin and hollow. Many bones are fused, so the skeleton is more rigid than the skeleton of a reptile or mammal. The rigid skeleton provides stability during flight. Note in Figure 44-4 the fused bones of the trunk and hip vertebrae and the pectoral and pelvic girdles. The large, keeled **sternum,** or breastbone, is an attachment point for flight muscles. The humerus, ulna, and radius, along with the pectoral girdle and the sternum, support the wing. The **pygostyle** (PIE-GUH-stiel), the terminal fused vertebrae of the spine, supports the tail feathers, which also play an important role in flight. The tail provides additional lift and aids in steering and braking.

Flight involves a series of complex wing movements, each one using a different set of muscles. On the downstroke the wings cut forward and downward through the air. During upstroke, they move upward and backward. These movements are made possible by large, powerful flight muscles. In some birds, flight muscles account for 50 percent of the body weight.

METABOLISM

Birds are endothermic; that is, they generate heat to warm the body internally. Rapid breathing and digestion of large quantities of food support the high metabolic rate necessary to generate this heat. Birds, unlike reptiles, cannot go for long periods without eating. To help conserve body heat they fluff out their feathers. Aquatic birds have a thin layer of fat that provides additional insulation.

Quick Lab

Comparing Wing Structures

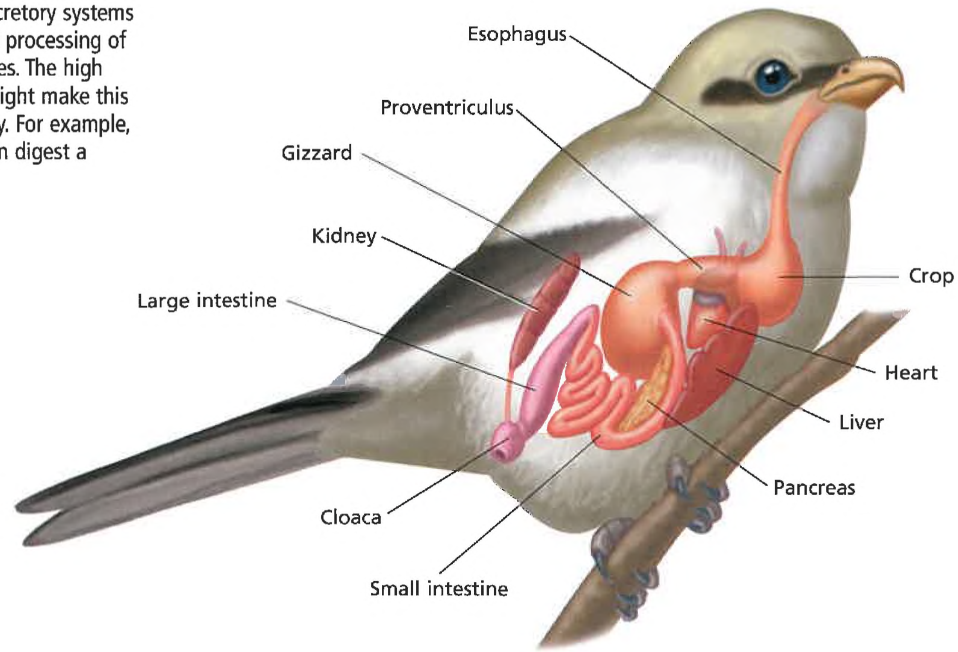
Materials photocopies of different birds featuring their wings, ruler

Procedure Examine each sheet of birds and their wings. Compare the structure and shape of the wings. Measure the wingspan relative to the bird's body length. Record your observations.

Analysis Predict the type of habitat in which each bird lives. How does the shape of the wing relate to the bird's niche? Explain why the type of wings each bird has might make the bird unsuccessful if it were introduced into a much different environment.

FIGURE 44-5

A bird's digestive and excretory systems are adapted for the rapid processing of food and metabolic wastes. The high energy requirements of flight make this efficient system necessary. For example, the carnivorous shrike can digest a mouse in three hours.



Word Roots and Origins

proventriculus

from the Greek *pro*, meaning "before," and the Latin *ventriculus*, meaning "stomach"

Digestive and Excretory Systems

The high amount of energy required to fly and regulate body heat is obtained by a quick and efficient digestive system, as illustrated in Figure 44-5. Because birds do not have teeth, they are not able to chew their food. Instead, food passes from the mouth cavity straight to the esophagus. An enlargement of the esophagus called the **crop** stores and moistens food. Food then passes to the two-part stomach. In the first chamber, the **proventriculus** (PROH-ven-TRIK-yuh-luhs), acid and digestive enzymes begin breaking down the food. Food then passes to the **gizzard,** the muscular portion of the stomach, which kneads and crushes the food. The gizzard often contains small stones that the bird has swallowed. These aid in the grinding process. Thus, the gizzard performs a function similar to that of teeth and jaws. Raptors, such as hawks and eagles, have modified systems for digesting protein. The crop and gizzard may be reduced or modified.

From the stomach, food passes into the small intestine. Here bile from the liver and enzymes made in the pancreas and intestine further break down the food. The nutrients are then absorbed into the bird's bloodstream. Passage of food through the digestive system of a bird is usually very rapid. For instance, a thrush can eat blackberries, digest them, and excrete the seeds 45 minutes later.

The avian excretory system is efficient and lightweight. Unlike other vertebrates, most birds do not store liquid waste in a urinary bladder. The two kidneys filter a nitrogenous waste called uric acid from the blood. Concentrated uric acid travels through ducts called ureters to the cloaca, where it mixes with undigested matter from the intestines and is then eliminated. Bird droppings are a mixture of feces and uric acid.

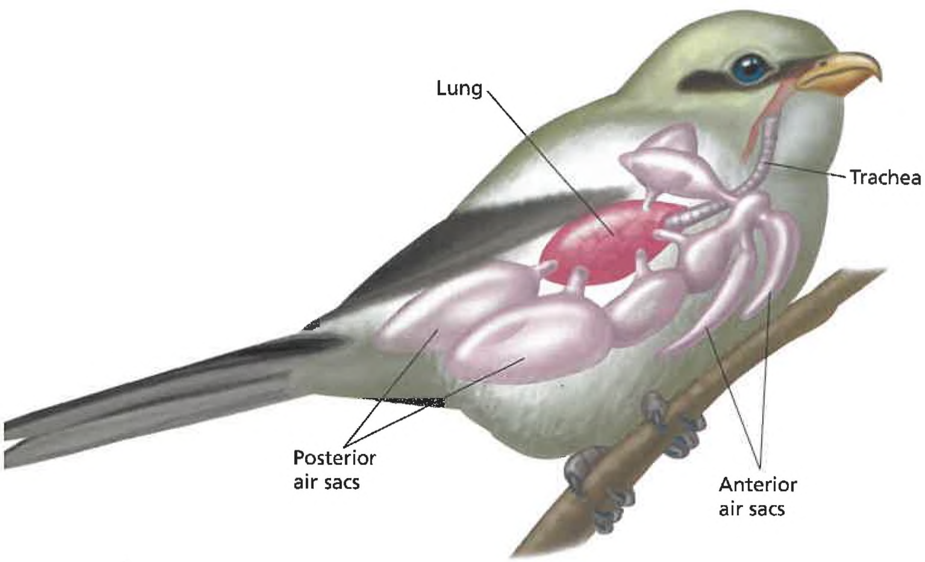


FIGURE 44-6

The unique architecture of the bird's respiratory system provides a virtual one-way flow of air. This highly efficient system of air flow allows birds to maintain the high metabolic rate necessary for flight. It also enables birds to function at high altitudes, where other animals would suffer from the lower levels of oxygen.

Respiratory System

The high metabolic rate of birds requires large amounts of oxygen. Yet some birds migrate thousands of miles at altitudes as high as 7,000 m (23,000 ft), where oxygen levels are very low. An elaborate and highly efficient respiratory system meets these oxygen needs. Air enters the bird's body through paired nostrils located near the base of the beak. The air passes down the trachea and enters the two primary bronchi. From the bronchi, some of the air moves to the lungs. However, about 75 percent of the air bypasses the lungs and flows directly to posterior air sacs, shown in Figure 44-6. Nine sacs extend from the lungs, in most birds, occupying a large portion of the bird's chest and abdominal cavity. These sacs also extend into some of the long bones. Thus, the air sacs not only function in respiration but also greatly reduce the bird's density.

Gas exchange does not occur in the air sacs. Their function is to store air. When the bird exhales, the carbon dioxide–rich air from its lungs is forced into the anterior air sacs, and the oxygen-rich air in the posterior air sacs is forced into the lungs. This way, the bird has oxygenated air in its lungs during both inhalation and exhalation.

Circulatory System

Like crocodiles and mammals, birds have a heart with two separate ventricles. Deoxygenated blood is always kept separate from oxygenated blood. In comparison with reptiles and most other vertebrates, most birds have a rapid heartbeat. A hummingbird's heart beats about 600 times a minute. An active chickadee's heart beats 1,000 times a minute. In contrast, the heart of the larger, less active ostrich averages 70 beats per minute, or about the same rate as a human heart. Avian red blood cells have nuclei.

Nervous System and Sense Organs

Relative to their body size, birds have large brains. The most highly developed areas of the bird's brain are those that control flight-related functions, such as the cerebellum, which coordinates movement. The cerebrum is also large. It controls complex behavior patterns, such as navigation, mating, nest building, and caring for the young. The large optic lobes receive and interpret visual stimuli.

Keen vision is necessary for taking off, landing, spotting landmarks, hunting, and feeding. Most birds have good color vision that aids them in finding food. In most species, the eyes are large and are located near the sides of the head, giving the bird a wide field of vision. Birds that have eyes located near the front of the head have better binocular vision, meaning they can perceive depth in the area where the visual fields of the two eyes overlap.

Hearing is important to songbirds and to nocturnal species, such as owls, which rely on sounds to help them locate their prey. Though birds lack external ears, owls have feathers shaped to create a trough around their ear openings, which helps direct sound into the ear. The sense of smell is also developed in many birds.

REPRODUCTION

In the male bird, sperm is produced in two testes that lie anterior to the kidneys. Sperm passes through small tubes called **vasa deferentia** into the male's cloaca. During mating, the male presses his cloaca to the female's cloaca and releases sperm. Most females have a single ovary located on the left side of the body. The ovary releases eggs into a long funnel-shaped **oviduct,** where they are fertilized by sperm. Fertilized eggs move down the oviduct, where they receive a protective covering and a shell. The egg passes out of the oviduct and into the cloaca. From the cloaca, it is expelled from the bird.

Nest Building and Parental Care

Birds usually lay their eggs in a nest. Nests hold the eggs, conceal young birds from predators, provide shelter from the elements, and sometimes serve to attract a mate. Most birds build nests in sheltered, well-hidden spots—from holes in the ground to treetops. Woodpeckers, for example, nest in a hole they have drilled in a tree. Orioles suspend their nests from branches, well beyond the reach of predators. And barn swallows build a saucer of mud on the beam of a building. Birds construct their nests from almost any available material. Twigs, grasses, feathers, and mud are the most common materials used.

One or both parents incubate, or warm, the eggs by sitting on them and covering them with a thickened, featherless patch of skin on the abdomen called a **brood patch.** Once the eggs hatch, the young usually receive extensive parental care. Birds have two methods of rearing young. Those that lay many eggs and incubate

Eco Connection

DDT and Bird Eggs

DDT is a pesticide that was widely used on crops until the 1970s. DDT was banned because of the harm it was causing to birds. DDT causes thinning of birds' egg shells, decreasing survival rates of the birds' offspring. This caused a significant drop in the numbers of raptors, brown pelicans, and other pelicans. The thinning of the eggs was so significant that even the weight of an incubating parent could crush the eggs. With the banning of DDT in the United States, populations of the affected birds have increased.

Research Notes

A Hemispheric Strategy: A Single Vast Wildlife Reserve

The numbers of shorebirds—such as sandpipers, plovers, and curlews—are declining worldwide, but people in North America and elsewhere are working to preserve and protect these valuable species. To do this, researchers must first determine shorebird populations and map their migratory routes. To appreciate the magnitude of the job, you should know that more than 40 North American shorebird species breed in the Arctic and migrate to wintering sites in Central and South America, an annual round trip of 12,000 to 25,000 km.

Today the work of preserving shorebirds has been greatly advanced and simplified through the use of computer technology. One group that uses computers in this work is the International Shorebird Survey (ISS). Migrating shorebirds recognize no national boundaries, so any strategy for preserving them must be international. The International Shorebird Survey was established in 1974 and consists of both volunteers and professional researchers. The volunteers record information on populations, habitat characteristics, weather conditions, and human activity. Researchers use computers to identify relationships among these variables. Complex methods of analysis have revealed much about the migratory habits of shorebirds—their velocity, altitude, flight path, and gathering sites, for example. Computers have also helped researchers identify significant trends, such as a 70 percent to 80 percent drop in the population of sanderlings and short-billed dowitchers.

Another organization that uses computers in its work of preserving shorebirds is the Western Hemisphere Shorebird Reserve Network (WHSRN). As an international group of conservation organizations, the Western Hemisphere Shorebird Reserve Network has identified more than 90 sites where significant numbers of shorebirds breed, feed, and rest. The organization has proposed that these sites be recognized internationally as a single vast wildlife reserve whose boundaries are, in effect, defined by the migrating birds.

Shorebirds congregate in a few strategic sites, making them especially vulnerable to human activity. Replacing one beach or wetland with a housing development can have serious effects on the population of a species that depends on that site. However, humans must also develop a strategy for the survival of the congregation sites. The hemispheric wildlife reserve is the basis of such a strategy.

Shorebird populations are likely to need ongoing analysis, sometimes for new reasons. For example, possible consequences of global warming, such as changes in weather patterns and sea level, could affect shorebird habitats drastically. Thus computer technology will continue to facilitate the work of international conservation organizations and individuals who devote themselves to preserving and protecting shorebirds.

Delaware Bay, located between Delaware and New Jersey, is a staging site for shorebirds that migrate between South America and the Arctic. Up to 80 percent of the population of red knots feed and rest at this site. Preservation of the bay is critical to the species.

FIGURE 44-7

This yellow warbler cares for its young by feeding and protecting them.

them for long periods hatch **precocial** (pree-KOH-shuhl) young. These young birds are active as soon as they hatch. The mother provides warmth and protection, but the newly hatched birds can walk, swim, and feed themselves. Ducks, quail, and other ground-nesting species produce precocial offspring. Birds that lay only a few eggs that hatch quickly produce **altricial** (al-TRI-shuhl) young. These birds hatch blind, naked, and helpless, as shown in Figure 44-7. They depend on both parents for several weeks. The parents keep the young warm and feed them. The young of woodpeckers, hawks, pigeons, parrots, warblers, and many aquatic birds are altricial.

MIGRATION

Each year, thousands of bird species exploit the spring and summer food resources of temperate regions. Then, when temperatures drop and the food supply dwindles, they travel to warmer climates. The seasonal movement of animals from one habitat to another habitat is called migration. Many of the birds that nest in the United States and Canada during the spring and summer fly south in the fall to spend the winter in Mexico, Central America, the Caribbean, or South America. For example, the blackburnian warbler is a small songbird that nests in forests of the northeastern United States and southern Canada but winters in Central and South America.

How do birds manage to navigate thousands of kilometers across varied terrains to the same spot year after year? **Ornithologists**—biologists who study birds—have learned that birds rely on a variety of cues to help them navigate. Some species monitor the position of the stars or the sun. Others rely on topographical landmarks, such as mountains. The Earth's magnetic field, changes in air pressure due to altitude, and low-frequency sounds may also provide information to migrating birds.

Many species migrate thousands of kilometers and must rely on their fat reserves in order to complete the journey. To prepare for their migration, some birds, such as blackpoll warblers, eat so much food before their journey that their weight nearly doubles.

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SECTION 44-2 REVIEW

1. Distinguish between vanes, barbs, and barbules.
2. What is the function of the keeled sternum?
3. In what way does the gizzard compensate for the lack of teeth in birds?
4. What are the functions of the anterior and posterior air sacs?
5. Ground-nesting birds often produce precocial young. How might this improve the odds of survival for the young?
6. CRITICAL THINKING How do you think the destruction of tropical rain forests affects populations of birds in the United States? Explain your answer.

SECTION

44-3

OBJECTIVES

▲ Describe the relationship between beak shape and diet in birds.

● List 12 orders of living birds, and name an example of each order.

■ Describe the function of the syrinx.

CLASSIFICATION

Birds are the most widespread terrestrial vertebrates. Their ability to navigate over long distances and their many adaptations for flight enable them to migrate to and inhabit virtually any environment. Their anatomical diversity reflects the diversity of places they inhabit.

DIVERSITY

By looking closely at a bird's beak and feet, you can infer many things about where it lives and how it feeds. Hawks and eagles have powerful beaks and clawed talons that help them capture and tear apart their prey. Swifts have a tiny beak that opens wide like a catcher's mitt to snare insects in midair. Because swifts spend most of their lives in flight, their feet are small and adapted for infrequent perching. The feet of flightless birds, on the other hand, are modified for walking and running. Some examples of the variety of bird beaks and feet are shown in Figure 44-8.

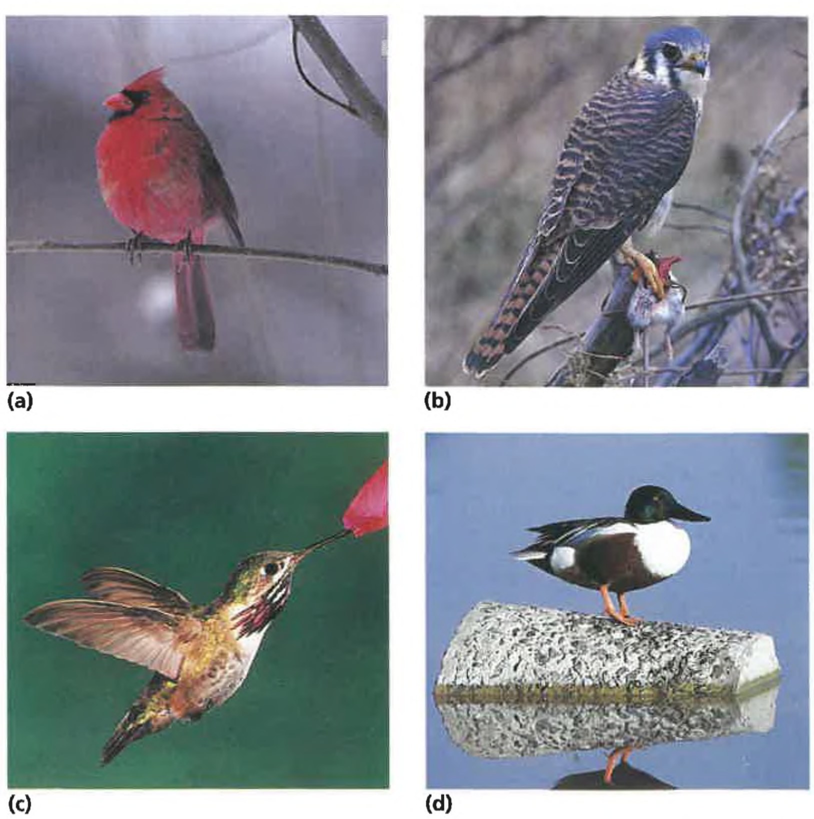


FIGURE 44-8

The cardinal (a), *Cardinalis cardinalis,* has a short, strong beak for cracking seeds and feet that enable it to perch on small tree branches. The kestrel (b), *Falco sparverius,* has a beak that enables it to tear flesh and talons that enable it to grip and kill prey. The calliope hummingbird (c), *Stellula calliope,* has a long, thin beak that enables it to extract nectar from flowers. The northern shoveler duck (d), *Anas clypeata,* has a flat beak that enables it to shovel mud while searching for food.

FIGURE 44-9

This mute swan, *Cygnus olor,* is able to take off from water and fly at very high speeds despite its great weight. Weighing up to 23 kg (50 lb), mute swans are the heaviest flying birds. Swans are monogamous, meaning they mate for life. While the female incubates the eggs, the male helps guard the nest.

FIGURE 44-10

The parrot pictured below is a lesser sulfur-crested cockatoo, *Cacatua sulphurea.* Parrots range in length from 8 cm (3 in.) to over 91 cm (3 ft). The earliest fossils of parrots indicate that they have existed as a group for at least 20 million years. Like most parrots, these cockatoos nest in holes in trees, and they usually lay only two eggs per year. Because of their low reproductive rate and destruction of habitat, many species have become extinct or endangered.

Most taxonomists divide the 10,000 species of living birds into 29 orders. Taxonomists have traditionally used morphological evidence from beaks, feet, plumage, bone structure, and musculature to classify birds. Technological advances in the analysis of blood proteins, chromosomes, and DNA have also been used. Despite the introduction of these new methods, the relationships among the 29 orders of birds are still not well resolved. Following are 12 of the most familiar orders of living birds.

Order Anseriformes

Swans, geese, and ducks—commonly called waterfowl—belong to this order of 160 species. Found worldwide, members of this order are usually aquatic and have webbed feet for paddling and swimming. Waterfowl feed on a variety of aquatic and terrestrial foods, ranging from small invertebrates and fish to grass. The bill is typically flattened. The young are precocial, and parental care is usually provided by the female. A mute swan is shown in Figure 44-9.

Order Strigiformes

This order contains the owls, the nocturnal counterparts to the raptors. Owls are predators that have a sharp, curved beak and sharp talons or claws. As you can see in the figure on page 860, owls also have large, forward-facing eyes that provide improved vision at night. Owls rely on their keen sense of hearing to help locate prey in the dark. There are about 180 species of owls, and they are found throughout the world.

Order Apodiformes

Hummingbirds and swifts belong to this order. All of the roughly 420 species are small, fast-flying, nimble birds with tiny feet. Swifts pursue insects and capture them in flight. Hummingbirds, by contrast, feed on nectar, which they lap up with a very long tongue. The long, narrow bill of a hummingbird can reach deep into a flower to locate nectar. Swifts have a worldwide distribution, but hummingbirds live only in the Western Hemisphere.

Order Psittaciformes

This order includes the parrots and their relatives, the parakeets, budgerigars, cockatoos, and cockatiels. Most of the roughly 360 species in this order live in the tropics. Parrots are characterized by a strong, hooked beak that is often used for opening seeds or slicing fruits. Their upper mandible is hinged on the skull and movable. Unlike most birds, parrots have two toes that point forward and two toes that point toward the rear, an adaptation for perching and climbing. They are vocal birds, and many species gather in large, noisy flocks. Parrots have long been prized as pets because of their colorful plumage and intelligence and because some species can be taught to mimic human speech. However, excessive collecting for the pet trade and habitat destruction now threaten many parrot species with extinction. Figure 44-10 shows a cockatoo.

Order Piciformes

This diverse group of tree-dwelling birds contains woodpeckers, honeyguides, and toucans. All members of this order nest in tree cavities. Like parrots, they have two forward-pointing toes and two that point to the rear. There are about 350 species found throughout the world except in Australia. The diversity of foods consumed by these birds is reflected in the diversity of their bills. Woodpeckers, which drill holes into trees to capture insects, have strong, sharp, chisel-like bills. Toucans feed mainly on fruit, which they pluck with a long bill, as shown in Figure 44-11.

FIGURE 44-11

Toucans, such as this keel-billed toucan, *Ramphastos sulfuratus,* mate once per year, usually laying two to four eggs. The male and female toucans take turns sitting on the eggs. The eggs usually hatch after about 15 days of incubation.

Order Falconiformes

Known as raptors, the members of this order have a sharp, curved beak and sharp talons. Raptors include ospreys, hawks, falcons, vultures, and eagles. The 310 or so species of raptors are distributed throughout the world. Most species are diurnal (daytime) hunters with keen vision. Vultures, however, feed on dead animals and use their sense of smell to detect the odor of decomposing flesh.

Order Passeriformes

This large order contains about 5,700 species—more than half the total number of bird species—and includes most of the familiar North American birds. Robins, warblers, blue jays, and wrens are just some of the birds belonging to this group. In most birds, three toes point forward and one points backward. Passerines have this same arrangement of toes, but the rear toe is enlarged and particularly flexible to provide a better grip on branches. Passerines are sometimes called perching birds. Passerines feed on a variety of foods, including nectar, seeds, fruit, and insects.

Many passerines are called songbirds because the males produce long, elaborate, and melodious songs. Male birds sing to warn away other males and to attract females. The song is produced in the structure known as the **syrinx** (SIR-inks), which is located at the base of the bird's trachea. By regulating the flow of air through the syrinx, birds can generate songs of great range and complexity.

Order Columbiformes

This globally distributed group contains about 310 species of pigeons and doves. Figure 44-12 shows a mourning dove. These birds usually are plump-breasted and have relatively small heads; short necks, legs, and beaks; and short, slender bills. Most feed on fruit or grain. The crop, which in most other birds is used to store food, secretes a nutritious milklike fluid called **crop milk.** Both sexes produce crop milk to feed their young. Columbiform birds usually lay a clutch of two eggs, which hatch after a two-week incubation period. The young usually leave the nest two weeks after hatching. Another member of this order is the now-extinct dodo of Mauritius, an island in the Indian Ocean.

FIGURE 44-12

The adult mourning dove, *Zenaida macroura,* stands about 30 cm (12 in.) tall and nests in trees or bushes. Mourning doves breed throughout North America. They winter as far south as Panama.

FIGURE 44-13

The great blue heron, *Ardea herodias,* uses its spearlike beak to stab fish, frogs, and other prey. Young herons must be taught how to hunt. Scientists have learned that young herons often miss their intended prey and must also learn what is and is not food.

Order Ciconiiformes

This group of long-necked, long-legged birds includes 120 species of herons, storks, ibises, and egrets. They tend to have a long, flexible neck and a long bill. Many are wading birds, and they feed on fish, frogs, and other small prey in shallow water. Some members of this order grow to be quite large. The marabou stork of Australia, for example, can be more than 1.5 m (59 in.) in height. Figure 44-13 shows a great blue heron, a common species in North America. The order has a worldwide distribution.

Order Galliformes

Members of this group, which includes turkeys, pheasants, chickens, grouse, and quails, are commonly called fowl. These terrestrial birds are usually plump-bodied and may have limited flying ability. Grains form a large part of the diet of many fowl, and all species have a large, strong gizzard. Some are also an important part of the human diet. The young are precocial. There are about 260 species distributed worldwide.

Order Sphenisciformes

Penguins are a unique group of flightless marine birds. All 17 species live in the Southern Hemisphere. The penguin's wedge-shaped wings have been modified into flippers, and the feet are webbed. Underwater, penguins flap their flippers to propel themselves forward—they "fly" through the water. Most species have a thick coat of insulating feathers and a layer of fat beneath the skin, enabling them to live in polar conditions. Penguins maintain this fat layer by consuming large quantities of fish and krill.

Order Struthioniformes

Only the ostrich, the world's largest bird, belongs to this order. Ostriches can attain a height of nearly 3 m and weigh 150 kg. Ostriches cannot fly, but they are specialized as high-speed runners. Propelled by their long, strong legs, ostriches can reach speeds of 55 km per hour. Each foot has only two toes. Reduction in the number of toes is common in running animals—horses have just one toe per foot, for instance. Ostriches are native to Africa.

Word Roots and Origins

syrinx

from the Greek *syrinx,* meaning "reed" or "pipe"

SECTION 44-3 REVIEW

1. **Name two birds mentioned in this section, and describe how their beaks are suited to their way of life.**
2. **Identify the order to which each of the following birds belongs: eagle, robin, goose, penguin.**
3. **Name two similarities between raptors and owls. Name one difference.**
4. **What is crop milk? What types of birds produce it?**
5. **What is the function of the syrinx?**
6. **CRITICAL THINKING Penguins have a large, keeled sternum, but ostriches do not. Provide an explanation for this difference.**

CHAPTER 44 REVIEW

SUMMARY/VOCABULARY

44-1

- Seven characteristics of birds are: feathers; wings; a lightweight, rigid flight skeleton; a respiratory system involving air sacs; endothermy; a beak instead of teeth; and oviparity.
- Birds evolved from small, carnivorous dinosaurs during the Jurassic period. The oldest known bird is *Archaeopteryx lithographica.*
- There are two hypotheses for the origin of flight in birds. One hypothesis is that flight began in the trees, with organisms progressing from jumping to gliding and flying. The second hypothesis is that birds began on the ground. Wings initially served as stabilizers or as "nets" for capturing insects. Feathers may have been used for heat regulation.
- Birds diversified after *Archaeopteryx,* a process that accelerated when the dinosaurs were wiped out.

Vocabulary

furcula (862)

44-2

- Feathers function in insulation and in flight. Down feathers provide insulation; contour feathers provide insulation and coloration and contribute most of the surface area of the wings and tail.
- Many of the bones in a bird's skeleton are hollow; many are also fused.
- The crop stores food. The two parts of the stomach are the proventriculus and the gizzard.
- Birds lack a urinary bladder and excrete their nitrogenous waste as uric acid.
- The lungs of a bird are connected to several air sacs that store air but do not participate in gas exchange.
- The cerebellum, cerebrum, and optic lobes of the bird's brain are large.
- All birds lay hard-shelled eggs. The eggs are usually laid in a nest and cared for by the parents.
- Many birds migrate using a variety of environmental cues to guide their migration.

Vocabulary

altricial (870)	down feather (864)	precocial (870)	shaft (864)
barb (864)	flight feather (864)	preen gland (864)	sternum (865)
barbule (864)	follicle (864)	preening (864)	vane (864)
brood patch (868)	gizzard (866)	proventriculus (866)	vasa deferentia (868)
contour feather (864)	ornithologist (870)	pygostyle (865)	
crop (866)	oviduct (868)		

44-3

- The feet and beak of a bird reflect its way of life.
- There are 29 orders of living birds, but scientists do not agree on the relationships among these orders.
- The majority of the world's birds belong to the order Passeriformes. Many are songbirds.
- Swifts and hummingbirds belong to the order Apodiformes. Parrots and relatives belong to the order Psittaciformes. Woodpeckers and toucans belong to the order Piciformes. Raptors belong to the order Falconiformes.
- Pigeons and doves belong to the order Columbiformes. Chickens and turkeys, belong to the order Galliformes. Owls are nocturnal hunters and belong to the order Strigiformes. Ducks, geese, and swans belong to the order Anseriformes.
- The herons and egrets belong to the order Ciconiiformes. Penguins belong to the Sphenisciformes, and the ostrich is in the order Struthioniformes.

Vocabulary

crop milk (873) syrinx (873)

REVIEW

Vocabulary

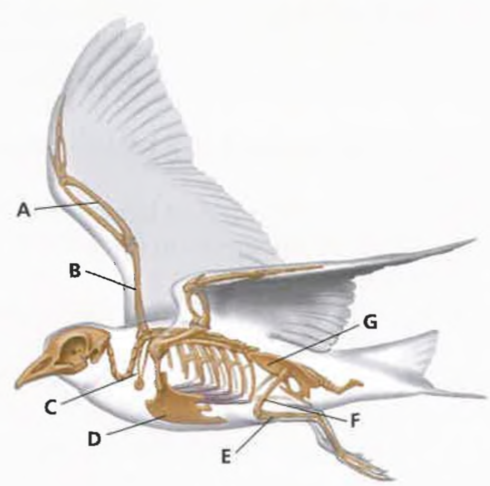
1. Differentiate between the terms *altricial* and *precocial.*
2. What are the differences between a barb and a barbule?
3. What are the differences between the furcula and the sternum?
4. Explain the difference between a crop and a gizzard.
5. Describe the differences between migration and preening.

Multiple Choice

6. Which of the following characteristics of *Archaeopteryx* is not shared by modern birds? (a) long tail (b) feathers (c) teeth (d) furcula
7. One similarity between birds and dinosaurs is (a) the presence of feathers (b) the lack of teeth (c) the structure of the ankle joint (d) size.
8. The function of the preen gland is to (a) produce digestive enzymes (b) produce an oily substance used to condition the feathers (c) release scents that help attract mates (d) control salt balance in the body.
9. The bone that supports the tail feathers is the (a) pelvic girdle (b) pygostyle (c) ulna (d) furcula.
10. Gas exchange in birds takes place in the (a) anterior air sacs (b) posterior air sacs (c) syrinx (d) lungs.
11. The structure that grinds food, aided by stones swallowed by the bird, is the (a) gizzard (b) proventriculus (c) crop (d) small intestine.
12. The excretory system of a bird (a) lacks a urinary bladder (b) excretes nitrogenous wastes as ammonia (c) stores large amounts of water (d) has only one kidney.
13. Birds that produce altricial young (a) abandon their newly hatched chicks immediately (b) lay only a few eggs at a time (c) usually build nests on the ground (d) incubate their eggs for a long period of time.
14. A cue that is believed to aid birds in navigation during their annual migrations is (a) the Earth's magnetic field (b) weather (c) cloud formations (d) phases of the moon.
15. Crop milk is produced by birds in the order (a) Ciconiiformes (b) Galliformes (c) Columbiformes (d) Falconiformes.

Short Answer

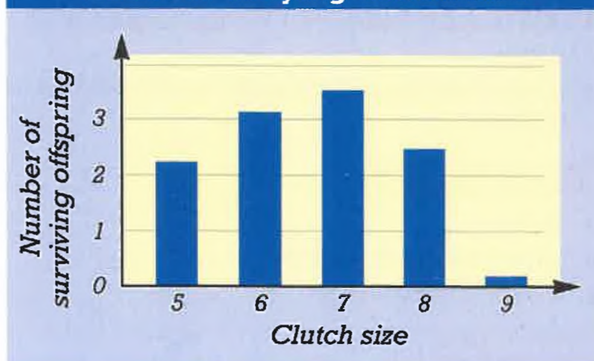
16. Summarize the evidence that *Archaeopteryx* could fly.
17. What characteristics did *Archaeopteryx* share with its dinosaur ancestors?
18. Contrast the function of down feathers with that of contour feathers.
19. What function does the crop serve in digestion?
20. How do air sacs increase respiratory efficiency in birds?
21. Why is binocular vision important to some birds?
22. Many birds migrate long distances over the ocean. What types of cues might these birds use to guide their movements?
23. Owls and raptors often coexist. Would you expect these two types of birds to compete? Explain your answer.
24. Explain why birds migrate.
25. Look at the diagram below of a bird's skeleton. Identify the following structures: pelvic girdle, furcula, sternum, femur, humerus, ulna, and tibiotarsus.



CRITICAL THINKING

1. What factors might explain why birds live in the Arctic but reptiles do not?
2. From studying the circulatory system of birds, you know that the right and left sides of a bird's heart are completely separated. This means that the oxygenated blood is never mixed with the deoxygenated blood. Why is this complete separation in the heart necessary?
3. Cowbirds lay their eggs in the nests of other birds. The young cowbirds hatch slightly earlier than the other birds do, and the cowbird hatchlings are slightly larger. Why might these distinctions be advantageous for the young cowbirds?
4. Although many species of temperate-zone birds migrate to the tropics to escape winter, some species remain behind. What benefits might these birds gain from not migrating?
5. From an evolutionary point of view, explain why the young of some birds, such as ducks and quail, are precocial.
6. The graph at right shows the results of an experiment on magpies in which the clutch size, that is, the number of eggs in the nest, was manipulated. Based on these data, determine whether the following statements are true or false.
   a. The greater the clutch size is, the greater the number of surviving offspring.
   b. More offspring died in nests containing eight eggs than in nests containing five eggs.
   c. Nests with nine eggs produced the fewest number of surviving offspring.

Effect of Varying Clutch Size



7. Drawing on data similar to that shown in the graph above, the ecologist David Lack argued that natural selection would favor intermediate clutch sizes. Explain the logic behind Lack's argument.

EXTENSION

1. Bird-watching is a fascinating and interesting hobby practiced by millions of Americans. From your library or bookstore, obtain a field guide to the birds in your area, and borrow a pair of binoculars. Take a long walk and try to locate as many birds as you can. Be sure to keep a notebook of the birds you find, including species, date sighted, location, and habits.
2. Many of the world's bird species have become extinct in the last 2,000 years. Three examples are the Carolina parakeet, the passenger pigeon, and the dodo. Using library resources or an on-line database, collect information on one of these extinct species. Find out as much as you can about its ecology and former distribution and about what caused it to become extinct. Write a report that summarizes your findings.
3. Read "Clown-Faced Hoarders" in *Audubon,* September–October 1999, on page 158. Describe the unique way acorn woodpeckers have of working together and storing food for the winter.

CHAPTER 44 INVESTIGATION

Comparing Feather Structure and Function

OBJECTIVES

- Observe a quill feather, a contour feather, and a down feather.
- Compare the structure and function of different kinds of feathers.

PROCESS SKILLS

- observing
- relating structure to function
- comparing and contrasting

MATERIALS

- 1 quill feather
- 1 contour feather
- 1 down feather
- unlined paper
- prepared slide of a contour feather
- compound light microscope
- prepared slide of a down feather

Background

1. List several distinguishing characteristics of birds.
2. How do birds differ from other vertebrates?
3. What are the functions of feathers?

Procedure

1. In your lab report, make a table like the one on the next page. Record your observations of each kind of feather in your data table.
2. Examine a quill feather. Hold the base of the central shaft with one hand and gently bend the tip of the feather with your other hand. Be careful not to break the feather. Next hold the shaft and wave the feather in the air. Record your observations concerning the structure of the quill feather. Relate your observations to the feather's possible function.

Flight feather

3. Examine the vane of the feather. Does the vane appear to be a solid structure? Include a description of the quill feather's vane structure under "Structure of feather" in your data table.
4. Make a drawing of the quill feather. Label the shaft, vanes, and barbs. Compare your feather with the figure above.
5. Examine a contour feather. Make a sketch of the contour feather in your data table. Label the shaft, vanes, and barbs on your sketch. Does the feather resemble the one in the figure on the next page?
6. Describe the structure of the contour feather under "Structure of feather" in your data table.
7. Examine a prepared slide of a contour feather under low power. Note the smaller barbs, called barbules, extending from each of the barbs.
8. How might you observe the region between the barbs? Locate the tiny hooks at the end of each barbule. Note the arrangement of the hooks on adjacent barbs. Why do you think the hooks are so small? Make a labeled drawing of the hooks in your lab report.
9. Examine the down feather and sketch it in your data table. How does your down feather compare with the figure on the next page?
10. Describe the structure of the down feather in your data table. Do you notice a difference in the structure of the contour and down feathers?

COMPARISON OF FEATHERS

Type of feather	Sketch of feather	Structure of feather	Function of feather
Quill feather			
Contour feather			
Down feather			

Contour feather

Down feather

11. Examine the prepared slide of the down feather under low power. Locate the barbs and barbules. Switch your microscope to high power, and make a labeled drawing of the down feather in your lab report. Does it resemble the one in the figure above?

12. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. What is the function of the shaft? What is the function of the vanes and barbs?
2. How do hooks increase the strength and air resistance of a feather?
3. How is the structure of the quill feather related to its function of aiding flight?
4. Based on your observations, why might down feathers be more effective at keeping a bird warm than the other two feather types you observed?
5. Based on your observations of the structure and function of the feathers, how do you expect to see these feathers oriented on a bird? Explain how orientation of the feather affects the function of the feather.
6. What evolutionary pressure(s) would have caused the evolution of these different types of feathers?

Further Inquiry

Each of the feather types you have examined has a specific structure and function. Review your observations, and try to think of features that account for the efficiency of the three types of feathers.

CHAPTER 45

MAMMALS

These young opossums depend on their mother to provide them with nourishment from her mammary glands—a unique mammalian trait.

FOCUS CONCEPT: *Stability and Homeostasis*

As you read the chapter, note the ways mammals meet the demands of their rapid metabolism.

SECTION

45-1

OBJECTIVES

▲ Name and describe six characteristics of mammals.

● Describe the characteristics of the early synapsids.

■ Summarize the importance of therapsids in mammalian evolution.

◆ Describe how dinosaurs affected the evolution of mammals.

ORIGIN AND EVOLUTION OF MAMMALS

There are about 4,400 species in the class Mammalia. Mammals are classified into more than 20 orders, one of which includes humans. Mammals live on every continent and in every ocean. Some mammals have the ability to fly, while others are exclusively aquatic.

KEY CHARACTERISTICS

Six important characteristics of mammals are listed below.

- **Endothermy**—Like birds, mammals produce body heat internally through metabolism. Mammals keep their body temperature high and nearly constant by controlling their metabolism and regulating the loss of heat through the body surface.
- **Hair**—All mammals have hair. The main function of hair is to insulate the body against heat loss. Most mammals (humans and whales are obvious exceptions) are covered with a thick coat of hair. Hair color also serves to camouflage a mammal from predators or a predator from being seen by its prey.
- **Completely divided heart**—Like crocodiles and birds, mammals have a four-chambered heart with two completely separate ventricles. Separate ventricles keep deoxygenated blood from diluting oxygenated blood and allow more efficient pumping of blood through both circuits of the circulatory system.
- **Milk**—Female mammals produce milk to feed their offspring. Milk is a nutritious fluid that contains fats, protein, and sugars. It is produced by the **mammary glands,** which are modified sweat glands located on the thorax or abdomen.
- **Single jawbone**—The lower jaw of a reptile is composed of several bones, but the lower jaw of a mammal is composed of a single bone. This characteristic is particularly important for identifying mammalian fossils because many of the other characteristics of mammals, such as hair and mammary glands, do not fossilize or leave traces on the skeleton.
- **Specialized teeth**—Teeth in different parts of a mammal's jaws are modified for different functions. Those at the front of the jaw are used for biting, cutting, or seizing prey, while those along the sides of the jaw are used for crushing, grinding, or slicing. The teeth of most reptiles are uniform in size and shape, regardless of where they are located in the mouth.

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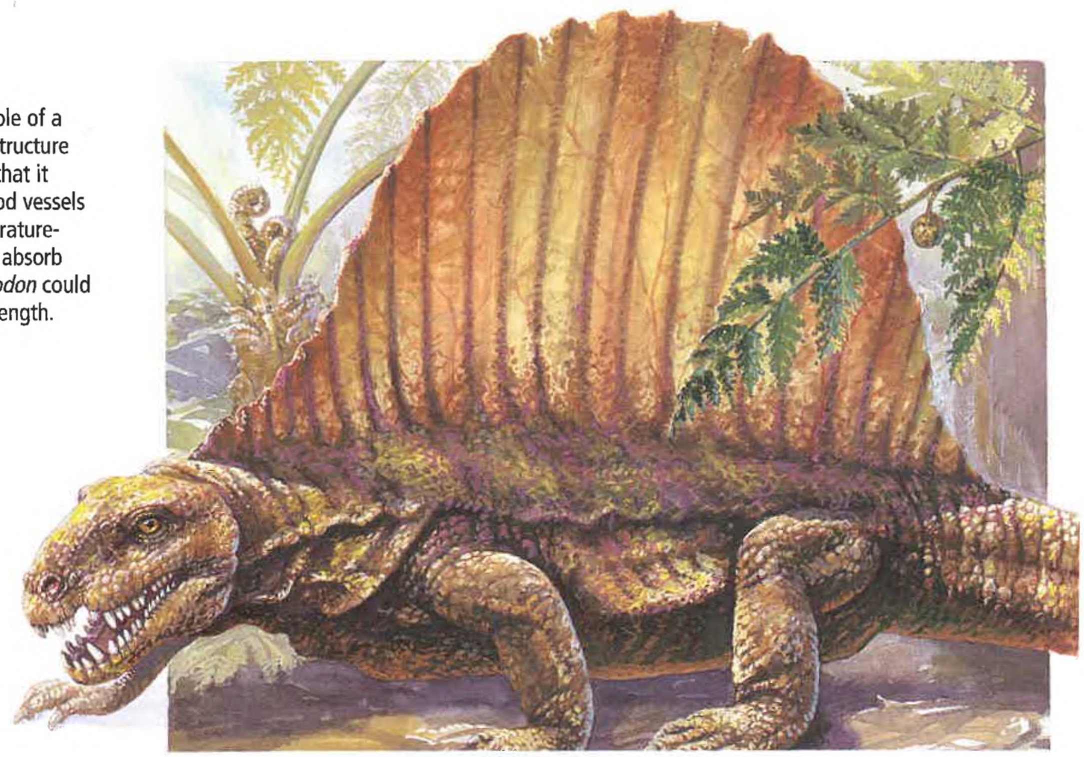


FIGURE 45-1

This *Dimetrodon* is an example of a synapsid. Note the sail-like structure on its back. Scientists think that it was probably filled with blood vessels and that it acted as a temperature-regulating device that could absorb heat during the day. *Dimetrodon* could grow up to 3.5 m (11 ft) in length.

ANCESTORS OF MAMMALS

The ancestors of mammals first appeared on Earth more than 300 million years ago. At that time, a major evolutionary split occurred in the terrestrial vertebrates, producing two groups of animals. Members of the first group gave rise to dinosaurs, birds, and all the living reptiles. Members of the second group, known as **synapsids,** include mammals and their closest relatives. Mammals are the only surviving synapsids. Early synapsids can be distinguished by the structure of their skull. There is a single opening in the outer layer of the skull just behind the eye socket. This same type of skull is found in all later synapsids, including mammals, although often in a highly modified form.

The first synapsids were only about 50 cm (20 in.) in length and resembled modern lizards. By the early Permian period (286–245 million years ago), an assortment of large synapsids, some of which reached 4 m (13 ft) in length and weighed more than 200 kg (440 lb), had appeared. Figure 45-1 shows a reconstruction of a carnivorous synapsid known as *Dimetrodon.* In most reptiles, teeth throughout the jaw are uniform in size and shape. But in many of the early carnivorous synapsids, including *Dimetrodon,* the teeth are specialized to a small degree, with long stabbing teeth in the front of the mouth and smaller teeth toward the back.

Therapsids

Among the synapsids that appeared later in the Permian period were the **therapsids,** the group that gave rise to mammals. Figure 45-2 shows a rendering of a therapsid. Therapsids were the most

FIGURE 45-2

Lycaenops was a carnivorous therapsid. Its legs supported its body more directly than did those of the early synapsids. The repositioning of the legs also improved its speed, making it a better predator.

abundant terrestrial vertebrates during the late Permian period. They survived through the Triassic period (245–208 million years ago) and into the Jurassic period (208–144 million years ago).

The evolution of mammals from therapsids involved changes in anatomy, physiology, ecology, and behavior. The rich and unusually complete fossil record of therapsids preserves many transitional forms that bridge the gap between therapsids and mammals. By studying these fossils, scientists can follow the anatomical changes that occurred during this transition and infer when some of the physiological, ecological, and behavioral changes must have happened.

Many of the features we associate with mammals evolved first among therapsids. For example, many therapsids had teeth differing in size, shape, and function, depending on their position in the jaw. The limbs of mammals are positioned directly beneath the body, as were the limbs of many therapsids. Some therapsids were probably endothermic, and some may have had hair.

Early Mammals

The first mammals and the first dinosaurs appeared at about the same time, during the Triassic period, and the dinosaurs had an important influence on the evolution of mammals for more than 150 million years. Figure 45-3 shows a reconstruction of an early mammal. The early mammals were about 10 cm (4 in.) long and

FIGURE 45-3

The first mammals, such as this *Eozostrodon,* had to compete with the larger, dominant dinosaurs. These first mammals functioned at night, when dinosaurs were probably less active.

Word Roots and Origins

monotreme

from the Greek *monos,* meaning "single," and *trema,* meaning "hole"

20–30 g (0.5 oz) in mass, or about the size of a mouse. Fossil skeletons show that early mammals had large eye sockets, which suggests that these creatures probably were active at night. Their teeth indicate that they probably fed on insects. By hiding during the day, mammals would have avoided predation by dinosaurs, and by feeding on insects, they would not have competed with dinosaurs for food. Although there is no direct evidence of mammary-gland development in early mammals, scientists infer from similarities of mammary tissue among different mammalian orders that mammary glands were present as early as the late Triassic period.

During this time, dinosaurs filled the majority of terrestrial habitats. Mammals remained small and probably were neither abundant nor diverse. By the end of the Jurassic period, at least five orders of mammals had evolved. And by the middle of the Cretaceous period (144–65 million years ago), the three main groups to which modern mammals belong had appeared. The first group, the **monotremes,** are oviparous, that is, they lay eggs. The second group is the **marsupials.** Marsupials are viviparous, which means they give birth to live young, but the period of development within the mother is short. **Placental mammals,** the third group, are also viviparous, but the young are born at a much later stage of development than are marsupial offspring. As they develop inside the mother's uterus, placental young are nourished through a structure called the placenta.

Diversification of Mammals

The dinosaurs became extinct about 65 million years ago, at the end of the Cretaceous period. This opened up many new habitats and resources to mammals, and mammals took over many of the ecological roles previously fulfilled by dinosaurs. For example, during the Jurassic and Cretaceous periods, most of the large terrestrial carnivores and herbivores were dinosaurs. Today, nearly all large terrestrial carnivores (lions, tigers, and wolves, for example) and herbivores (elephants, giraffes, cattle, and horses, for example) are mammals.

SECTION 45-1 REVIEW

1. How does hair help a mammal maintain its body temperature?
2. Identify two differences between the jaw of a mammal and the jaw of a reptile.
3. What is one characteristic shared by mammals and the early synapsids?
4. List two characteristics of therapsids.
5. Why was it advantageous for the early mammals to be nocturnal?
6. **CRITICAL THINKING** Scientists think that mammals were rare during the time of the dinosaurs because there are few fossils of mammals from that time period. However, the early mammals were very small, and their fossils are very fragile. How might these factors influence estimates of the abundance of early mammals?

SECTION

45-2

OBJECTIVES

▲ Describe the advantage of endothermy in mammals.

● Describe two features of the mammalian respiratory and circulatory systems that help sustain a rapid metabolism.

■ Describe two mammalian adaptations for digesting plants.

◆ Compare and contrast reproduction in monotremes, marsupials, and placental mammals.

CHARACTERISTICS OF MAMMALS

Mammals inhabit a wide range of habitats on land and in the water. They can survive in some of the coldest and hottest environments on Earth. Adaptations have enabled mammals to inhabit such diverse environments.

ENDOTHERMY

Endotherms generate heat internally by breaking down food, while ectotherms absorb most of their heat from their surroundings. Endothermy determines many of the capabilities of mammals. For instance, mammals can live in cold climates and be active. Perhaps more important, their rapid metabolism provides mammals with the energy to perform strenuous activities for long periods of time. As a general rule, ectotherms are not capable of sustained activity because they tire quickly.

The organ systems of mammals also differ from the organ systems of ectotherms. Figure 45-4 shows the internal anatomy of a typical mammal.

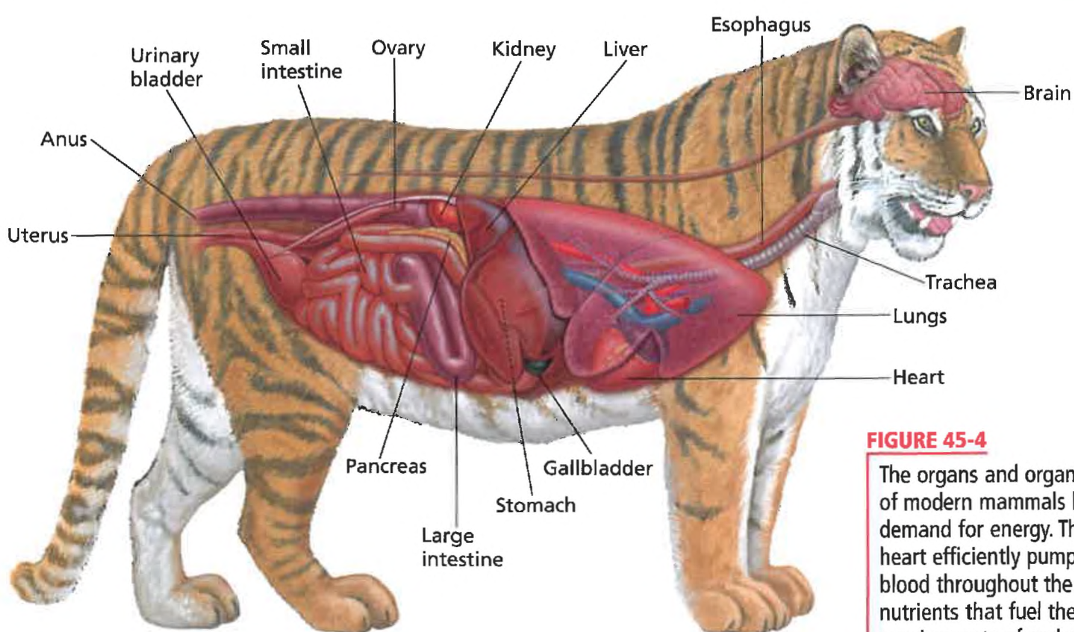


FIGURE 45-4

The organs and organ systems of modern mammals have a high demand for energy. The mammalian heart efficiently pumps oxygenated blood throughout the body, delivering nutrients that fuel the high-energy requirements of endothermy.

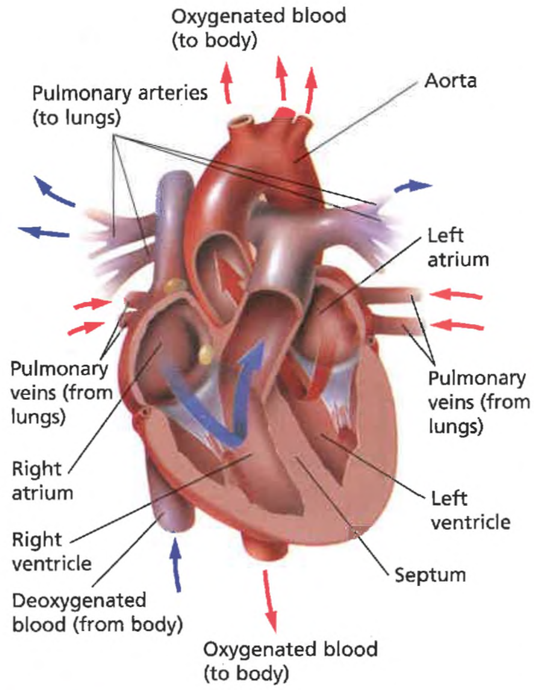


FIGURE 45-5
The red arrows show the path of oxygenated blood through the heart, and the blue arrows show the path of deoxygenated blood. As you can see, the ventricle is completely divided by a septum. As a result, the blood pumped to the body contains a higher percentage of oxygen than results from blood pumped by a reptilian or fish heart.

Because of its faster metabolism, a mammal needs more oxygen and food than does a reptile of the same size. Heat is constantly escaping from a mammal's body through its skin and exhaled air. Because producing heat requires so much energy, mammals need to limit their loss of body heat to the environment. Hair and fat layers serve as insulation for most mammals. For example, mammals that live in very cold climates usually have a very thick coat of hair. Large tropical mammals, such as elephants, have very little hair.

Circulatory System

The structure of the mammalian heart helps ensure the efficient flow of blood throughout the body. As you can see in Figure 45-5, the heart has two atria and two completely separated ventricles. Note that oxygenated and deoxygenated blood never mix. Recall that in the heart of a lizard or turtle, deoxygenated blood and oxygenated blood can mix when the animal is inactive. However, mammals have such a high demand for oxygen that they cannot tolerate the dilution of oxygenated blood by deoxygenated blood.

Respiratory System

The respiratory system of a mammal is adapted for efficient gas exchange. The lungs are large and contain millions of alveoli, the small chambers in which gas exchange occurs. Compared with the lung of a reptile, the lung of a mammal has a much larger surface area available for gas exchange. For example, the internal surface area of a pair of human lungs is about 140 m^2 (1,500 ft^2). Another adaptation that contributes to the efficiency of respiration is the **diaphragm,** a sheet of muscle below the rib cage. Contraction of the diaphragm during inhalation helps draw air into the lungs.

Feeding and Digestion

For most mammals, the breakdown of food begins with chewing in the mouth. Other vertebrates simply swallow their food whole or in large pieces. Chewing speeds up digestion by breaking food into small pieces that can be more easily digested by enzymes. Most mammals have specialized teeth for gripping and holding food, and for chewing. Chisel-like **incisors** cut. Pointed **canines** grip, puncture, and tear. **Premolars** shear, shred, cut, or grind. **Molars** grind, crush, or cut. Variations in the size and shape of teeth among different mammalian species reflect differences in diet. For instance, notice the differences between the teeth of a carnivore and those of a herbivore, as shown in Figure 45-6.

Baleen whales, such as the blue whale, do not have teeth. Instead they have **baleen,** thin plates of fingernail-like material that hang from the roof of the mouth. As a baleen whale swims, it gulps huge quantities of water. Then it closes its mouth and pushes the water through the baleen. Shrimp and other small invertebrates are trapped in the baleen and then swallowed.

Adaptations for Digesting Plants

Plants can be difficult to digest because they contain large amounts of cellulose, which is a polymer of glucose, and no vertebrates produce enzymes to break down cellulose. However, some mammals can digest cellulose with the aid of microorganisms. Cows, sheep, goats, giraffes, and many other hoofed mammals have a large stomach with four chambers. The first chamber, known as the **rumen** (ROO-muhn), contains symbiotic bacteria and other microorganisms. After plant material is chewed and swallowed, it enters the rumen. Microorganisms then begin to break down the cellulose. The food is further digested in the rumen, then regurgitated, chewed again, and swallowed again (a cow chewing its cud is actually rechewing partially digested food). Food may be regurgitated and swallowed several times. Microorganisms that live in the rumen break down cellulose into small molecules that are eventually absorbed into the animal's bloodstream when the food reaches the small intestine.

In horses, rodents, rabbits, and elephants, microorganisms that live in the **cecum** (SEE-kuhm) complete digestion of the food. The cecum is a large sac that branches from the small intestine and acts as a fermentation chamber. Food passes through the stomach and small intestine before entering the cecum. The human appendix is a vestigial cecum. Mammals with a cecum do not chew cud.

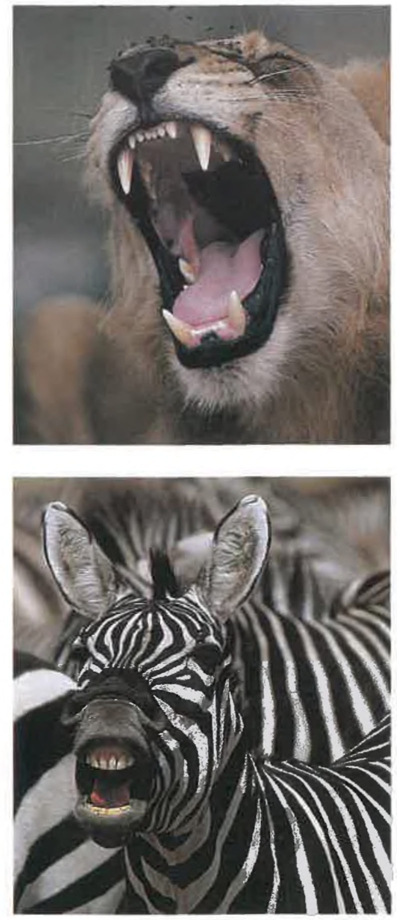


FIGURE 45-6

Carnivores, such as this lion, have large, sharp incisor and canine teeth that are able to cut and tear flesh. Herbivores, such as the zebra, have flat teeth that are useful for grinding grass and grain, which are the staples of their diet.

NERVOUS SYSTEM AND SENSE ORGANS

The brain of a mammal is about 15 times heavier than the brain of a similarly sized fish, amphibian, or reptile. Enlargement of one part of the brain, the cerebrum, accounts for most of this size increase. In mammals, the cerebrum is the largest part of the brain. The cerebrum's surface is usually folded and wrinkled, which greatly increases its surface area without increasing its volume. The cerebrum evaluates input from the sense organs, controls movement, and initiates and regulates behavior. It is also involved in memory and learning. Humans have the highest brain-to-body-size ratio.

Like other terrestrial vertebrates, mammals depend on five major senses: vision, hearing, smell, touch, and taste. The importance of each sense often depends on the mammal's environment. For instance, most bats, which are active at night, rely on sound rather than vision for navigating and finding food. Using a process called **echolocation** (EK-oh-loh-KAY-shuhn), these bats emit high-frequency sound waves, which bounce off objects, and then they analyze the returning echoes to determine the size, distance, direction, and speed of the objects.

Word Roots and Origins

cecum

from the Latin *intestinum caecum,* meaning "blind intestine"

FIGURE 45-7

Marsupials, such as this young kangaroo, are born soon after conception and must crawl into their mother's pouch for the rest of their development. The level of development is so low that many marsupials are born before separation of the heart ventricle is complete. Other organs not yet completed include lungs, kidneys, and major nerves.

REPRODUCTION

Each main group of mammals—monotremes, marsupials, and placental mammals—has a unique reproductive pattern. A female monotreme typically lays one or two large eggs that have thin leathery shells and incubates them with her body heat. The developing embryo is nourished by the yolk within the egg. At hatching, a monotreme is very small and only partially developed. Its mother protects it and feeds it milk from her mammary glands until it is ready to survive on its own.

Marsupials are characterized by a very short period of development within the mother's uterus. Newborn marsupials emerge from the uterus after they have completed enough development to be able to survive outside the uterus. The newborn offspring of a kangaroo, for example, is only 2 to 3 cm (1 in.) long. Figure 45-7 shows a marsupial soon after birth. The newborn crawls into the mother's pouch, located on her abdomen, and attaches to a nipple. The newborn's development and growth then continue in the pouch.

Placental mammals, the group that includes cats, dogs, humans, and most other familiar mammals, give birth to their young after a much longer period of development. During this period, the mother provides nourishment and oxygen to her developing offspring through the placenta. The placenta begins to form shortly after fertilization, when the fertilized egg attaches to the lining of the uterus. Extensions from the chorion, the outer membrane surrounding the egg, grow into the lining of the uterus, and blood vessels from the uterus surround these extensions. When completely formed, the placenta contains tissue and blood vessels from both the mother and the offspring. Nutrients and oxygen diffuse from the mother's blood into the blood of the offspring, and carbon dioxide and other wastes diffuse from the offspring into the mother's blood.

Newborn mammals are nourished with milk from the mother's mammary glands. Young mammals are dependent on the mother for food and care.

SECTION 45-2 REVIEW

1. **A mammal eats about 10 times as much food as a lizard of the same size. Explain this difference.**
2. **How does the heart of a mammal differ from the heart of a lizard?**
3. **What is the function of the rumen in hoofed mammals?**
4. **Bats, which are active only at night, often have very large ears. Why might large ears be advantageous to a bat?**
5. **Identify one difference and one similarity between the reproductive patterns of monotremes and marsupials.**
6. **CRITICAL THINKING What sort of ecological relationship exists between a cow and the microorganisms living in its rumen? Explain your answer.**

Literature & Life

Gorillas in the Mist

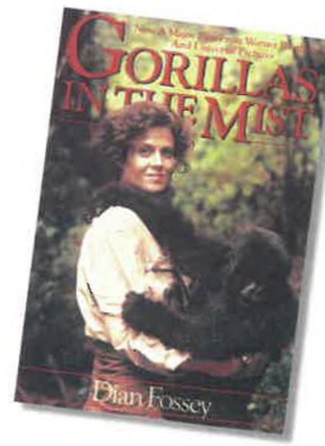
This excerpt is from *Gorillas in the Mist,* by Dian Fossey.

During the early days of the study at Kabara, it was difficult to establish contacts because the gorillas were not habituated or accustomed to my presence and usually fled on seeing me. I could often choose between two different kinds of contacts: obscured, when the gorillas didn't know I was watching them, or open contacts, when they were aware of my presence.

Obscured contacts were especially valuable in revealing behavior that otherwise would have been inhibited by my presence. The drawback to this method was that it contributed nothing toward the habituation process. Open contacts, however, slowly helped me win the animals' acceptance. This was especially true when I learned that imitation of some of their ordinary activities such as scratching and feeding or copying their contentment vocalizations tended to put the animals at ease more rapidly than if I simply looked at them through binoculars while taking notes. I always wrapped vines around the binoculars in an attempt to disguise the potentially threatening glass eyes from the shy animals. With gorillas, as is often the case with humans, direct staring constitutes a threat.

Not only was it necessary to get the gorillas accustomed to the blue-jeaned creature who had become a part of their daily lives, it was also very necessary for me to know and recognize the particular animals of each group as the amazing individuals they were. Just as George Schaller had done some seven and a half years before me, I relied heavily upon "noseprints" for identification purposes. There is a tendency for the gorillas of each group to resemble one another, especially within matrilineal lines. As no two humans have exactly the same

fingerprints, no two gorillas have the same "noseprint"—the shape of the nostrils and the outstanding troughs seen on the bridges of their noses. Since the gorillas initially were unhabituated, I had to use binoculars, but even from a distance I could quickly make sketches of noseprints seen on the more curious group members peeking back at me from partially hidden positions in



the dense vegetation. These sketches proved invaluable at a time when close-up photography was out of the question. Also, I would have needed a third hand in order to manage a camera, binoculars, and note taking, not to mention carrying on with the imitative routine of feeding, scratching, and vocalizing needed to relax the gorillas as well as to arouse their curiosity.

Reading for Meaning

What do you think Fossey means when she says the gorillas "were not habituated"?

Read Further

Gorillas in the Mist tells about Dian Fossey's experiences during 13 years she spent observing African mountain gorillas in their natural habitat. How did her growing understanding of the gorillas help her become almost a part of their community?

SECTION

45-3

OBJECTIVES

▲

Name the orders of mammals, and give an example of each.

●

Describe two differences between marsupials and monotremes.

■

Distinguish between artiodactyls and perissodactyls.

◆

Identify two orders whose members are aquatic, and describe one adaptation for aquatic life shown by each order.

MAMMALIAN CLASSIFICATION

The roughly 4,400 species of mammals are divided into more than 20 orders. One order contains the monotremes, one order contains marsupials, and the remaining orders contain placental mammals.

ORDER MONOTREMATA

Monotremes are the only egg-laying mammals. Just three species exist, one platypus and two anteaters, or echidna, and they have a very restricted distribution. Monotremes live only in Australia and New Guinea. Figure 45-8 shows an example of a platypus and an echidna. Monotremes are considered to be the most primitive of all the mammals, as is illustrated in the phylogenetic tree in Figure 45-9.

The duckbill platypus is adapted to life in water. It has waterproof fur, webbed feet, and a flattened tail that aids in swimming. Its most distinctive characteristic is its flat, sensitive, rubbery muzzle, which it uses to root for worms, crayfish, and other invertebrates in soft mud. The female platypus digs a den in the bank of a river or stream to lay her eggs. She curls around the eggs to protect and incubate them. After hatching, the newborns lick milk from nippleless mammary glands on the mother's abdomen.

Echidnas are terrestrial. They have a coat of protective spines and a long snout for probing into anthills and termite nests. Echidnas incubate their eggs in a pouch on the belly.

(a)

(b)

FIGURE 45-8

The duckbill platypus (a) and the spiny anteater (b) are two of the three species in the order Monotremata. The platypus's scientific name is *Ornithorhynchus anatinus,* and the anteater's scientific name is *Tachyglossus aculeatus.*

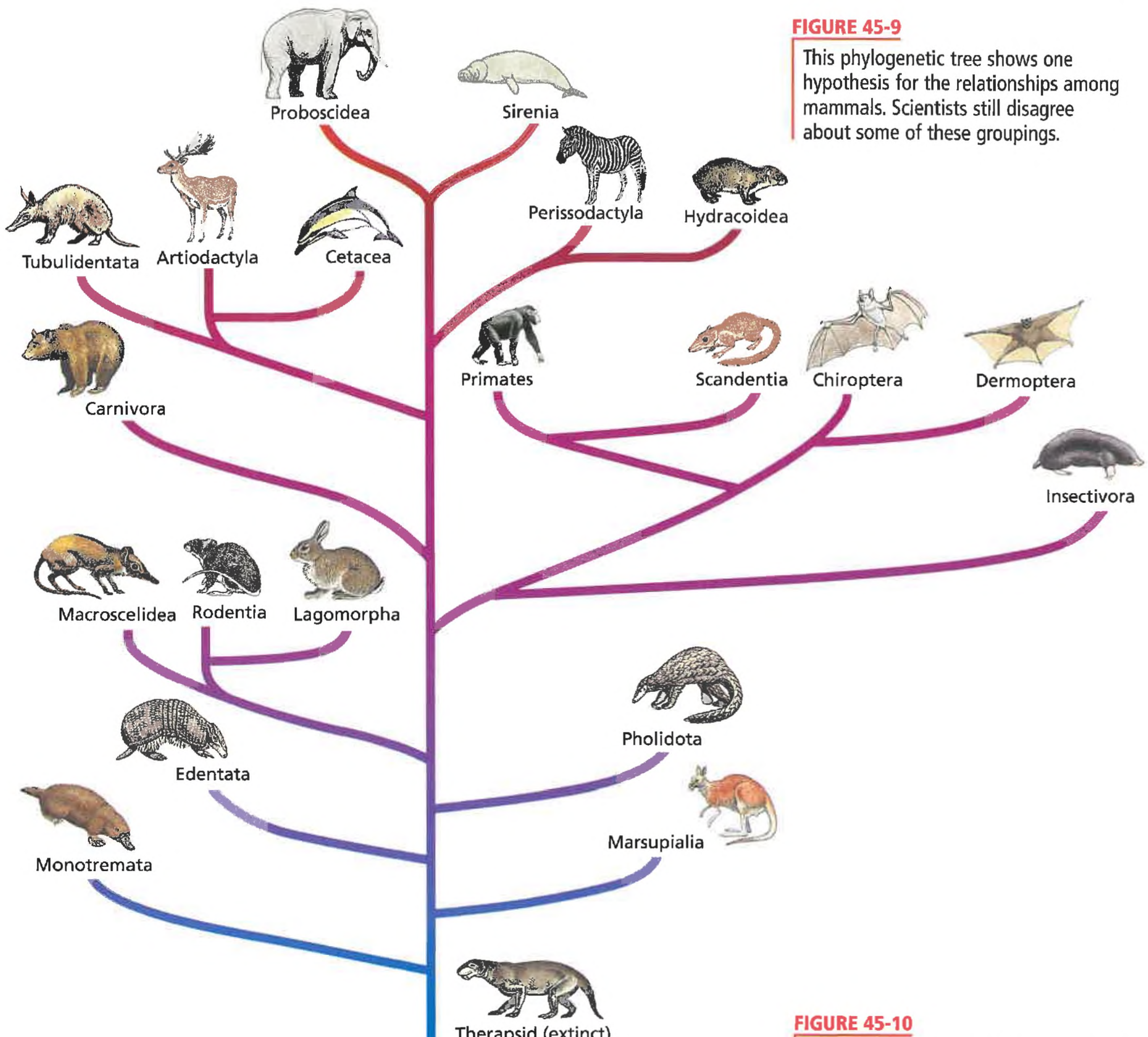


FIGURE 45-9
This phylogenetic tree shows one hypothesis for the relationships among mammals. Scientists still disagree about some of these groupings.

ORDER MARSUPIALIA

About 280 marsupial species exist today, inhabiting Australia, New Guinea, and the Americas. The United States has only one marsupial species, the Virginia opossum. Figure 45-10 shows an example of a marsupial.

These unique mammals evolved during a long period of isolation. Recall that Australia and New Guinea drifted away from the other continents more than 40 million years ago. At that time, placental mammals were apparently rare in the region. According to the fossil record, marsupials once dominated South America; they were gradually displaced by placental mammals, and many species became extinct.

FIGURE 45-10
Some marsupials, such as the fat-tailed dunnart, eat insects and small vertebrates. The marsupial line split from the placental-mammal line during the late Jurassic or early Cretaceous periods.

FIGURE 45-11

These porcupines are members of the order Rodentia. The range of the North American porcupine, *Erithizon dorsatum,* on the left, extends from Canada to northern Mexico. The Brazilian porcupine, *Coendou prehensilis,* on the right, has a prehensile tail that enables it to maintain a firm grip on tree branches.

Quick Lab

Comparing Gestation Periods

Materials paper, pencil

Procedure

1. Make a table of gestation periods for different mammals. Make three columns labeled "Mammal," "Gestation period," and "Offspring per pregnancy."
2. Fill in your table with the following data:

Bat, 210 days, 1 offspring

Gerbil, 19–21 days, 4–7 offspring

Horse, 332–342 days, 1 offspring

Monkey, 226–232 days, 1 offspring

Squirrel, 44 days, 3 offspring

Rabbit, 31 days, 3–6 offspring

Whale, 420–430 days, 1 offspring

Wolf, 63 days, 4–5 offspring

Analysis

1. State a generalization about the relationship of the length of the gestation period to the number of offspring per pregnancy.
2. Propose a hypothesis to explain this relationship.
3. Rearrange your table, if necessary, to show this relationship more clearly.

PLACENTAL MAMMALS

Placental mammals are a diverse group that comprises at least 18 orders. Ninety-five percent of all mammal species are placental mammals. They live on land, in water, and in the air.

Order Rodentia

Rodentia, the largest mammalian order, includes more than 1,800 species, or about 40 percent of all placental mammals. Rodents flourish on every continent except Antarctica and are adapted to a wide range of habitats. Squirrels, marmots, chipmunks, gophers, muskrats, mice, rats, and porcupines are rodents. Rodents have only two pairs of incisors, which continue to grow as long as the rodent lives. Rodent incisors are sharp, an adaptation for the rodent's diet of hard seeds, twigs, roots, and bark. As a rodent gnaws, the back surface of the tooth wears away faster than the front surface, maintaining the tooth's chisel-like edge. Rodents also have a very high reproductive capacity. Figure 45-11 shows two examples of rodents.

Order Edentata

The order Edentata is made up of about 30 living species, including anteaters, armadillos, and sloths. These mammals are found in southern North America, Central America, and South America. The name of this order means "toothless." However, only anteaters are completely toothless; armadillos and sloths have teeth, although the teeth are peglike and lack enamel. Most edentates feed on insects, which they capture with a long, sticky tongue. Their powerful front paws have large, sharp claws, which they use to rip open anthills and termite nests. Armadillos supplement their insect diet with small reptiles, frogs, mollusks, and carrion. Sloths, on the other hand, are herbivores; their continuously growing teeth are an adaptation for grinding plants.

Order Lagomorpha

About 70 species make up the order Lagomorpha, which includes rabbits, hares, and pikas. Lagomorphs are found worldwide. They differ from rodents in that they have a double row of upper incisors, with two large front teeth backed by two smaller ones. Lagomorph teeth continue to grow throughout the animal's lifetime. Such teeth are an adaptation to the lagomorph's herbivorous diet.

Order Insectivora

The order Insectivora consists of about 390 species of shrews, hedgehogs, and moles. Insectivores are usually small animals with a high metabolic rate. Insectivores are found in North America, Africa, Europe, and Asia. Most have long, pointed noses that enable them to probe in the soil for insects, worms, and other invertebrates. They have teeth adapted for grasping and piercing their prey.

Insectivores are adapted to life on the ground, in trees, in water, and underground. Shrews, for example, feed on the surface of the ground, catching insects with their sharp teeth. Moles, on the other hand, burrow underground. They have stout limbs for digging, small eyes, and no external ears.

Order Primates

Recall from Chapter 17 that humans belong to the order Primates. The 235 species of living primates are classified as either prosimians, which include lemurs, tarsiers, and lorises, or anthropoids, which include monkeys, apes, and humans. Most primates are omnivores and have teeth suited for a varied diet. Primates have particularly large brains, which make possible the complex behaviors characteristic of this group.

Primates vary greatly in size and weight. The smallest primates weigh tens of grams, while the largest primate, the gorilla, *Gorilla gorilla,* can weigh 140–180 kg (300–400 lb). Most primates have two forward-facing eyes, a feature that enables depth perception. All primates have grasping hands and, with one notable exception, grasping feet, and many primates also have a grasping tail. The grasping feet, hands, and tail are excellent adaptations for life in the trees. Because of the wide range of body sizes and adaptations, primates live in a variety of habitats. The rhesus monkey, *Macaca mulatta,* is a tree-living species that is native to India. The gorilla, which is too large to climb trees, lives on the ground in the mountainous areas of Africa.

Order Chiroptera

This order includes bats, the only mammals that can fly. There are more than 900 species of bats, and they live throughout the world, except in polar environments. A bat's wing is a modified front limb with a skin membrane that stretches between extremely long finger bones to the hind limb. A bat's wingspan can measure up to 1.5 m (4.5 ft). The bat's clawed thumb sticks out from the top edge of the wing. Bats use their thumbs for walking, climbing, and grasping. Figure 45-12 shows an example of a bat.

Most bats use echolocation for navigation and have small eyes and large ears. Most feed on insects. However, some tropical bats feed on fruit or flower nectar and do not use echolocation. These bats, sometimes called "flying foxes," have large eyes and a keen sense of smell.

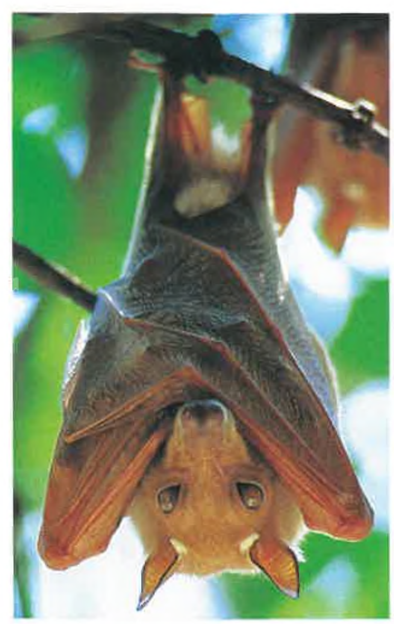


FIGURE 45-12

Peter's epauletted fruit bat is a member of the order Chiroptera, the only flying mammals. The physics of the bat's wing in flight gives the bat more lift in relation to its body weight than most birds have. This enables bats to remain airborne at slower speeds than birds are capable of.

FIGURE 45-13

This caribou is a member of the order Artiodactyla. Artiodactyls are native to all continents except Australia and Antarctica. The first domesticated artiodactyls were probably sheep and goats.

FIGURE 45-14

Although this tapir, *Tapirus bairdi*, looks like a pig, it is a member of the order Perissodactyla, making it more closely related to the horse and rhinoceros. This is another example of convergent evolution.

Order Carnivora

The 274 living species of the order Carnivora are distributed worldwide. Dogs, cats, raccoons, bears, hyenas, otters, seals, and sea lions are some well-known carnivores. Most of the species eat meat, which explains the name of the order. Carnivores generally have long canine teeth, strong jaws, and clawed toes, which they use for seizing and holding prey. Most have keen senses of sight and smell, which aid in hunting. Skeletal adaptations, such as long limbs, enable terrestrial carnivores to run quickly. Aquatic carnivores, such as sea lions, seals, and walruses, have streamlined bodies for efficient swimming and are known as **pinnipeds.** Pinnipeds propel themselves through the water and steer with their flattened, paddlelike forelimbs and hind limbs. Although pinnipeds spend much of their time in the sea feeding, they return to land to sleep and to give birth. Some scientists think that pinnipeds should be in their own order—Pinnipedia.

Pinnipeds are generally larger than land carnivores, weighing 90–3,600 kg (198–7,920 lb). Pinnipeds spend a large part of their life in cold water, so their large size serves to help maintain endothermy. Perhaps one of the most impressive feats of pinnipeds is their diving ability. Pinnipeds generally can dive to depths of 100 m (330 ft), and some species can dive to 400 m (1,313 ft). Most pinnipeds can remain underwater for up to five minutes, and some species can remain submerged for up to an hour.

Order Artiodactyla

Ungulates (UHN-gyoo-luhts) are mammals with hooves. Ungulates with an even number of toes make up the order Artiodactyla. Deer, elk, bison, moose, cattle, sheep, goats, pigs, and camels are artiodactyls (AHRT-ee-oh-DAK-tuhls). About 210 species belong to this order. Artiodactyls are native to every continent except Antarctica and Australia. They are fast runners and use speed as their major defense.

Most artiodactyls are herbivores, although pigs are omnivores. Their molars tend to be large and flat, for grinding plant material. As you learned in the last section, artiodactyls have a storage chamber in the stomach, called the rumen, in which bacteria and other microorganisms break down cellulose. This mutualistic relationship with microorganisms enables artiodactyls to extract nutrients efficiently from plants. Figure 45-13 shows an example of an artiodactyl.

Order Perissodactyla

Ungulates with an odd number of toes make up the order Perissodactyla, which includes about 17 living species. Horses, zebras, rhinoceroses, and tapirs are examples of perissodactyls (PER-is-oh-DAK-tuhls). Most species are native to Africa and Asia. However, some species of tapirs live in Central and South America. Figure 45-14 shows a tapir.

Like artiodactyls, perissodactyls have adaptations that help them digest the cellulose found in plant material. Members of this

FIGURE 45-15
Most cetaceans, like this killer whale, *Orcinus orca,* live in the oceans, but some species of dolphins live in fresh-water lakes and rivers.

order have a cecum, instead of a rumen, in which microorganisms break down cellulose, releasing nutrients that the perissodactyl can absorb.

Order Cetacea

The order Cetacea includes 90 species of whales, dolphins, and porpoises. Cetaceans (se-TAY-shuhns) are distributed worldwide. Cetaceans have fishlike bodies with forelimbs modified as flippers. They lack hind limbs but have broad, flat tails that help propel them through the water. Cetaceans breathe through blowholes located on the top of the head. They are completely hairless, except for a few bristles on the snout. A thick layer of blubber below the skin provides insulation. Like bats, cetaceans navigate and find prey by using echolocation.

Cetaceans are exclusively aquatic and even give birth underwater, but they evolved from land-dwelling mammals. Cetaceans are divided into two groups: toothed whales and baleen whales. Toothed whales include sperm whales, beluga whales, narwhals, killer whales, dolphins, and porpoises. They can have from 1 to 100 teeth, and they prey on fish, squid, seals, and other whales. Figure 45-15 shows a killer whale. Baleen whales, such as blue whales, lack teeth and filter invertebrates from the water with a mesh of baleen that hangs from the roof of the mouth.

Word Roots and Origins

ungulate

from the Latin *ungula,* meaning "hoof"

Order Sirenia

The order Sirenia is made up of four species of manatees and dugongs. These large herbivores inhabit tropical seas, estuaries, and rivers. Their front limbs are flippers modified for swimming. Like whales (order Cetacea), sirenians lack hind limbs but have a flattened tail for propulsion. Although manatees and dugongs superficially resemble whales, they are more closely related to elephants. The similarities between whales and sirenians came about through convergent evolution. Figure 45-16 shows the only sirenian found in North America, the manatee.

FIGURE 45-16
This manatee, *Trichechus manatus,* or sea cow, is one of three species of manatee. Sirenian fossils that date to 50 million years ago have been found.

TABLE 45-1 Minor Orders of Mammals

Order	Characteristic	Example
Macroscelidea	ground-dwelling insectivores with long, flexible snouts; 15 species found only in Africa	elephant shrew
Pholidota	insectivores with protective scales composed of fused hair; resemble reptiles; found in Africa and southern Asia	pangolin
Tubulidentata	nearly hairless insectivores with piglike bodies and long snouts; found in southern Africa	aardvark
Scandentia	squirrel-like omnivores that live on ground and in trees; feed on fruit and small animals; found in tropical Asia	tree shrew
Dermoptera	only two species exist; glide in air using a thin membrane stretched between their limbs; found only in parts of Asia	flying lemur
Hyracoidea	small rabbitlike herbivores; 7 species found only in Africa	hyrax

Order Proboscidea

Members of the order Proboscidea are characterized by a boneless, trunked nose, or proboscis. Only two species of this order exist today, the Asian elephant and the African elephant. Mammoths are an extinct member of this order. Elephants are the largest land animals alive today. The African elephant, the larger of the two species, can reach 6,000 kg (13,200 lb). To sustain such a large body, an elephant must feed on plants for up to 18 hours a day. Elephants use the trunk to gather leaves from high branches. They have modified incisors, called tusks, for digging up roots and for stripping bark from branches. The large, jagged molars, which can grow up to 30 cm (1 ft) long, are used for grinding plant material.

Elephants have one of the longest gestation periods of any animal. A female calf takes 20 months to develop, and a male calf takes 22 months to develop. Female elephants can continue to have calves until the age of 70, and elephants can live to be 80 years old.

The 12 orders just described include most of the familiar placental mammals. The six remaining orders contain just 1 percent of the mammalian species. These orders are summarized in Table 45-1.

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SECTION 45-3 REVIEW

1. List any five orders of placental mammals, and name an example of each order.
2. Where would you go to find both monotremes and marsupials?
3. What is unusual about the incisors of rodents?
4. Name two differences between artiodactyls and perissodactyls.
5. What are some feeding adaptations of whales?
6. **CRITICAL THINKING** The pouch of the marsupial mole opens toward the rear of the body. How would such a pouch aid in the survival of this burrowing animal's young?

CHAPTER 45 REVIEW

SUMMARY/VOCABULARY

45-1

- Six key characteristics of mammals are endothermy; a fully divided heart; hair; milk production by females; a single jawbone; and complex, diverse teeth.
- Mammals belong to a group called synapsids. Synapsids have a skull with one opening behind the eye socket.
- Synapsids called therapsids gave rise to mammals. Therapsids had complex teeth and legs positioned beneath their body.
- Mammals first appeared about 225 million years ago. During the time of the dinosaurs they remained small and lacked diversity. After the extinction of dinosaurs, mammals evolved rapidly.

Vocabulary

mammary gland (881)
marsupial (884)
monotreme (884)
placental mammal (884)
synapsid (882)
therapsid (882)

45-2

- Mammals are endothermic.
- Endothermy expands the range of habitats mammals can occupy and facilitates sustained, strenuous activity. It also requires abundant supplies of food and oxygen.
- The heart of a mammal has two atria and two ventricles.
- Mammals have large lungs with a large internal surface area.
- Mammals, unlike most vertebrates, chew their food to begin its breakdown. Mammals have incisors, canines, premolars, and molars.
- Some hoofed mammals digest cellulose with the aid of microorganisms that live in the rumen. Elephants, rodents, and horses digest cellulose with the aid of microorganisms living in the cecum.
- Mammals have much larger brains than most other vertebrates.
- Monotremes lay eggs. Marsupials give birth to partially developed young that continue development in the mother's pouch. Placental mammals give birth to fully developed young.

Vocabulary

baleen (886)
canine (886)
cecum (887)
diaphragm (886)
echolocation (887)
incisor (886)
molar (886)
premolar (886)
rumen (887)

45-3

- There are at least 20 orders of mammals. Eighteen contain placental mammals. The other orders are monotremes and marsupials.
- Edentates—the sloths, anteaters, and armadillos—have either small teeth or no teeth. Rodents have two continuously growing incisors. Lagomorphs, such as rabbits, have four continuously growing incisors. Insectivores, such as shrews, are small and are adapted for eating invertebrates.
- Primates, including apes, monkeys, and humans, have very large brains and complex behaviors. Bats (order Chiroptera) are the only flying mammals. Carnivores, such as lions, are meat eaters. Deer, cattle, and sheep (order Artiodactyla) are hoofed mammals with an even number of toes. Hoofed mammals with an odd number of toes, such as rhinoceroses, belong to the order Perissodactyla. Whales and dolphins (order Cetacea) are exclusively aquatic and lack hind limbs. Elephants (order Proboscidea) have a long, prehensile nose called a trunk. Manatees and dugongs (order Sirenia) are large aquatic herbivores.

Vocabulary

pinniped (894)
ungulate (894)

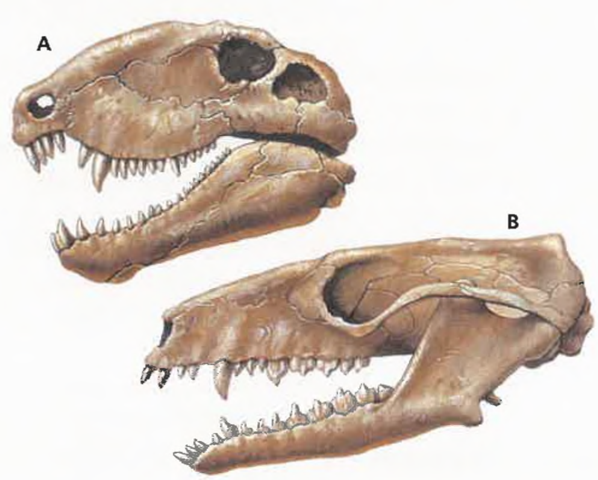
REVIEW

Vocabulary
Explain the differences in meaning between each pair of terms.

1. rumen, cecum
2. ventricle, diaphragm
3. baleen, incisor
4. monotreme, placental mammal
5. canine, molar

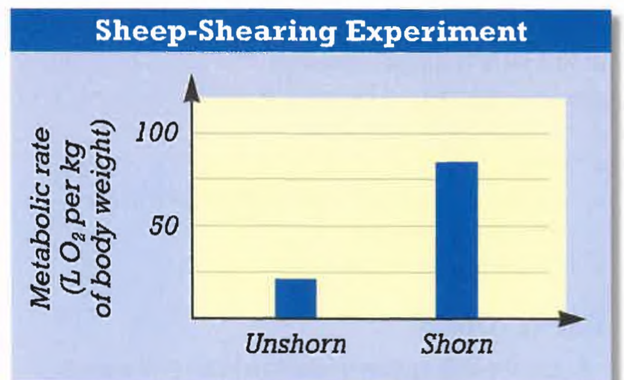
Multiple Choice
6. Which of the following characteristics is present in all synapsids? (a) hair (b) placenta (c) skull with one opening behind the eye socket (d) endothermic metabolism
7. Which of the following is not true of therapsids? (a) may have been endothermic (b) gave rise to mammals (c) died out after dinosaurs (d) legs were positioned beneath the body
8. Evidence that early mammals were active at night includes the fossils of mammals with (a) a single jawbone (b) large eye sockets (c) a four-chambered heart (d) mammary glands.
9. After the dinosaurs became extinct, mammal species flourished because (a) many new habitats were suddenly available to them (b) the climate became warmer and wetter (c) the reptiles had undergone adaptive radiation (d) the reptiles had become endothermic.
10. The diaphragm allows mammals to (a) carry the young inside the uterus (b) have a divided ventricle (c) provide nourishment for their young (d) breathe efficiently.
11. Which of the following is not part of the mammalian heart? (a) conus arteriosus (b) septum (c) ventricle (d) atrium
12. Marsupials differ from monotremes in that marsupials (a) lay eggs (b) carry developing young in a pouch (c) live only in Australia (d) nourish their newborns with milk from mammary glands.
13. Which of these mammals is a marsupial? (a) kangaroo (b) duckbill platypus (c) lion (d) echidna
14. The order Chiroptera is made up of (a) toothless mammals (b) marine mammals (c) flying mammals (d) arboreal mammals.
15. Baleen whales feed on (a) fish (b) marine mammals (c) invertebrates (d) algae.

Short Answer
16. Name and describe two characteristics common to all mammals.
17. Describe two benefits of endothermy for mammals.
18. The ventricles of the mammalian heart are completely separated. How does this help a mammal maintain a constant body temperature?
19. Describe how specialized teeth aid mammals in digesting food.
20. Mammals cannot produce enzymes that break down cellulose, yet many mammals eat plants. Describe two mammalian adaptations for digesting plants.
21. In a famous study conducted 200 years ago, the Italian scientist Lazzaro Spallanzani showed that a blinded bat could still fly and capture insects. A bat whose ears had been plugged with wax could neither fly nor hunt. Explain Spallanzani's observations.
22. How is reproduction in reptiles and monotremes similar? How is it different?
23. Whales have only a few hairs on their snout, yet they are able to live in the coldest oceans. How do they retain their body heat in such environments?
24. How do the teeth of rodents differ from those of lagomorphs?
25. Examine the two skulls below. Which is mammalian? Justify your answer.



CRITICAL THINKING

1. Evaluate this statement by the paleontologist Robert Bakker: "Dinosaurs suppressed the evolutionary potential of mammals, not the other way around."
2. Mammals that live in very cold environments are usually larger than members of the same species that live in warmer climates. Propose a functional explanation for this. (Hint: Consider the effect that increasing size has on volume and surface area.)
3. Mice give birth only 21 days after mating. Why might this characteristic make mice ideal laboratory animals for experiments dealing with mammalian development and heredity?
4. Sloths are arboreal edentates that spend most of their lives hanging upside down from tree branches in the tropical forests of Central and South America. Most sloths have green algae growing in tiny pits in their hair. How might this be an advantage for the sloth? What advantage might the green algae gain by colonizing the sloth's fur?
5. In recent years, surgeons have tried transplanting baboon and pig hearts into humans. Explain why surgeons tried these hearts rather than a turtle's heart.
6. When performing surgery on animals such as cows, veterinarians try not to puncture the stomach because of the danger of infection. Explain what is meant by this statement. Why would it be unwise to completely sterilize the inside and outside of the animal?
7. The metabolic rates of two groups of sheep were measured as the amount of oxygen consumed per hour. One group was sheared before the experiment and the other was not. Explain the results shown below. How do these results support the theory that hair is an evolutionary advantage for endotherms?



EXTENSION

1. Choose a nondomesticated mammal species, and write a report on its classification; habitat; morphology; life cycle; and adaptations for feeding, defense, and reproduction. Discuss its evolution if the information is available. You may wish to visit a zoo to observe the mammal. If possible, include labeled drawings or photographs of the mammal.
2. Read "Mind of a Dog" in *New Scientist,* March 4, 2000, on page 22. How long does dog mitochondrial DNA evidence suggest that humans have lived with dogs? Why does the author think dogs are particularly well suited to living with human society?
3. Obtain a live mammal, such as a mouse, hamster, or gerbil, from a pet store or your school. Get instructions on the care and feeding of the mammal. Then observe the mammal for at least 3 weeks. Take notes on its feeding and sleeping behavior. Share what you learn with your class.

CHAPTER 45 INVESTIGATION

Mammalian Characteristics

OBJECTIVES

- Observe examples of mammals.
- Examine the distinguishing characteristics of mammals.

PROCESS SKILLS

- observing
- inferring

MATERIALS

- hand lens or stereomicroscope
- microscope slide of mammalian skin
- compound light microscope
- mirror
- selection of vertebrate skulls (some mammalian, some nonmammalian)
- field guide to mammals

Background

1. List the distinguishing characteristics of mammals.
2. Define the term *endothermy.*
3. Mammalian skin is characterized by cutaneous glands, such as sebaceous glands and sweat glands, that develop as ingrowths from the epidermis into the dermis.

PART A Mammalian Hair and Skin

1. Use a hand lens to examine several areas of your skin that appear to be hairless. Record your observations in your lab report.
2. Compare the amount of hair on humans with the amount on other mammals that you have seen or read about. What role does hair or fur play in endothermy? What other roles does hair (or whiskers) play in mammals?
3. Examine a slide of mammalian skin under low power. Notice the glands in the skin.
4. Identify the sebaceous glands and the sweat glands in the skin. Sweat glands are found only in mammals, but some mammals do not have them or have few of them. What mechanism for cooling might these other animals have? Which other glands are unique to mammals?

PART B Mammalian Reproduction

5. Look at the photographs of mammals on this page. What characteristics do these animals share?
6. Name the two kinds of mammals represented in the photographs on this page.

PART C Mammalian Mouth and Teeth

7. Use a mirror to look in your mouth, and identify the four kinds of mammalian teeth. Count how many of each you have on one side of your lower jaw.
8. Look at the skulls of several mammals. Identify the four kinds of teeth in each skull, and count them as you counted your own. How are the four types of teeth different from yours?
9. Look at the skulls of several nonmammalian vertebrates. Describe the teeth in each one, and compare them with mammalian teeth.
10. Breathe with your mouth closed. Do you feel a flow of air into your mouth? You have a hard palate (the roof of your mouth) that separates your mouth from your nose.
11. Look again at the different skulls. In which vertebrates do you see a hard palate? What is an advantage of having a hard palate?
12. Compare the jaws of the mammalian skulls with those of the nonmammalian skulls. Notice how the upper jawbone and the lower jawbone connect in each skull. Is there a similarity in the mammalian jaws that distinguishes them from the nonmammalian jaws? Explain.
13. Create a data table, similar to the model below, to record your observations for your lab report. For example, the table below is designed to record observations of differences that you will find among the animal skulls. Remember to allow plenty of space to record your observations.

PART D Vertebrate Diversity

14. Use a field guide to find out more about the following mammal orders: Cetacea, Edentata, Philodota, and Chiroptera. Answer the following questions about these mammals in your lab report:
    a. Cetaceans, such as whales and dolphins, are marine mammals. Except for a few bristles, cetaceans are hairless. Why do you think cetaceans are classified as mammals? How do they survive without hair or fur?
    b. Some mammals—including some members of Edentata (anteaters and armadillos) and Philodota (pangolins)—lack teeth. What characteristics do these animals share with other mammals?
    c. Like many birds, chiropterans (bats) have wings, fly, and are endotherms. What characteristics distinguish these mammals from birds?

Analysis and Conclusions

1. List the characteristics that distinguish mammals from other vertebrates.
2. List several characteristics you observed that most mammals share.
3. Birds are also endotherms. What structure in birds serves the same function as hair in mammals? Explain.
4. Compare the data you collected on the teeth from different animal skulls with the diet of each of those animals. How does the type of teeth that they have help with the particular diet that each animal has?

Further Inquiry

Find out how mammalian brains are different from the brains of other vertebrates. What adaptive advantage might these differences provide mammals?

OBSERVATIONS OF ANIMAL SKULLS

Animal	Mammal?	Number of incisors	Number of canines	Number of premolars	Number of molars	Hard palate?	Jaw