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Biology A

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CHAPTER 1 Plant Evolution and Classification

Chapter Outline

If you take a walk in a damp wooded area in the spring, you might smell this interesting plant before you notice its striking yellow hood. The hood surrounds a stalk covered with tiny flowers. It's an intriguing sight—but don't get too close! It grows on a plant called the skunk cabbage. It's aptly named for its unpleasant odor, which smells like rotten meat. The plant stores food in its fleshy roots all winter so it can grow the hood and flowers in the spring. They emerge from the soil so early that there may still be snow on the ground, but the plant produces enough heat to melt the snow.

Why does the skunk cabbage put so much energy into producing its unusual, smelly flowers? As you will read in this chapter, flowering plants have devised many ways to attract pollinators to their flowers so they can reproduce. The skunk cabbage is no exception. What pollinators do you think its stinky flowers might attract?

1.1 Introduction to the Plant Kingdom

Lesson Objectives

- Identify traits of plants.
- Explain the importance of plants.
- Give an overview of the plant life cycle.
- Outline major events in plant evolution.
- Describe how plants are classified.

Vocabulary

- alternation of generations
- angiosperm
- cone
- flower
- fruit
- gametophyte
- germination
- gymnosperm
- lignin
- ovary
- plant
- rhizoid
- seed
- sporophyte
- vascular tissue
- vegetative reproduction
- weed

Introduction

Like the skunk cabbage, most of the plants you are familiar with produce flowers. However, plants existed for hundreds of millions of years before they evolved flowers. In fact, the earliest plants were different from most modern plants in several important ways. They not only lacked flowers. They also lacked leaves, roots, and stems. You might not even recognize them as plants. So why are the earliest plants placed in the plant kingdom? What traits define a plant?

What Are Plants?

Plants are multicellular eukaryotes with cell walls made of cellulose. Plant cells also have chloroplasts. In addition, plants have specialized reproductive organs. These are structures that produce reproductive cells. Male reproductive organs produce sperm, and female reproductive organs produce eggs. Male and female reproductive organs may be on the same or different plants.

How Do Plants Obtain Food?

Almost all plants make food by photosynthesis. Only about 1 percent of the estimated 300,000 species of plants have lost the ability to photosynthesize. These other species are consumers, many of them predators. How do plants prey on other organisms? The Venus fly trap in **Figure** 1.1 shows one way this occurs.

FIGURE 1.1
Venus fly trap plants use their flowers to trap insects. The flowers secrete enzymes that digest the insects, and then they absorb the resulting nutrient molecules.

What Do Plants Need?

Plants need temperatures above freezing while they are actively growing and photosynthesizing. They also need sunlight, carbon dioxide, and water for photosynthesis. Like most other organisms, plants need oxygen for cellular respiration and minerals to build proteins and other organic molecules. Most plants support themselves above the ground with stiff stems in order to get light, carbon dioxide, and oxygen. Most plants also grow roots down into the soil to absorb water and minerals.

The Importance of Plants

The importance of plants to humans and just about all other life on Earth is staggering. Life as we know it would not be possible without plants. Why are plants so important?

- Plants supply food to nearly all terrestrial organisms, including humans. We eat either plants or other organisms that eat plants.
- Plants maintain the atmosphere. They produce oxygen and absorb carbon dioxide during photosynthesis. Oxygen is essential for cellular respiration for all aerobic organisms. It also maintains the ozone layer that helps protect Earth's life from damaging UV radiation. Removal of carbon dioxide from the atmosphere reduces the greenhouse effect and global warming.
- Plants recycle matter in biogeochemical cycles. For example, through transpiration, plants move enormous amounts of water from the soil to the atmosphere. Plants such as peas host bacteria that fix nitrogen. This makes nitrogen available to all plants, which pass it on to consumers.
- Plants provide many products for human use, such as firewood, timber, fibers, medicines, dyes, pesticides, oils, and rubber.
- Plants create habitats for many organisms. A single tree may provide food and shelter to many species of insects, worms, small mammals, birds, and reptiles (see **Figure** 1.2).

FIGURE 1.2
Red-eyed tree frogs like this one live in banana trees.

We obviously can't live without plants, but sometimes they cause us problems. Many plants are weeds. **Weeds** are plants that grow where people don't want them, such as gardens and lawns. They take up space and use resources, hindering the growth of more desirable plants. People often introduce plants to new habitats where they lack natural predators and parasites. The introduced plants may spread rapidly and drive out native plants. Many plants produce pollen, which can cause allergies. Plants may also produce toxins that harm human health (see **Figure** 1.3).

FIGURE 1.3
Poison ivy causes allergic skin rashes. It's easy to recognize the plant by its arrangement of leaves in groups of three. That's the origin of the old saying, "leaves of three, leave it be."

Life Cycle of Plants

All plants have a characteristic life cycle that includes **alternation of generations**. Plants alternate between haploid and diploid generations. Alternation of generations allows for both asexual and sexual reproduction. Asexual reproduction with spores produces haploid individuals called **gametophytes**. Sexual reproduction with gametes and fertilization produces diploid individuals called **sporophytes**. A typical plant's life cycle is diagrammed in **Figure** 1.4.

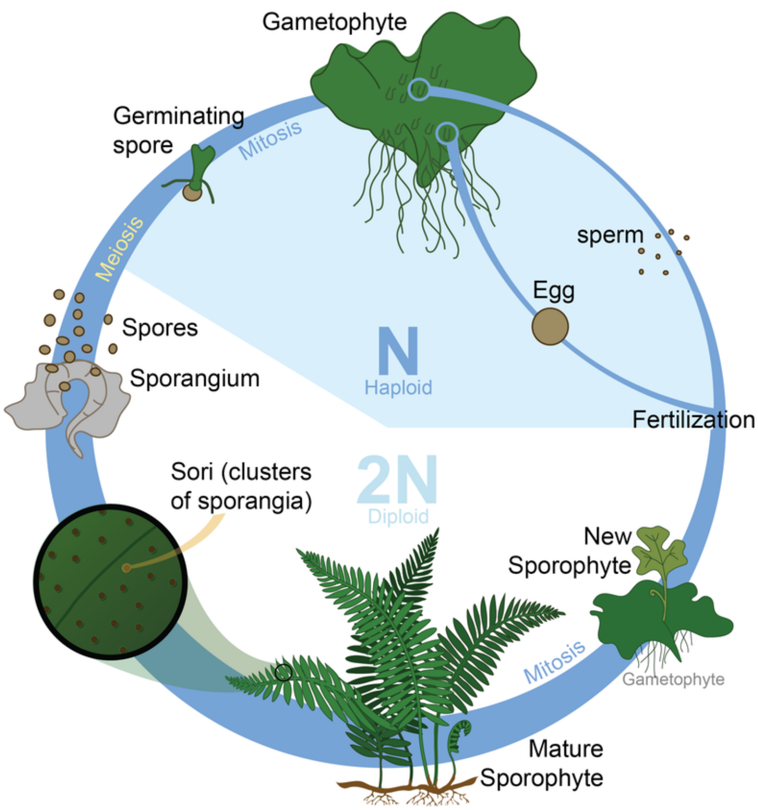


FIGURE 1.4
Life Cycle of Plants. This diagram shows the general life cycle of a plant.

Early plants reproduced mainly with spores and spent most of their life cycle as haploid gametophytes. Spores require little energy and matter to produce, and they grow into new individuals without the need for fertilization. In contrast, most modern plants reproduce with gametes using pollen and seeds, and they spend most of their life cycle as diploid sporophytes. Many modern plants can also reproduce asexually using roots, stems, or leaves. This is called **vegetative reproduction**. One way this can occur is shown in **Figure** 1.5.

FIGURE 1.5
Strawberry plants have horizontal stems called stolons that run over the ground surface. If they take root, they form new plants.

Evolution of Plants

As shown in **Figure** 1.6, plants are thought to have evolved from an aquatic green alga. Later, they evolved important adaptations for land, including vascular tissues, seeds, and flowers. Each of these major adaptations made plants better suited for dry land and much more successful.

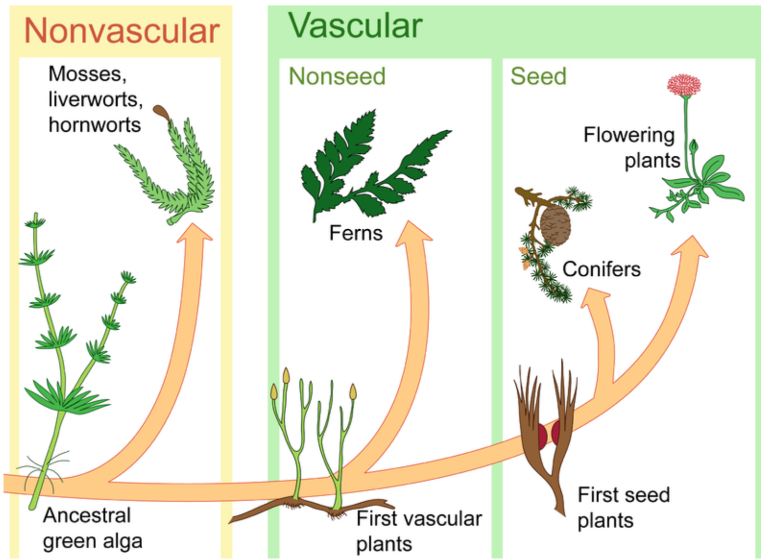


FIGURE 1.6
From a simple, green alga ancestor that lived in the water, plants eventually evolved several major adaptations for life on land.

The Earliest Plants

The earliest plants were probably similar to the stonewort, an aquatic algae pictured in **Figure** 1.7. Unlike most modern plants, stoneworts have stalks rather than stiff stems, and they have hair-like structures called **rhizoids** instead of roots. On the other hand, stoneworts have distinct male and female reproductive structures, which is a plant characteristic. For fertilization to occur, sperm need at least a thin film of moisture to swim to eggs. In all these ways, the first plants may have resembled stoneworts.

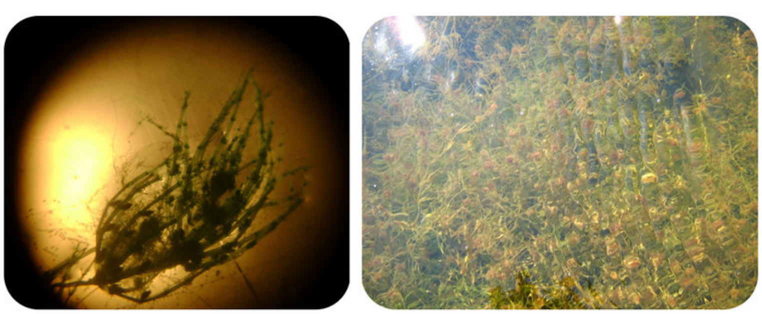


FIGURE 1.7
Modern stoneworts may be similar to the earliest plants. Shown is a field of modern stoneworts (right), and an example from the Charophyta, a division of green algae that includes the closest relatives of the earliest plants (left).

Life on Land

By the time the earliest plants evolved, animals were already the dominant living things in the ocean. Plants were also constrained to the upper layer of water that received enough sunlight for photosynthesis. Therefore, plants never became dominant marine organisms. But when plants moved to land, everything was wide open. Why was the land devoid of other life? Without plants growing on land, there was nothing for other organisms to feed on. Land could not be colonized by other organisms until land plants became established.

Plants may have colonized the land as early as 700 million years ago. The oldest fossils of land plants date back about 470 million years. The first land plants probably resembled modern plants called liverworts, like the one shown in **Figure** 1.8.

FIGURE 1.8
The first land plants may have been similar to liverworts like this one.

Colonization of the land was a huge step in plant evolution. Until then, virtually all life had evolved in the ocean. Dry land was a very different kind of place. The biggest problem was the dryness. Simply absorbing enough water to stay alive was a huge challenge. It kept early plants small and low to the ground. Water was also needed for sexual reproduction, so sperm could swim to eggs. In addition, temperatures on land were extreme and always changing. Sunlight was also strong and dangerous. It put land organisms at high risk of mutations.

Vascular Plants Evolve

Plants evolved a number of adaptations that helped them cope with these problems on dry land. One of the earliest and most important was the evolution of vascular tissues. **Vascular tissues** form a plant's "plumbing system." They carry water and minerals from soil to leaves for photosynthesis. They also carry food (sugar dissolved in water) from photosynthetic cells to other cells in the plant for growth or storage. The evolution of vascular tissues revolutionized the plant kingdom. The tissues allowed plants to grow large and endure periods of drought in harsh land environments. Early vascular plants probably resembled the fern shown in **Figure** 1.9.

In addition to vascular tissues, these early plants evolved other adaptations to life on land, including lignin, leaves, roots, and a change in their life cycle.

- **Lignin** is a tough carbohydrate molecule that is hydrophobic ("water fearing"). It adds support to vascular tissues in stems. It also waterproofs the tissues so they don't leak, which makes them more efficient at transporting fluids. Because most other organisms cannot break down lignin, it helps protect plants from herbivores and parasites.

FIGURE 1.9
Early vascular plants may have looked like this modern fern.

- Leaves are rich in chloroplasts that function as solar collectors and food factories. The first leaves were very small, but leaves became larger over time.
- Roots are vascular organs that can penetrate soil and even rock. They absorb water and minerals from soil and carry them to leaves. They also anchor a plant in the soil. Roots evolved from rhizoids, which nonvascular plants had used for absorption.
- Land plants evolved a dominant diploid sporophyte generation. This was adaptive because diploid individuals are less likely to suffer harmful effects of mutations. They have two copies of each gene, so if a mutation occurs in one gene, they have a backup copy. This is extremely important on land, where there's a lot of solar radiation.

With all these advantages, it's easy to see why vascular plants spread quickly and widely on land. Many nonvascular plants went extinct as vascular plants became more numerous. Vascular plants are now the dominant land plants on Earth.

Seed Plants Emerge

For reproduction, early vascular plants still needed moisture. Sperm had to swim from male to female reproductive organs for fertilization. Spores also needed some water to grow and often to disperse as well. Of course, dryness and other harsh conditions made it very difficult for tiny new offspring plants to survive. With the evolution of seeds in vascular plants, all that changed. Seed plants evolved a number of adaptations that made it possible to reproduce without water. As a result, seed plants were wildly successful. They exploded into virtually all of Earth's habitats.

Why are seeds so adaptive on land? A **seed** contains an embryo and a food supply enclosed within a tough coating. An embryo is a zygote that has already started to develop and grow. Early growth and development of a plant embryo in a seed is called **germination**. The seed protects and nourishes the embryo and gives it a huge head start in the "race" of life. Many seeds can wait to germinate until conditions are favorable for growth. This increases the offspring's chance of surviving even more.

Other reproductive adaptations that evolved in seed plants include ovules, pollen, pollen tubes, and pollination by animals.

- An **ovule** is a female reproductive structure in seed plants that contains a tiny female gametophyte. The

gametophyte produces an egg cell. After the egg is fertilized by sperm, the ovule develops into a seed.

- A grain of pollen is a tiny male gametophyte enclosed in a tough capsule (see **Figure** 1.10). It carries sperm to an ovule while preventing it from drying out. Pollen grains can't swim, but they are very light, so the wind can carry them. Therefore, they can travel through air instead of water.
- Wind-blown pollen might land anywhere and be wasted. Another adaptation solved this problem. Plants evolved traits that attract specific animal pollinators. Like the bee in **Figure** 1.10, a pollinator picks up pollen on its body and carries it directly to another plant of the same species. This greatly increases the chance that fertilization will occur.
- Pollen also evolved the ability to grow a tube, called a pollen tube, through which sperm could be transferred directly from the pollen grain to the egg. This allowed sperm to reach an egg without swimming through a film of water. It finally freed up plants from depending on moisture to reproduce.

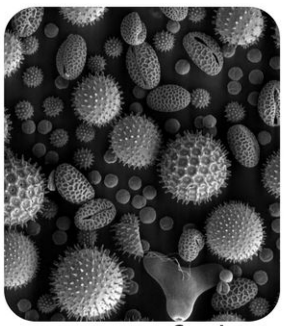


FIGURE 1.10
Individual grains of pollen may have prickly surfaces that help them stick to pollinators such as bees. What other animals pollinate plants?

Seed Plants Diverge

The first seed plants formed seeds in cones. **Cones** are made up of overlapping scales, which are modified leaves (see **Figure** 1.11). Male cones contain pollen, and female cones contain eggs. Seeds also develop in female cones. Modern seed plants that produce seeds in cones are called **gymnosperms**.

Later, seed plants called **angiosperms** evolved. They produce **flowers**, which consist of both male and female reproductive structures. The female reproductive structure in a flower includes an organ called an **ovary**. Eggs form in ovules inside ovaries, which also enclose and protect developing seeds after fertilization occurs. In many species of flowering plants, ovaries develop into **fruits**, which attract animals that disperse the seeds.

Classification of Plants

The scientific classification of modern land plants is under constant revision. Informally, land plants can be classified into the groups listed in **Table** 1.1. The most basic division is between nonvascular and vascular plants. Vascular plants are further divided into those that reproduce without seeds and those that reproduce with seeds. Seed plants, in turn, are divided into those that produce seeds in cones and those that produce seeds in the ovaries of flowers. You can read more about each of these groups of plants in the next lesson.

Major divisions and types of modern land plants are organized in **Table** 1.1. Why do the first five types of plants require a moist habitat?

FIGURE 1.11
Gymnosperms produce seeds in cones (left). Each scale has a seed attached (right).

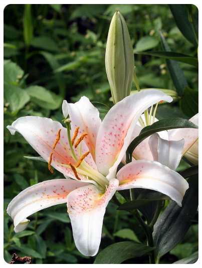
TABLE 1.1: Classification of Living Land Plants

Major Division	Types of Plants	No. of Living Species	Description
Nonvascular Plants			
	Liverworts	7,000	
	Hornworts	150	
	Mosses	10,000	They lack leaves and roots. They have no stems, so they grow low to the ground. They reproduce with spores. They need a moist habitat.

TABLE 1.1: (continued)

Major Division	Types of Plants	No. of Living Species	Description
Vascular Plants			
	Clubmosses	1,200	They have roots and tiny leaves. They have no stems, so they grow low to the ground. They reproduce with spores. They need a moist habitat.
	Ferns	11,000	They have large leaves in fronds. They have stiff stems, so they are tall growing; some are trees. They reproduce with spores. They need a moist habitat.
	Ginkgoes	1	
	Cycads	160	
	Conifers	700	
	Gnetae	70	Most are trees with wood trunks. They have adaptations to dryness such as needle-like leaves. They reproduce with seeds and pollen. They produce seeds in cones.

TABLE 1.1: (continued)

Major Division	Types of Plants	No. of Living Species	Description
	Flowering Plants	258,650	They have tremendous diversity in size, shape, and other characteristics. They reproduce with seeds and pollen. They produce seeds in the ovaries of flowers. Ovaries may develop into fruits, which enhance seed dispersal.

KQED: Albino Redwoods, Ghosts of the Forest

Albino redwood trees? Really? Yes, these pale ghosts that hide amid their gigantic siblings, only a few dozen albino redwood trees are known to exist. They are genetic mutants that lack the chlorophyll needed for photosynthesis. But how and why they survive is a scientific mystery. See http://www.kqed.org/quest/television/science-on-the-spot-albino-redwoods-ghosts-of-the-forest and http://www.kqed.org/quest/blog/2010/11/22/ghostbusters/ to find out about these wonders of the plant kingdom, and how geneticists are trying to understand the redwood genome.

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Lesson Summary

- Plants are multicellular eukaryotes. They have organelles called chloroplasts and cell walls made of cellulose. Plants also have specialized reproductive organs. Almost all plants make food by photosynthesis. Life as we know it would not be possible without plants.
- All plants have a characteristic life cycle that includes alternation of generations. Asexual reproduction with spores produces a haploid gametophyte generation. Sexual reproduction with gametes and fertilization produces a diploid sporophyte generation.

- The earliest plants are thought to have evolved in the ocean from a green alga ancestor. Plants were among the earliest organisms to leave the water and colonize land. The evolution of vascular tissues allowed plants to grow larger and thrive on land. The evolution of seeds and pollen allowed them to reproduce on land without moisture. Flowering plants evolved flowers with ovaries that formed fruits. They have been the most successful plants of all.
- The most basic division of living plants is between nonvascular and vascular plants. Vascular plants are further divided into seedless and seed plants. Seed plants called gymnosperms produce seeds in cones. Seed plants called angiosperms produce seeds in the ovaries of flowers.

Lesson Review Questions

Recall

1. What traits do all plants share?

2. What do plants need?

3. List reasons that plants are important to life on Earth.

4. When is a plant considered a weed?

5. What are vascular tissues? What is their function?

Apply Concepts

6. Draw a diagram of a typical plant life cycle that illustrates the concept of alternation of generations.

Think Critically

7. Explain why life on land was difficult for early plants. Why did plants need to become established on land before other organisms could colonize the land?

8. Compare the different types of plants in the **Classification of Living Land Plants** (**Table** 1.1). Which type of plants would you say is most successful? Support your answer with data from the table.

9. Which major plant adaptation—vascular tissues or seeds—do you think was more important in the evolution of plants? Choose one of the two adaptations, and write a logical argument to support your choice.

10. Compare and contrast gymnosperms and angiosperms, and give an example of each.

Points to Consider

Vascular plants are now the most common plants on Earth. However, nonvascular plants should not be ignored. They were the first plants to evolve, and some still survive today.

- In what ways do you think modern nonvascular plants are different from other types of modern plants? In what ways do you think they are similar?
- How might modern nonvascular plants differ from other eukaryotes, such as fungi?

1.2 Four Types of Modern Plants

Lesson Objectives

- Describe modern nonvascular plants.
- Give an overview of living vascular plants.
- Outline the classification and evolution of seed plants.
- Summarize the adaptations and evolution of flowering plants.

Vocabulary

- bryophyte
- endosperm
- nectar
- petal
- phloem
- pistil
- seed coat
- sepal
- spermatophyte
- stamen
- tracheophyte
- xylem

Introduction

The types of living plants today reflect the evolutionary past of the plant kingdom. From tiny nonvascular mosses to large flowering and fruiting trees, there are modern plants that represent each of the major evolutionary changes that occurred in this important eukaryotic kingdom.

Nonvascular Plants

Nonvascular plants are called **bryophytes**. Despite the dominance of vascular plants today, more than 17,000 species of bryophytes still survive. They include liverworts, hornworts, and mosses.

Characteristics of Nonvascular Plants

Most bryophytes are small. They not only lack vascular tissues; they also lack true leaves, seeds, and flowers. Instead of roots, they have hair-like rhizoids to anchor them to the ground and to absorb water and minerals (see **Figure** 1.12). Bryophytes occupy niches in moist habitats. Without the adaptations of vascular plants, they are not very efficient at absorbing water.

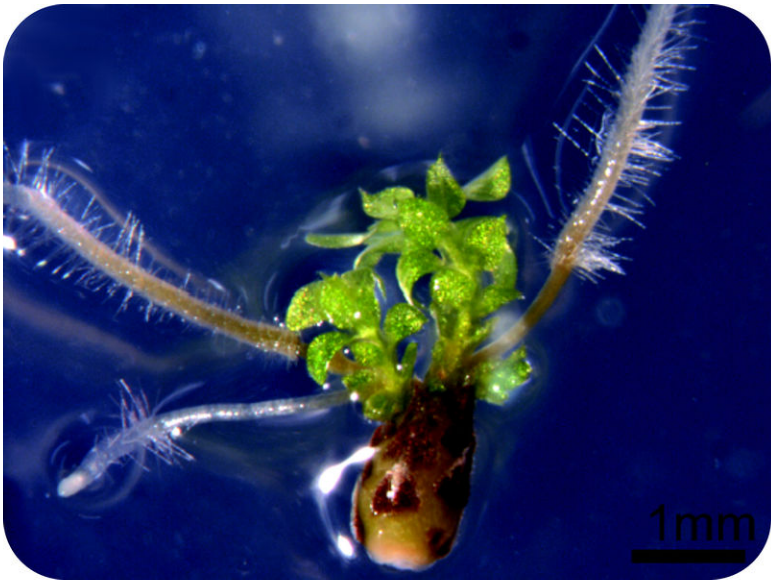

FIGURE 1.12
The rhizoids of a bryophyte (shown in purple) may be so fine that they are just one cell thick.

Bryophytes also depend on moisture to reproduce. Sperm produced by a male gametophyte must swim through a layer of rainwater or dew to reach an egg produced by a female gametophyte. The tiny, diploid sporophyte generation then undergoes meiosis to produce haploid spores. The spores may also need moisture to disperse.

Evolution of Nonvascular Plants

The first nonvascular plants to evolve were the liverworts. The hornworts evolved somewhat later, and mosses apparently evolved last. Of all the bryophytes, mosses are most similar to vascular plants. Presumably, they share the most recent common ancestor with vascular plants.

Diversity of Nonvascular Plants

The three types of modern nonvascular plants are pictured in **Figure** 1.13.

- Liverworts are tiny nonvascular plants that have leaf-like, lobed, or ribbon-like photosynthetic tissues rather than leaves. Their rhizoids are very fine, they lack stems, and they are generally less than 10 centimeters (4 inches) tall. They often grow in colonies that carpet the ground.
- Hornworts are minute nonvascular plants, similar in size to liverworts. They also have very fine rhizoids and lack stems. Their sporophytes are long and pointed, like tiny horns. They rise several centimeters above the gametophytes of the plant.
- Mosses are larger nonvascular plants that have coarser, multicellular rhizoids that are more like roots. They also have tiny, photosynthetic structures similar to leaves that encircle a central stem-like structure. Mosses grow in dense clumps, which help them retain moisture.

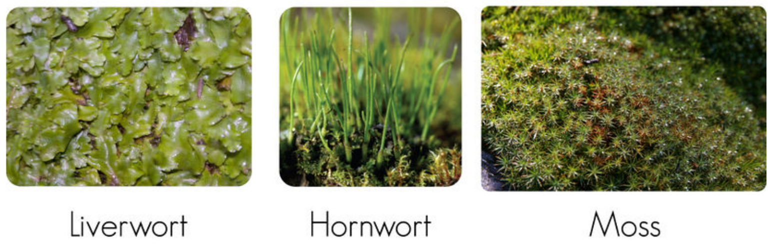

FIGURE 1.13
Liverworts, hornworts, and mosses are modern bryophytes. Liverworts are named for the liver-shaped leaves of some species. Hornworts are named for their horn-like sporophytes.

Vascular Plants

Vascular plants are known as **tracheophytes**, which literally means "tube plants." The earliest vascular plants quickly came to dominate terrestrial ecosystems. Why were they so successful? It was mainly because of their tube-like vascular tissues.

Vascular Tissues

The vascular tissues for which these plants are named are specialized to transport fluid. They consist of long, narrow cells arranged end-to-end, forming tubes. There are two different types of vascular tissues, called xylem and phloem. Both are shown in **Figure** 1.14.

- **Xylem** is vascular tissue that transports water and dissolved minerals from roots to stems and leaves. This type of tissue consists of dead cells that lack end walls between adjacent cells. The side walls are thick and reinforced with lignin, which makes them stiff and water proof.
- **Phloem** is vascular tissue that transports food (sugar dissolved in water) from photosynthetic cells to other parts of the plant for growth or storage. This type of tissue consists of living cells that are separated by end walls with tiny perforations, or holes.

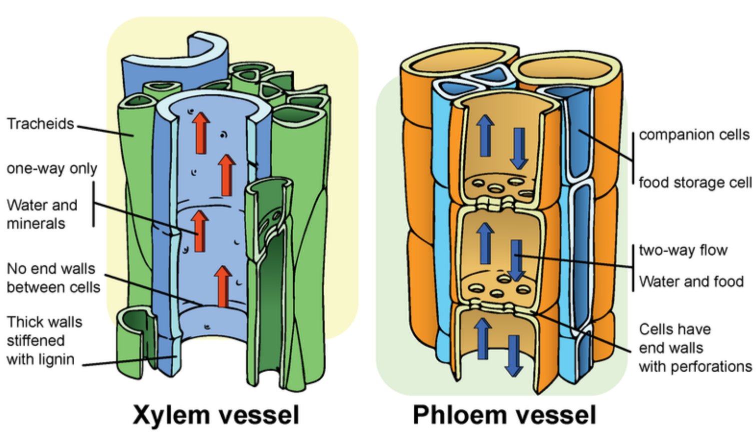

FIGURE 1.14
Xylem and phloem are the two types of vascular tissues in vascular plants.

Evolution of Vascular Plants

The first vascular plants evolved about 420 million years ago. They probably evolved from moss-like bryophyte ancestors, but they had a life cycle dominated by the diploid sporophyte generation. As they continued to evolve, early vascular plants became more plant-like in other ways as well.

- Vascular plants evolved true roots made of vascular tissues. Compared with rhizoids, roots can absorb more water and minerals from the soil. They also anchor plants securely in the ground, so plants can grow larger without toppling over.
- Vascular plants evolved stems made of vascular tissues and lignin. Because of lignin, stems are stiff, so plants can grow high above the ground where they can get more light and air. Because of their vascular tissues, stems keep even tall plants supplied with water so they don't dry out in the air.
- Vascular plants evolved leaves to collect sunlight. At first, leaves were tiny and needle-like, which helped reduce water loss. Later, leaves were much larger and broader, so plants could collect more light.

With their vascular tissues and other adaptations, early vascular plants had the edge over nonvascular plants. The could grow tall and take advantage of sunlight high up in the air. Bryophytes were the photosynthetic pioneers onto land, but early vascular plants were the photosynthetic pioneers into air.

Diversity of Seedless Vascular Plants

Surviving descendants of early vascular plants include clubmosses and ferns. There are 1,200 species of clubmoss and more than 20,000 species of fern. Both types of vascular plants are seedless and reproduce with spores. Two examples are pictured in **Figures** 1.15 and 1.16.

- Clubmosses look like mosses and grow low to the ground. Unlike mosses, they have roots, stems, and leaves, although the leaves are very small.
- Ferns look more like "typical" plants. They have large leaves and may grow very tall. Some even develop into trees.

Seed Plants

Seed plants are called **spermatophytes**. The evolution of seeds by vascular plants was a very big deal. In fact, it was arguably as important as the evolution of vascular tissues. Seeds solved the problem of releasing offspring into a dry world. Once seeds evolved, vascular seed plants and their descendants diversified to fill terrestrial niches everywhere. Today, vascular seed plants dominate Earth.

Parts of a Seed

As shown in **Figure** 1.17, a seed consists of at least three basic parts: the embryo, seed coat, and stored food.

- The embryo develops from a fertilized egg. While still inside the seed, the embryo forms its first leaf (cotyledon) and starts to develop a stem (hypocotyl) and root (radicle).
- The tough **seed coat** protects the embryo and keeps it from drying out until conditions are favorable for germination.
- The stored food in a seed is called **endosperm**. It nourishes the embryo until it can start making food on its own.

FIGURE 1.15
Clubmosses like these are often confused with mosses.

Many seeds have additional structures that help them disperse. Some examples are shown in **Figure** 1.18. Structures may help them travel in the wind or stick to animals. Dispersal of seeds away from parent plants helps reduce competition with the parents and increases the chance of offspring surviving.

Classification of Seed Plants

The two major divisions of seed plants are the gymnosperms (seeds in cones) and angiosperms (seeds in ovaries of flowers). **Figure** 1.19 shows how the seeds of gymnosperms and angiosperms differ. Do you see the main difference between the two seeds? The angiosperm seed is surrounded by an ovary.

There are only about 1,000 living species of gymnosperms, whereas there are hundreds of thousands of living species of angiosperms. Because angiosperms are so numerous and diverse, they are described separately below. Living gymnosperms are typically classified in the divisions described in **Table** 1.2. Most modern gymnosperms are trees with woody trunks. The majority are conifers such as pine trees.

TABLE 1.2: Classification of Living Gymnosperms

	Division	Description
	Ginkgoes	There is only one living species (Ginkgo biloba); some living trees are more than 2000 years old; they originated in Asia but now are cultivated all over the world; they have been used for medicines for thousands of years.

TABLE 1.2: (continued)

	Division	Description
	Conifers	There are more than 700 living species; most are trees such as pines with needle-like leaves; they are often the dominant plants in their habitats; they are valuable to humans for paper and timber.
	Cycads	There are about 300 living species; they are typically trees with stout trunks and fern-like leaves; they live only in tropical and subtropical climates; they have large, brightly-colored seed cones to attract animal pollinators.
	Gnetae	There are fewer than 100 living species; most are woody vines with evergreen leaves; they live mainly in tropical climates; they are the least well known gymnosperms but the most similar to angiosperms.

FIGURE 1.16

There's no confusing ferns with mosses. Why do these ferns look more plant-like?

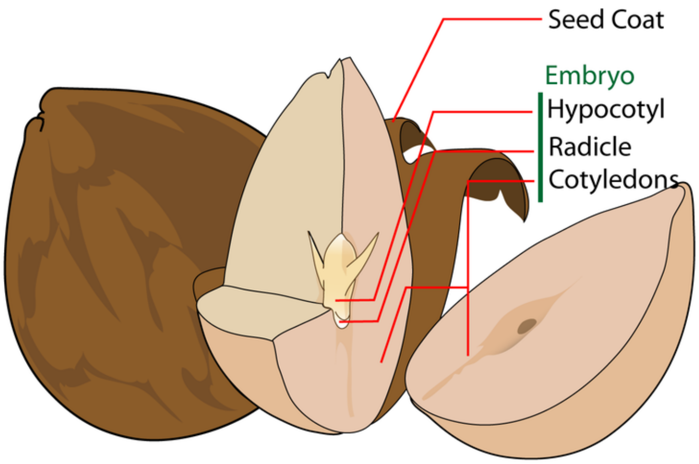

FIGURE 1.17
A typical plant seed, like this avocado seed, contains an embryo, seed coat, and endosperm. How does each part contribute to the successful development of the new plant?

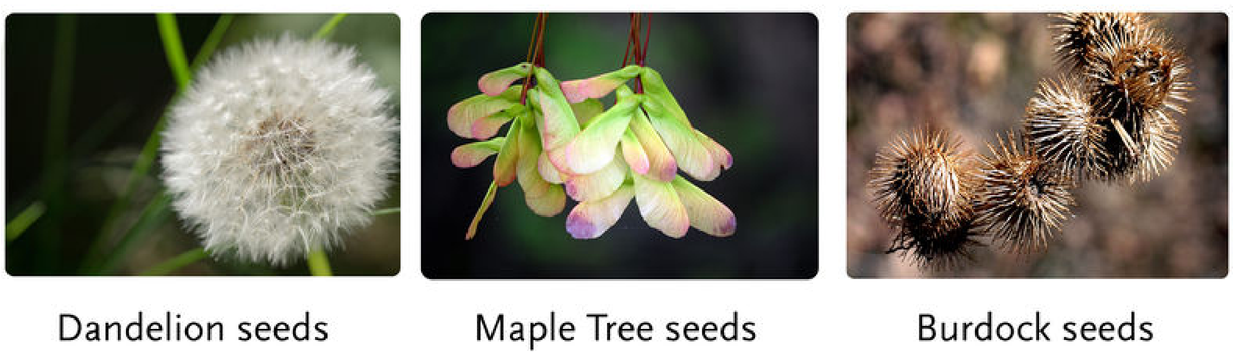

FIGURE 1.18
Dandelion seeds have tiny "parachutes." Maple seeds have "wings" that act like little gliders. Burdock seeds are covered with tiny hooks that cling to animal fur.

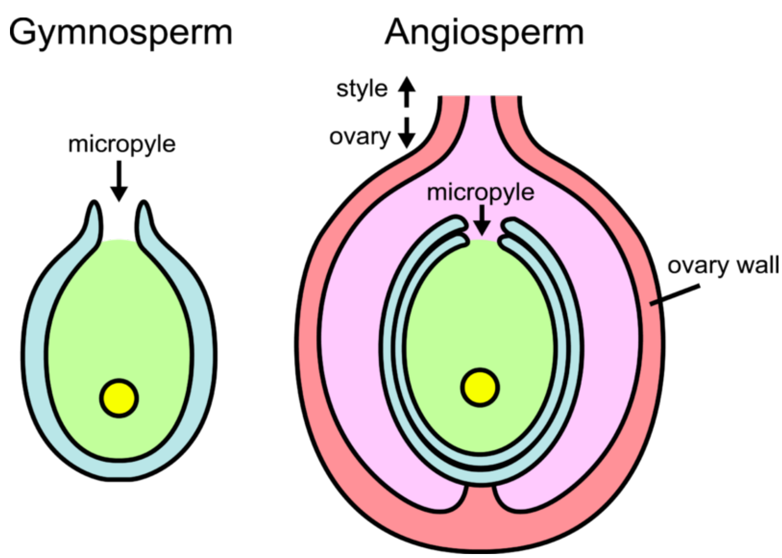

FIGURE 1.19

In gymnosperms, a seed develops on the scale of a cone. Only an angiosperm seed develops inside an ovary.

Evolution of Seed Plants

The earliest seed plants probably evolved close to 300 million years ago. They were similar to modern ginkgoes and reproduced with pollen and seeds in cones. Early seed plants quickly came to dominate forests during the Mesozoic Era, or Age of the Dinosaurs, about 250 to 65 million years ago.

As seed plants continued to evolve, Earth's overall climate became drier, so early seed plants evolved adaptations to help them live with low levels of water. Some also evolved adaptations to cold. They had woody trunks and needle-like, evergreen leaves covered with a thick coating of waxy cuticle to reduce water loss. Some of the trees were huge, like today's giant sequoia, a modern conifer (see **Figure** 1.20).

FIGURE 1.20
The person standing at the foot of this giant sequoia show just how enormous the tree is. Some early seed plants also grew very large.

Eventually, some gymnosperms started to evolve angiosperm-like traits. For example, cycad ancestors were the first plants to use insects as pollinators. They also used birds and monkeys to disperse their brightly colored seeds. Of modern gymnosperms, Gnetae probably share the most recent common ancestor with angiosperms. Among other similarities, Gnetae produce **nectar**, a sweet, sugary liquid that attracts insect pollinators. Most modern flowering plants also produce nectar.

Flowering Plants

Angiosperms, or flowering seed plants, form seeds in ovaries. As the seeds develop, the ovaries may develop into fruits. Flowers attract pollinators, and fruits encourage animals to disperse the seeds.

Parts of a Flower

A flower consists of male and female reproductive structures. The main parts of a flower are shown in **Figure** 1.21. They include the stamen, pistil, petals, and sepals.

- The **stamen** is the male reproductive structure of a flower. It consists of a stalk-like filament that ends in an anther. The anther contains pollen sacs, in which meiosis occurs and pollen grains form. The filament raises the anther up high so its pollen will be more likely to blow in the wind or be picked up by an animal pollinator.

- The **pistil** is the female reproductive structure of a flower. It consists of a stigma, style, and ovary. The stigma is raised and sticky to help it catch pollen. The style supports the stigma and connects it to the ovary, which contains the egg. **Petals** attract pollinators to the flower. Petals are often brightly colored so pollinators will notice them.
- **Sepals** protect the developing flower while it is still a bud. Sepals are usually green, which camouflages the bud from possible consumers.

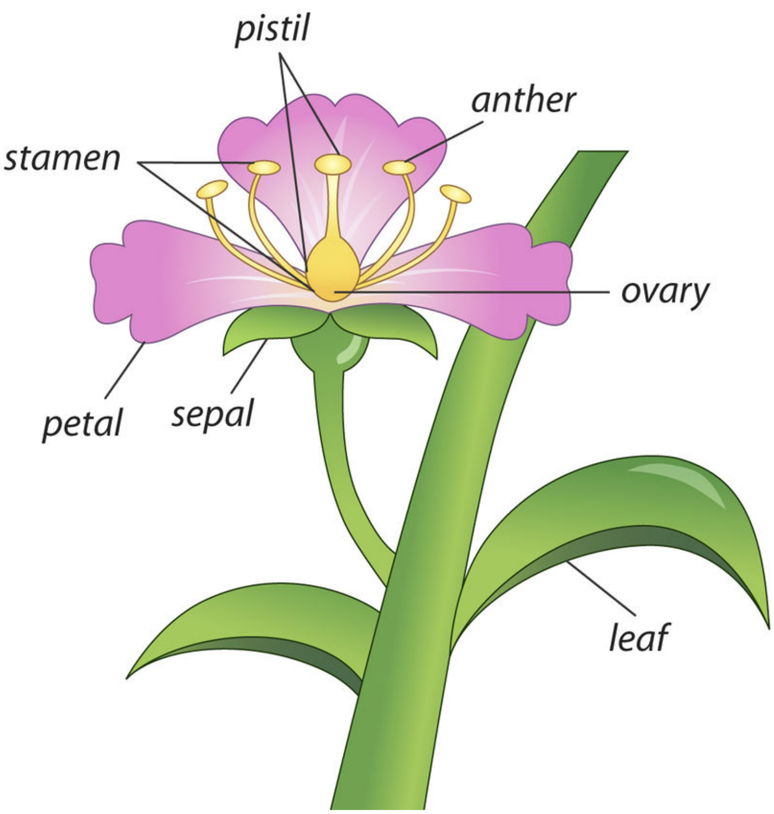

FIGURE 1.21
A flower includes both male and female reproductive structures.

Flowers and Pollinators

Many flowers have bright colors, strong scents, and sweet nectar to attract animal pollinators. They may attract insects, birds, mammals, and even reptiles. While visiting a flower, a pollinator picks up pollen from the anthers. When the pollinator visits the next flower, some of the pollen brushes off on the stigma. This allows cross-pollination, which increases genetic diversity.

See *The beauty of pollination* at http://www.youtube.com/watch?v=xHkq1edcbk4 for an amazing look at this process.

MEDIA
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Other Characteristics of Flowering Plants

Although flowers and their components are the major innovations of angiosperms, they are not the only ones. Angiosperms also have more efficient vascular tissues. In addition, in many flowering plants, the ovaries ripen into fruits. Fruits are often brightly colored, so animals are likely to see and eat them and disperse their seeds (see **Figure** 1.22).

FIGURE 1.22
Brightly colored fruits attract animals that may disperse their seeds. It's hard to miss the bright red apples on these trees.

Evolution of Flowering Plants

Flowering plants are thought to have evolved at least 200 million years ago from gymnosperms like Gnetae. The earliest known fossils of flowering plants are about 125 million years old. The fossil flowers have male and female reproductive organs but no petals or sepals.

Scientists think that the earliest flowers attracted insects and other animals, which spread pollen from flower to flower. This greatly increased the efficiency of fertilization over wind-spread pollen, which might or might not actually land on another flower. To take better advantage of this "animal labor," plants evolved traits such as brightly colored petals to attract pollinators. In exchange for pollination, flowers gave the pollinators nectar.

Giving free nectar to any animal that happened to come along was not an efficient use of resources. Much of the pollen might be carried to flowers of different species and therefore wasted. As a result, many plants evolved ways to "hide" their nectar from all but very specific pollinators, which would be more likely to visit only flowers of the same species. For their part, animal pollinators co-evolved traits that allowed them to get to the hidden nectar. Two examples of this type of co-evolution are shown in **Figure** 1.23.

Some of the most recent angiosperms to evolve are grasses. Humans started domesticating grasses such as wheat about 10,000 years ago. Why grasses? They have many large, edible seeds that contain a lot of nutritious stored food. They are also relatively easy to harvest. Since then, humans have helped shaped the evolution of grasses, as illustrated by the example in **Figure** 1.24. Grasses supply most of the food consumed by people worldwide. What other grass seeds do you eat?

FIGURE 1.23
The bat is active at night, so bright night-blooming flowers attract it. The humming-bird hawk-moth has a long needle-like mouthpart (called a proboscis) to reach nectar at the bottom of the tube-shaped flowers. In each case, the flowering plant and its pollinator co-evolved to become better suited for their roles in the symbiotic relationship.

FIGURE 1.24
The plant on the left, called teosinte, is the ancestor of modern, domesticated corn, shown on the right. An intermediate stage is pictured in the middle. How were humans able to change the plant so dramatically?

Classification of Flowering Plants

There are more than a quarter million species of flowering plants, and they show tremendous diversity. Nonetheless, almost all flowering plants fall into one of three major groups: monocots, eudicots, or magnolids. The three groups differ in several ways. For example, monocot embryos form just one cotyledon, whereas eudicot and magnolid embryos form two cotyledons. The arrangement of their vascular tissues is also different. Examples of the three groups of flowering plants are given in **Table** 1.3.

TABLE 1.3: Groups of Living Angiosperms

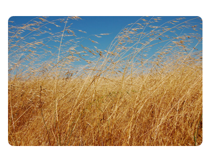
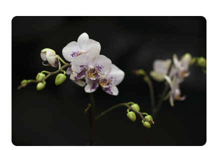
Group	Sample Families	Sample Families
Monocots	Grasses 	Orchids 

TABLE 1.3: (continued)

Group	Sample Families	Sample Families
Eudicots	Daisies 	Peas 
Magnolids	Magnolias 	Avocados 

Lesson Summary

- Nonvascular plants are called bryophytes. They include liverworts, hornworts, and mosses. They lack roots, stems, and leaves. They are low-growing, reproduce with spores, and need a moist habitat.
- Vascular plants are known as tracheophytes. Vascular tissues include xylem and phloem. They allow plants to grow tall in the air without drying out. Vascular plants also have roots, stems, and leaves.
- Most vascular plants are seed plants, or spermatophytes. They reproduce with seeds and pollen. Some modern seed plants are gymnosperms that produce seeds in cones.
- Most modern seed plants are angiosperms that produce seeds in the ovaries of flowers. Ovaries may develop into fruits. Flowers attract pollinators, and fruits are eaten by animals, which help disperse the seeds.

Lesson Review Questions

Recall

1. Describe nonvascular plants.

2. Identify the parts of a seed and the role of each part.

3. Name and describe the division of gymnosperms.

4. Describe the male and female reproductive structures of flowers and their functions.

5. State how fruits help flowering plants reproduce.

Apply Concepts

6. Charles Darwin predicted the existence of a moth with a very long "tongue" after he discovered a species of night-blooming flowers with extremely long, tube-shaped blooms. About 50 years after Darwin died, such a moth was discovered. Apply lesson concepts to explain the basis for Darwin's prediction.

Think Critically

7. Compare and contrast xylem and phloem.
8. How did vascular tissues and lignin allow vascular plants to be "photosynthetic pioneers into air"?
9. Explain how flowering plants and their animal pollinators co-evolved.

Points to Consider

In this chapter, you read about the evolution and classification of plants. In the next chapter, you can read more about the special cells, tissues, and organs of plants that make them such important and successful organisms.

- How do you think plant cells differ from the cells of other eukaryotes, such as animals? What unique structures do plant cells contain?
- Besides vascular tissues, what other types of tissues do you think plants might have?

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Chapter 2 Plant Biology

Chapter Outline

This lush green landscape is thickly carpeted with trees and myriad of other plants. Much of Earth's land is dominated by plants. Yet compared to our active existence as animals, plants are—literally—rooted to the ground. Their sedentary lives may seem less interesting than the active lives of animals, but plants are very busy doing extremely important work. All plants are chemical factories. Each year, they transform huge amounts of carbon (from carbon dioxide) into food for themselves and virtually all other land organisms.

Plants are complex organisms that carry out complex tasks. But unlike animals, they don't have nerves, bones, or muscles to do their work. How do plants do it? Read on to find out.

2.1 Plant Tissues and Growth

Lesson Objectives

- Describe plant cell structures, and list types of plant cells.
- Compare and contrast different types of plant tissues.
- Explain how plants grow.

Vocabulary

- cuticle
- dermal tissue
- ground tissue
- meristem

Introduction

Like animals, plants have organs that are specialized to carry out complex functions. An organ is a structure composed of more than one type of tissue. A tissue, in turn, is a group of cells of the same kind that do the same job. In this lesson, you will read about the tissues that do the important work of plants. The cells that make up plant tissues are described first.

Plant Cells

Plant cells resemble other eukaryotic cells in many ways. For example, they are enclosed by a plasma membrane and have a nucleus and other membrane-bound organelles. A typical plant cell is represented by the diagram in **Figure** 2.1.

Plant Cell Structures

Structures found in plant cells but not animal cells include a large central vacuole, cell wall, and plastids such as chloroplasts.

- The large central vacuole is surrounded by its own membrane and contains water and dissolved substances. Its primary role is to maintain pressure against the inside of the cell wall, giving the cell shape and helping to support the plant.
- The cell wall is located outside the cell membrane. It consists mainly of cellulose and may also contain lignin, which makes it more rigid. The cell wall shapes, supports, and protects the cell. It prevents the cell from absorbing too much water and bursting. It also keeps large, damaging molecules out of the cell.

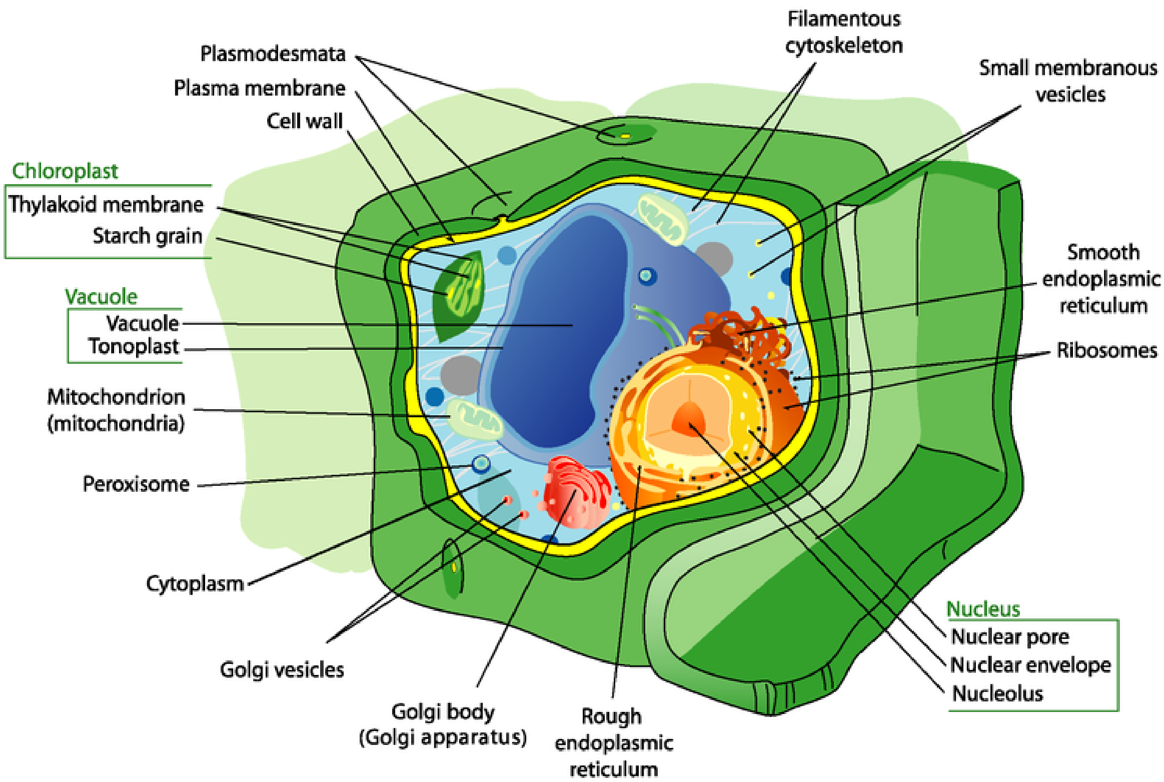

FIGURE 2.1
Plant cells have all the same structures as animal cells, plus some additional structures. Can you identify the unique plant structures in the diagram?

- Plastids are membrane-bound organelles with their own DNA. Examples are chloroplasts and chromoplasts. Chloroplasts contain the green pigment chlorophyll and carry out photosynthesis. Chromoplasts make and store other pigments. They give flower petals their bright colors.

Types of Plant Cells

There are three basic types of cells in most plants. The three types are described in **Table** 2.1. The different types of plant cells have different structures and functions.

TABLE 2.1: Types of Plant Cells

Type of Cell	Structure	Functions	Example

TABLE 2.1: (continued)

Type of Cell	Structure	Functions	Example
Parenchymal	cube-shaped loosely packed thin-walled relatively unspecialized contain chloroplasts	photosynthesis cellular respiration storage	food storage tissues of potatoes 
Collenchymal	elongated irregularly thickened walls	support wind resistance	*strings* running through a stalk of celery 
Sclerenchymal	very thick cell walls containing lignin	support strength	tough fibers in jute (used to make rope) 

Plant Tissues

All three types of plant cells are found in most plant tissues. Three major types of plant tissues are dermal, ground, and vascular tissues.

Dermal Tissue

Dermal tissue covers the outside of a plant in a single layer of cells called the epidermis. You can think of the epidermis as the plant's skin. It mediates most of the interactions between a plant and its environment. Epidermal cells secrete a waxy substance called **cuticle**, which coats, waterproofs, and protects the above-ground parts of plants. Cuticle helps prevent water loss, abrasions, infections, and damage from toxins.

Ground Tissue

Ground tissue makes up much of the interior of a plant and carries out basic metabolic functions. Ground tissue in stems provides support and may store food or water. Ground tissues in roots may also store food.

Vascular Tissue

Vascular tissue runs through the ground tissue inside a plant. It consists of xylem and phloem, which transport fluids. Xylem and phloem are packaged together in bundles, as shown in **Figure** 2.2.

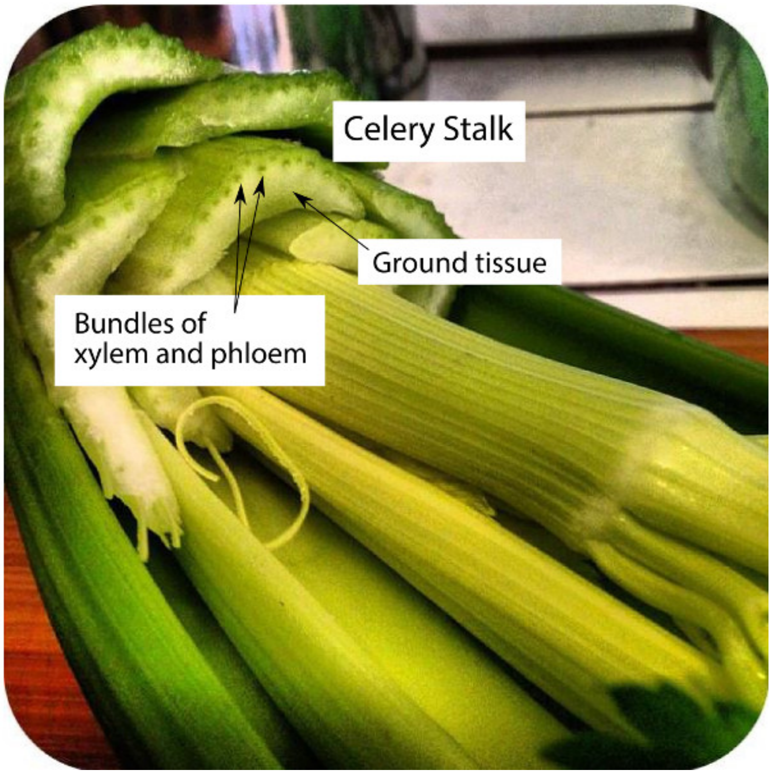

FIGURE 2.2
Bundles of xylem and phloem run through the ground tissue inside this stalk of celery. What function do these tissues serve?

Growth of Plants

Most plants continue to grow throughout their lives. Like other multicellular organisms, plants grow through a combination of cell growth and cell division. Cell growth increases cell size, while cell division (mitosis) increases the number of cells. As plant cells grow, they also become specialized into different cell types through cellular differentiation. Once cells differentiate, they can no longer divide. How do plants grow or replace damaged cells after that?

The key to continued growth and repair of plant cells is **meristem**. Meristem is a type of plant tissue consisting of undifferentiated cells that can continue to divide and differentiate. Meristem at the tips of roots and stems allows them to grow in length. This is called primary growth. Meristem within and around vascular tissues allows growth in width. This is called secondary growth.

Lesson Summary

- Plants have eukaryotic cells with large central vacuoles, cell walls containing cellulose, and plastids such as chloroplasts and chromoplasts. Different types of plant cells include parenchymal, collenchymal, and

sclerenchymal cells. The three types differ in structure and function.

- The three types of plant cells are found in each of the major types of plant tissues: dermal, ground, and vascular tissues. Dermal tissue covers the outside of a plant in a single layer of cells called the epidermis. It mediates most of the interactions between a plant and its environment. Ground tissue makes up most of the interior of a plant. It carries out basic metabolic functions and stores food and water. Vascular tissue runs through the ground tissue inside a plant. It consists of bundles of xylem and phloem, which transport fluids throughout the plant.
- Most plants continue to grow as long as they live. They grow through a combination of cell growth and cell division (mitosis). The key to plant growth is meristem, a type of plant tissue consisting of undifferentiated cells that can continue to divide and differentiate. Meristem allows plant stems and roots to grow longer (primary growth) and wider (secondary growth).

Lesson Review Questions

Recall

1. Identify three structures found in plant cells but not animal cells. What is the function of each structure?

2. Describe parenchymal plant cells and state their functions.

3. What is cuticle? What is its role?

4. Define meristem.

Apply Concepts

5. An important concept in biology is that form follows function. In other words, the structure of an organism, or part of an organism, depends on its function. Apply this concept to plants, and explain why plants have different types of cells and tissues.

Think Critically

6. Compare and contrast dermal, ground, and vascular tissues of plants.

7. Explain why plants need special tissues for growth.

Points to Consider

Plants are complex organisms with tissues organized into organs.

- What organs do you think plants might have?
- Think about human organs, such as the heart, stomach, lungs, and kidneys. What are their functions? Do you think plants might have organs with similar functions as these human organs?

2.2 Plant Organs: Roots, Stems, and Leaves

Lesson Objectives

- Outline the structure, function, and growth of roots.
- Give an overview of stem diversity and how stems function and grow.
- Describe leaf variation, and explain how leaves make food and change seasonally.

Vocabulary

- bark
- deciduous plant
- evergreen plant
- fibrous root
- mesophyll
- root hair
- root system
- stomata (singular, stoma)
- taproot

Introduction

Plants have specialized organs that help them survive and reproduce in a great diversity of habitats. Major organs of most plants include roots, stems, and leaves.

Roots

Roots are important organs in all vascular plants. Most vascular plants have two types of roots: primary roots that grow downward and secondary roots that branch out to the side. Together, all the roots of a plant make up a **root system**.

Root Systems

There are two basic types of root systems in plants: taproot systems and fibrous root systems. Both are illustrated in **Figure** 2.3.

- Taproot systems feature a single, thick primary root, called the **taproot**, with smaller secondary roots growing out from the sides. The taproot may penetrate as many as 60 meters (almost 200 feet) below the ground

surface. It can plumb very deep water sources and store a lot of food to help the plant survive drought and other environmental extremes. The taproot also anchors the plant very securely in the ground.

- Fibrous root systems have many small branching roots, called fibrous roots, but no large primary root. The huge number of threadlike roots increases the surface area for absorption of water and minerals, but **fibrous roots** anchor the plant less securely.

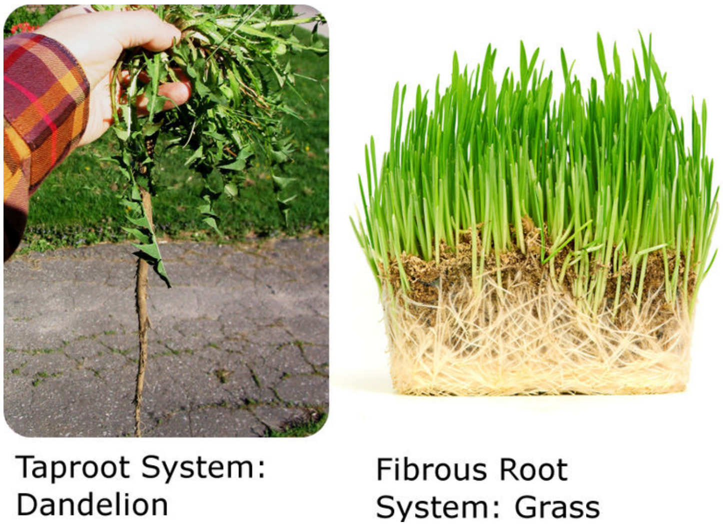

FIGURE 2.3
Dandelions have taproot systems; grasses have fibrous root systems.

Root Structures and Functions

As shown in **Figure** 2.4, the tip of a root is called the root cap. It consists of specialized cells that help regulate primary growth of the root at the tip. Above the root cap is primary meristem, where growth in length occurs.

Above the meristem, the rest of the root is covered with a single layer of epidermal cells. These cells may have **root hairs** that increase the surface area for the absorption of water and minerals from the soil. Beneath the epidermis is ground tissue, which may be filled with stored starch. Bundles of vascular tissues form the center of the root. Waxy layers waterproof the vascular tissues so they don't leak, making them more efficient at carrying fluids. Secondary meristem is located within and around the vascular tissues. This is where growth in thickness occurs.

The structure of roots helps them perform their primary functions. What do roots do? They have three major jobs: absorbing water and minerals, anchoring and supporting the plant, and storing food.

- Absorbing water and minerals: Thin-walled epidermal cells and root hairs are well suited to absorb water and dissolved minerals from the soil. The roots of many plants also have a mycorrhizal relationship with fungi for greater absorption.
- Anchoring and supporting the plant: Root systems help anchor plants to the ground, allowing plants to grow tall without toppling over. A tough covering may replace the epidermis in older roots, making them ropelike and even stronger. As shown in **Figure** 2.5, some roots have unusual specializations for anchoring plants.
- Storing food: In many plants, ground tissues in roots store food produced by the leaves during photosynthesis. The bloodroot shown in **Figure** 2.5 stores food in its roots over the winter.

Root Growth

Roots have primary and secondary meristems for growth in length and width. As roots grow longer, they always grow down into the ground. Even if you turn a plant upside down, its roots will try to grow downward. How do

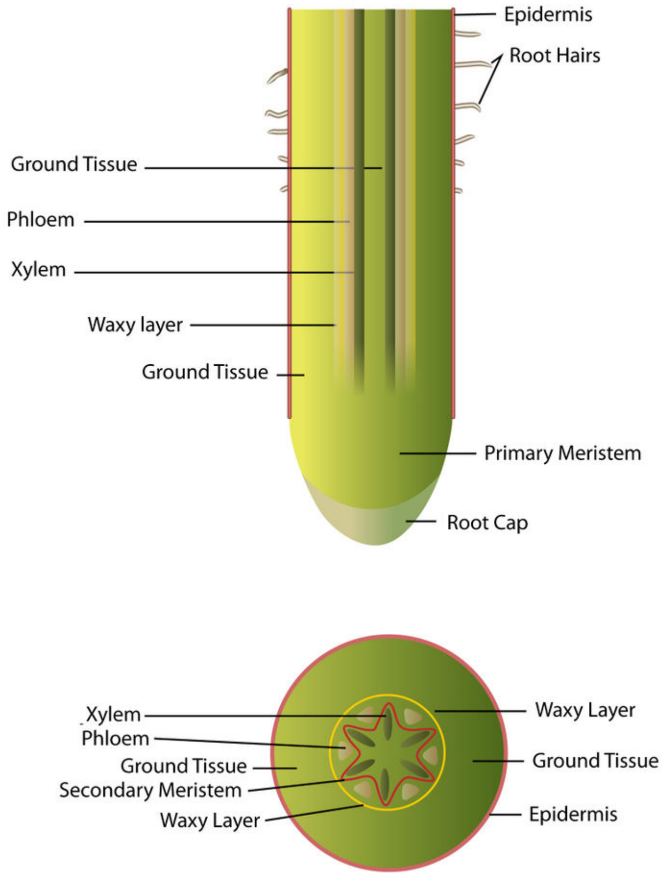

FIGURE 2.4
A root is a complex organ consisting of several types of tissue. What is the function of each tissue type?

FIGURE 2.5
Mangrove roots are like stilts, allowing mangrove trees to rise high above the water. The trunk and leaves are above water even at high tide. A bloodroot plant uses food stored over the winter to grow flowers in the early spring.

roots "know" which way to grow? How can they tell down from up? Specialized cells in root caps are able to detect gravity. The cells direct meristem in the tips of roots to grow downward toward the center of Earth. This is generally adaptive for land plants. Can you explain why?

As roots grow thicker, they can't absorb water and minerals as well. However, they may be even better at transporting fluids, anchoring the plant, and storing food (see **Figure** 2.6).

FIGURE 2.6
Secondary growth of sweet potato roots provides more space to store food. Roots store sugar from photosynthesis as starch. What other starchy roots do people eat?

Stems

In vascular plants, stems are the organs that hold plants upright so they can get the sunlight and air they need. Stems also bear leaves, flowers, cones, and secondary stems. These structures grow at points called nodes (shown in **Figure** 2.7). At each node, there is a bud of meristem tissue that can divide and specialize to form a particular structure.

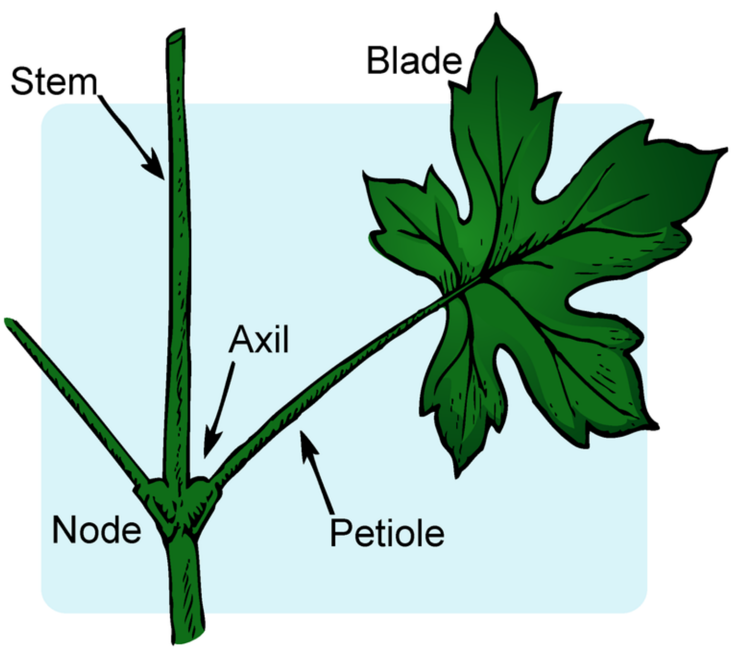

FIGURE 2.7
The stem of a vascular plant has nodes where leaves and other structures may grow.

Another vital function of stems is transporting water and minerals from roots to leaves and carrying food from leaves to the rest of the plant. Without this connection between roots and leaves, plants could not survive high above ground in the air. In many plants, stems also store food or water during cold or dry seasons.

Stem Diversity

Stems show variation because many stems are specialized. **Figure** 2.8 shows examples of stem specialization. With specialized stems, plants can exploit a diversity of niches in virtually all terrestrial ecosystems.

FIGURE 2.8
Stem specializations such as these let plants grow in many different habitats.

Stem Tissues and Functions

Like roots, the stems of vascular plants are made of dermal, vascular, and ground tissues.

- A single-celled layer of epidermis protects and waterproofs the stem and controls gas exchange.

- In trees, some of the epidermal tissue is replaced by bark. **Bark** is a combination of tissues that provides a tough, woody external covering on the stems of trees. The inner part of bark is alive and growing; the outer part is dead and provides strength, support, and protection.
- Ground tissue forms the interior of the stem. The large central vacuoles of ground tissue cells fill with water to support the plant. The cells may also store food.
- Bundles of vascular tissue run through the ground tissue of a stem and transport fluids. Plants may vary in how these bundles are arranged.

Stem Growth

The stems of all vascular plants get longer through primary growth. This occurs in primary meristem at the tips and nodes of the stems. Most stems also grow in thickness through secondary growth. This occurs in secondary meristem, which is located in and around the vascular tissues. Secondary growth forms secondary vascular tissues and bark. In many trees, the yearly growth of new vascular tissues results in an annual growth ring like the one in **Figure** 2.9. When a tree is cut down, the rings in the trunk can be counted to estimate the tree's age.

FIGURE 2.9

The number of rings in this cross-section of tree trunk show how many years the tree lived. What does each ring represent?

Leaves

Leaves are the keys not only to plant life but to all terrestrial life. The primary role of leaves is to collect sunlight and make food by photosynthesis. Despite the fundamental importance of the work they do, there is great diversity in the leaves of plants. However, given the diversity of habitats in which plants live, it's not surprising that there is no single best way to collect solar energy for photosynthesis.

Leaf Variation

Leaves may vary in size, shape, and their arrangement on stems. Nonflowering vascular plants have three basic types of leaves: microphylls ("tiny leaves"), fronds, and needles. **Figure** 2.10 describes each type.

Flowering vascular plants also have diverse leaves. However, the leaves of all flowering plants have two basic parts in common: the blade and petiole (see **Figure** 2.7). The blade of the leaf is the relatively wide, flat part of the leaf that gathers sunlight and undergoes photosynthesis. The petiole is the part that attaches the leaf to a stem of the plant. This occurs at a node.

Flowering plant leaves vary in how the leaves are arranged on the stem and how the blade is divided. This is illustrated in **Figure** 2.11. Generally, the form and arrangement of leaves maximizes light exposure while conserving water, reducing wind resistance, or benefiting the plant in some other way in its particular habitat.

- Leaves arranged in whorls encircle upright stems at intervals. They collect sunlight from all directions.

FIGURE 2.10
Leaf variation in nonflowering plants reflects their evolutionary origins. Can you explain how?

- Leaves arranged in basal rosettes take advantage of warm temperatures near the ground.
- Leaves arranged in alternate or opposing pairs collect light from above. They are typically found on plants with a single, upright stem.
- The blades of simple leaves are not divided. This provides the maximum surface area for collecting sunlight.
- The blades of compound leaves are divided into many smaller leaflets. This reduces wind resistance and water loss.

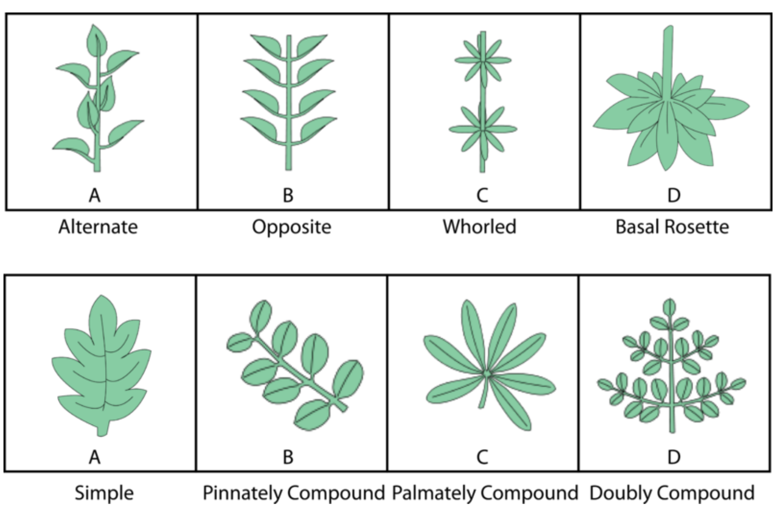

FIGURE 2.11
Leaf variation in flowering plants may include variations in the arrangement of leaves and the divisions of the blade.

Factories for Photosynthesis

You can think of a single leaf as a photosynthesis factory. A factory has specialized machines to produce a product. It's also connected to a transportation system that supplies it with raw materials and carries away the finished product. In all these ways, a leaf resembles a factory. The cross section of a leaf in **Figure** 2.12 lets you look inside a leaf "factory."

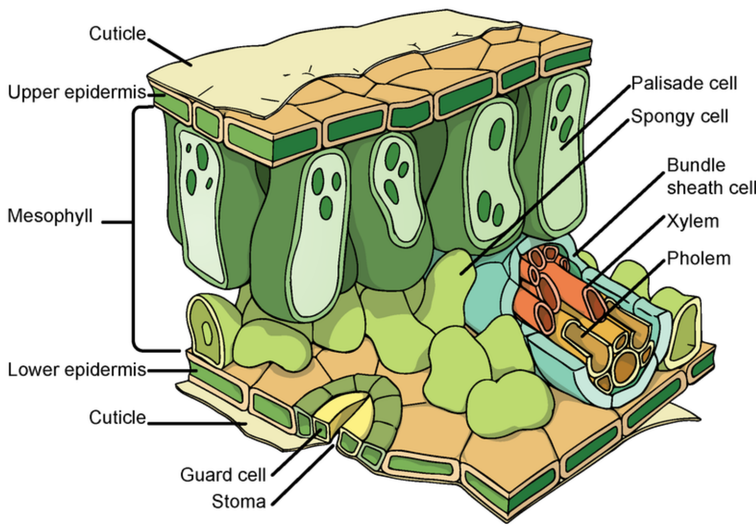

FIGURE 2.12
There's more to a leaf than meets the eye. Can you identify the functions of each of the labeled structures in the diagram?

A leaf consists of several different kinds of specialized tissues that work together to make food by photosynthesis. The major tissues are mesophyll, veins, and epidermis.

- **Mesophyll** makes up most of the leaf's interior. This is where photosynthesis occurs. Mesophyll consists mainly of parenchymal cells with chloroplasts.
- Veins are made primarily of xylem and phloem. They transport water and minerals to the cells of leaves and carry away dissolved sugar.
- The epidermis of the leaf consists of a single layer of tightly-packed dermal cells. They secrete waxy cuticle to prevent evaporation of water from the leaf. The epidermis has tiny pores called **stomata** (singular, stoma) that control transpiration and gas exchange with the air. **Figure** 2.13 explains how stomata carry out this vital function.

Seasonal Changes in Leaves

Even if you don't live in a place where leaves turn color in the fall, no doubt you've seen photos of their "fall colors" (see **Figure** 2.14). The leaves of many plants turn from green to other, glorious colors during autumn each year. The change is triggered by shorter days and cooler temperatures. Leaves respond to these environmental stimuli by producing less chlorophyll. This allows other leaf pigments—such as oranges and yellows—to be seen.

After leaves turn color in the fall, they may all fall off the plant for the winter. Plants that shed their leaves seasonally each year are called **deciduous plants**. Shedding leaves is a strategy for reducing water loss during seasons of extreme dryness. On the downside, the plant must grow new leaves in the spring, and that takes a lot of energy and matter. Some plants may "bank" energy over the winter by storing food. That way, they are ready to grow new leaves as soon as spring arrives.

Evergreen plants have a different strategy for adapting to seasonal dryness. They don't waste energy and matter growing new leaves each year. Instead, they keep their leaves and stay green year-round. However, to reduce water

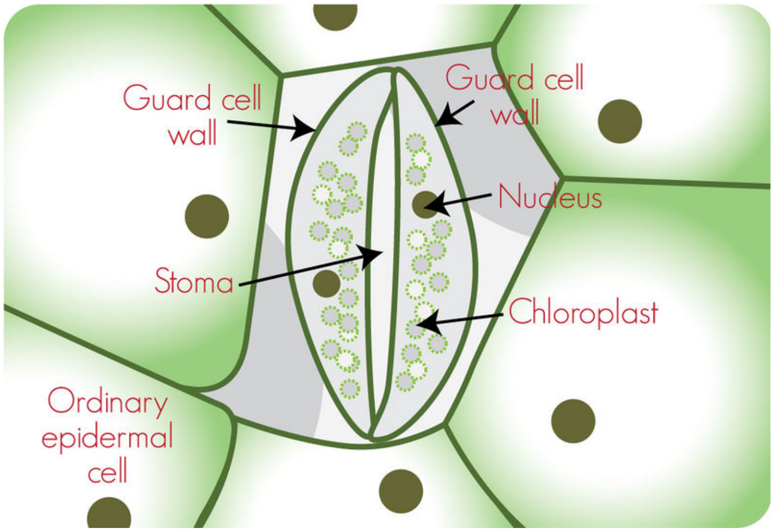

FIGURE 2.13
For photosynthesis, stomata must control the transpiration of water vapor and the exchange of carbon dioxide and oxygen. Stomata are flanked by guard cells that swell or shrink by taking in or losing water through osmosis. When they do, they open or close the stomata.

FIGURE 2.14
A deciduous tree goes through dramatic seasonal changes each year. Can you identify the seasons in the photo?

loss, they have needle-like leaves with very thick cuticle. On the downside, needle-like leaves reduce the surface area for collecting sunlight. This is one reason that needles may be especially rich in chlorophyll, as you can see from the dark green pine needles in **Figure** 2.15. This is also an important adaptation for low levels of sunlight, allowing evergreens to live far from the equator.

Lesson Summary

- Roots absorb water and minerals and transport them to stems. They also anchor and support a plant, and store food. A root system consists of primary and secondary roots. Each root is made of dermal, ground, and vascular tissues. Roots grow in length and width from primary and secondary meristem.
- Stems hold plants upright, bear leaves and other structures, and transport fluids between roots and leaves. Like

FIGURE 2.15
Compare the color of the evergreen needles and the deciduous leaf. Why is the darker color of the needles adaptive?

roots, stems contain dermal, ground, and vascular tissues. Trees have woody stems covered with bark.

- The primary function of leaves is to collect sunlight and make food by photosynthesis. Specialized tissues in leaves work together to perform this function. In a deciduous plant, leaves seasonally turn color and fall off the plant. They are replaced with new leaves later in the year. An evergreen plant keeps its green leaves year-round. It may have needle-like leaves to reduce water loss.

Lesson Review Questions

Recall

1. What are root hairs? What is their role?
2. Identify three major functions of roots.
3. Describe two types of specialized stems. What is each type of stem specialized for?
4. What is bark? What purposes does it serve?
5. Name the two main parts of an angiosperm leaf. What is the function of each part?
6. Identify strategies used by deciduous and evergreen plants to adapt to seasonal dryness.

Apply Concepts

7. Apply lesson concepts to predict how the stem of a desert plant might be specialized for its environment.
8. Devise a model to demonstrate the concept that simple and compound leaves differ in the amount of light they absorb.

Think Critically

9. Contrast a taproot system with a fibrous root system.
10. Explain how roots “know” which way to grow.
11. Relate leaf variation to environmental variation.
12. Explain how a leaf is like a factory.

Points to Consider

In this lesson you read about the diversity of roots, stems, and leaves. The life cycles of plants are also diverse.

- What do you already know about the life cycle of plants? What type of life cycle do plants have?
- Predict how the life cycles of different plants might vary. For example, how might the life cycle of seed plants differ from the life cycle of seedless vascular plants?

2.3 Variation in Plant Life Cycles

Lesson Objectives

- Describe a general plant life cycle.
- Outline the life cycle of nonvascular plants.
- Describe the life cycle of seedless vascular plants.
- Summarize the gymnosperm life cycle.
- Describe the angiosperm life cycle.

Vocabulary

- antheridia (singular, antheridium)
- archegonia (singular, archegonium)
- sporangium (plural, sporangia)

Introduction

The life cycle of all plants is complex because it is characterized by alternation of generations. Plants alternate between diploid sporophyte and haploid gametophyte generations, and between sexual and asexual reproduction. The ability to reproduce both sexually and asexually gives plants the flexibility to adapt to changing environments. Their complex life cycle allows for great variation.

General Plant Life Cycle

A general plant life cycle is represented by the diagram in **Figure** 2.16. From the figure, you can see that the diploid sporophyte has a structure called a **sporangium** (plural, sporangia) that undergoes meiosis to form haploid spores. A spore develops into a haploid gametophyte. The gametophyte has male or female reproductive organs that undergo mitosis to form haploid gametes (sperm or eggs). Fertilization of gametes produces a diploid zygote. The zygote grows and develops into a mature sporophyte, and the cycle repeats.

One of the two generations of a plant's life cycle is typically dominant to the other generation. Whether it's the sporophyte or gametophyte generation, individuals in the dominant generation live longer and grow larger. They are the green, photosynthetic structures that you would recognize as a fern, tree, or other plant (see **Figure** 2.17). Individuals in the nondominant generation, in contrast, may be very small and rarely seen. They may live in or on the dominant plant.

The dominant generation in nonvascular plants is the gametophyte; in vascular plants, it's the sporophyte. Why is a dominant sporophyte generation an advantage on land?

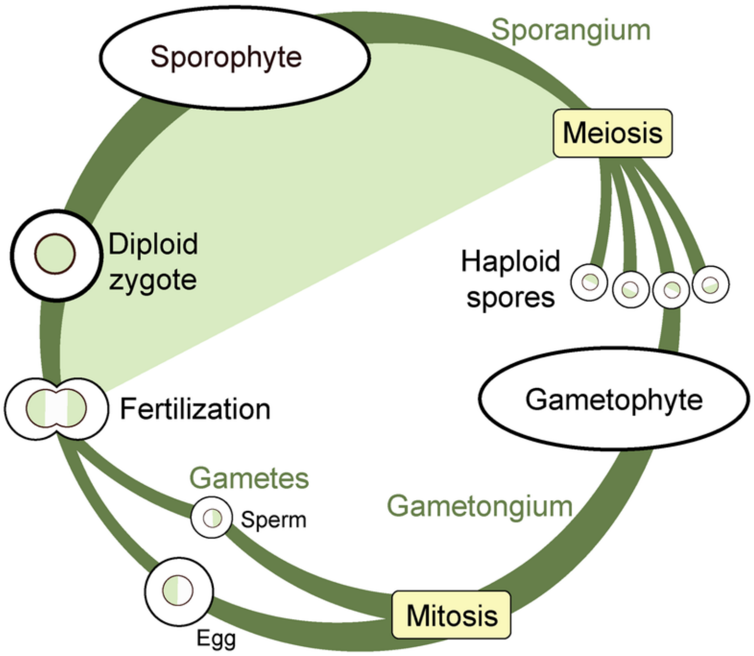

FIGURE 2.16
This diagram represents the life cycle that generally characterizes plants.

FIGURE 2.17
All of these photos show plants of the dominant generation in their life cycle.

Life Cycle of Nonvascular Plants

Nonvascular plants include mosses, liverworts, and hornworts. They are the only plants with a life cycle in which the gametophyte generation is dominant. **Figure** 2.18 shows the life cycle of moss. The familiar, green, photosynthetic moss plants are gametophytes. The sporophyte generation is very small and dependent on the gametophyte plant.

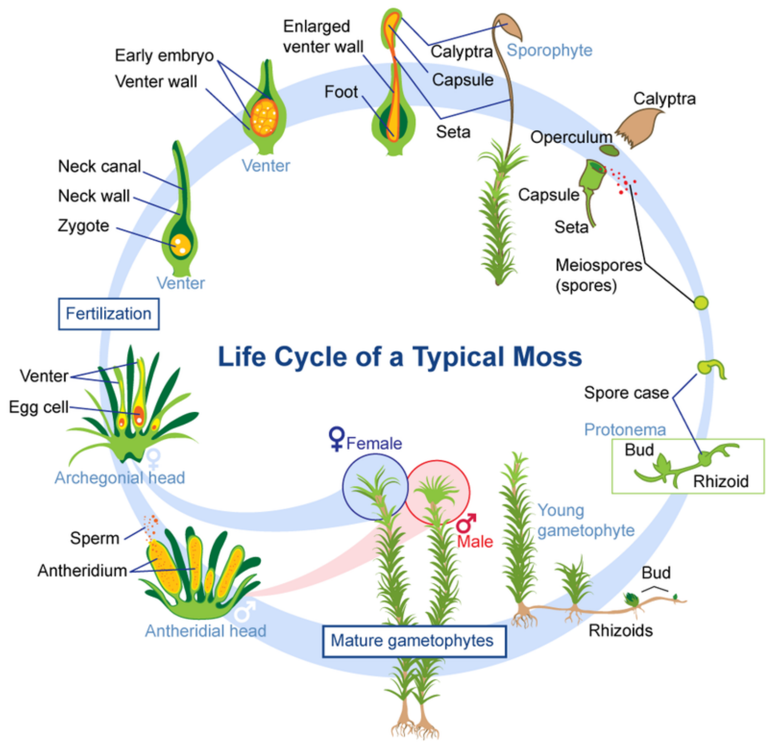

FIGURE 2.18
Like other bryophytes, moss plants spend most of their life cycle as gametophytes. Find the sporophyte in the diagram. Do you see how it is growing on the gametophyte plant?

The gametophytes of nonvascular plants have distinct male or female reproductive organs (see **Figure** 2.19). Male reproductive organs, called **antheridia** (singular, antheridium), produce motile sperm with two flagella. Female reproductive organs, called archegonia (singular, **archegonium**), produce eggs.

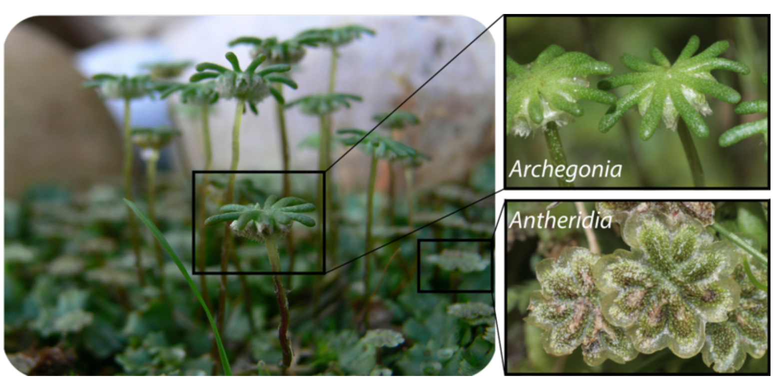

FIGURE 2.19
The reproductive organs of bryophytes like this liverwort are male antheridia and female archegonia.

In order for fertilization to occur, sperm must swim in a drop of water from an antheridium to an egg in an archegonium. If fertilization takes place, it results in a zygote that develops into a tiny sporophyte on the parent gametophyte

plant. The sporophyte produces haploid spores, and these develop into the next generation of gametophyte plants. Then the cycle repeats.

Life Cycle of Seedless Vascular Plants

Unlike nonvascular plants, all vascular plants—including seedless vascular plants—have a dominant sporophyte generation. Seedless vascular plants include clubmosses and ferns. **Figure** 2.20 shows a typical fern life cycle.

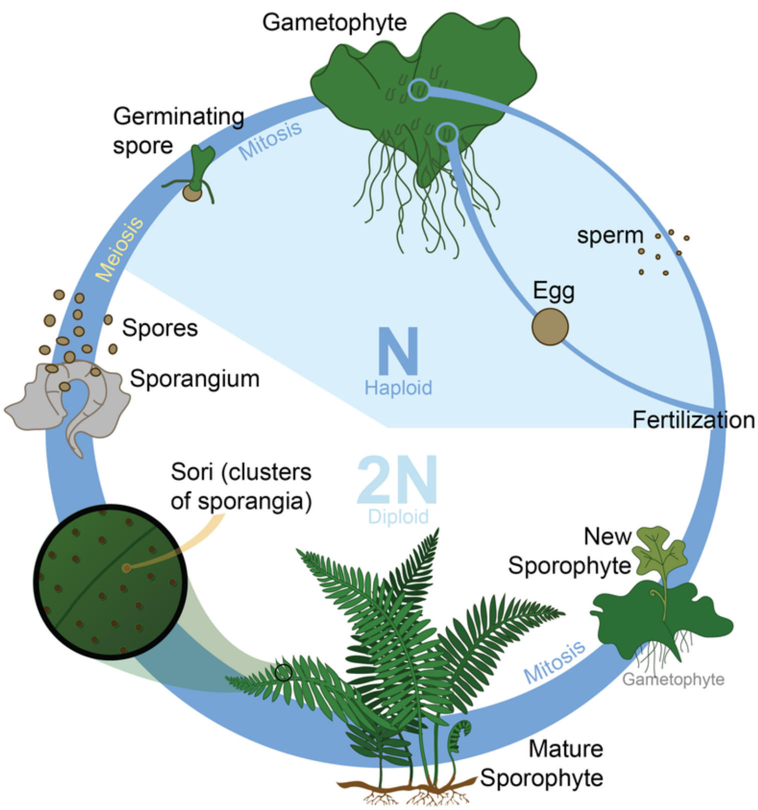

FIGURE 2.20

In the life cycle of a fern, the sporophyte generation is dominant.

A mature sporophyte fern has the familiar leafy fronds. The undersides of the leaves are dotted with clusters of sporangia. Sporangia produce spores that develop into tiny, heart-shaped gametophytes. Gametophytes have antheridia and archegonia. Antheridia produce sperm with many cilia; archegonia produce eggs. Fertilization occurs when sperm swim to an egg inside an archegonium. The resulting zygote develops into an embryo that becomes a new sporophyte plant. Then the cycle repeats.

Life Cycle of Gymnosperms

Gymnosperms are vascular plants that produce seeds in cones. Examples include conifers such as pine and spruce trees. The gymnosperm life cycle has a very dominant sporophyte generation. Both gametophytes and the next generation's new sporophytes develop on the sporophyte parent plant. **Figure** 2.21 is a diagram of a gymnosperm life cycle.

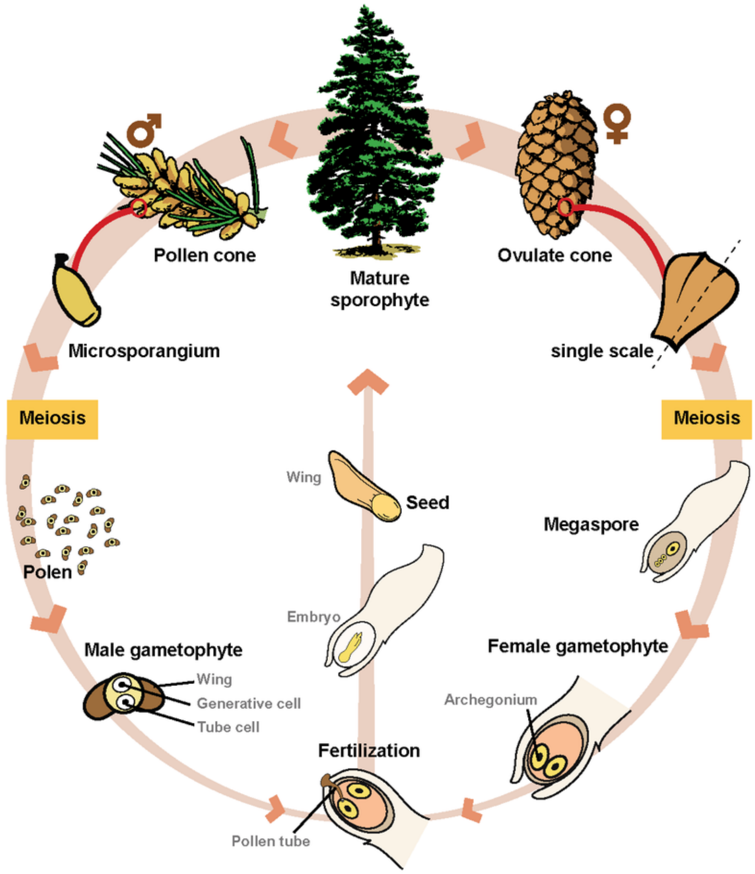

FIGURE 2.21

The gymnosperm life cycle follows the general plant life cycle, but with some new adaptations. Can you identify them?

Cones form on a mature sporophyte plant. Inside male cones, male spores develop into male gametophytes. Each male gametophyte consists of several cells enclosed within a grain of pollen. Inside female cones, female spores develop into female gametophytes. Each female gametophyte produces an egg inside an ovule.

Pollination occurs when pollen is transferred from a male to female cone. If sperm then travel from the pollen to an egg so fertilization can occur, a diploid zygote results. The zygote develops into an embryo within a seed, which forms from the ovule inside the female cone. If the seed germinates, it may grow into a mature sporophyte tree, which repeats the cycle.

Life Cycle of Angiosperms

Angiosperms, or flowering plants, are the most abundant and diverse plants on Earth. Angiosperms evolved several reproductive adaptations that have contributed to their success. Like all vascular plants, their life cycle is dominated by the sporophyte generation. A typical angiosperm life cycle is shown in **Figure** 2.22.

The flower in **Figure** 2.22 is obviously an innovation in the angiosperm life cycle. Flowers form on the dominant sporophyte plant. They consist of highly specialized male and female reproductive organs. Flowers produce spores that develop into gametophytes. Male gametophytes consist of just a few cells within a pollen grain and produce sperm. Female gametophytes produce eggs inside the ovaries of flowers. Flowers also attract animal pollinators.

If pollination and fertilization occur, a diploid zygote forms within an ovule in the ovary. The zygote develops into an embryo inside a seed, which forms from the ovule and also contains food to nourish the embryo. The ovary

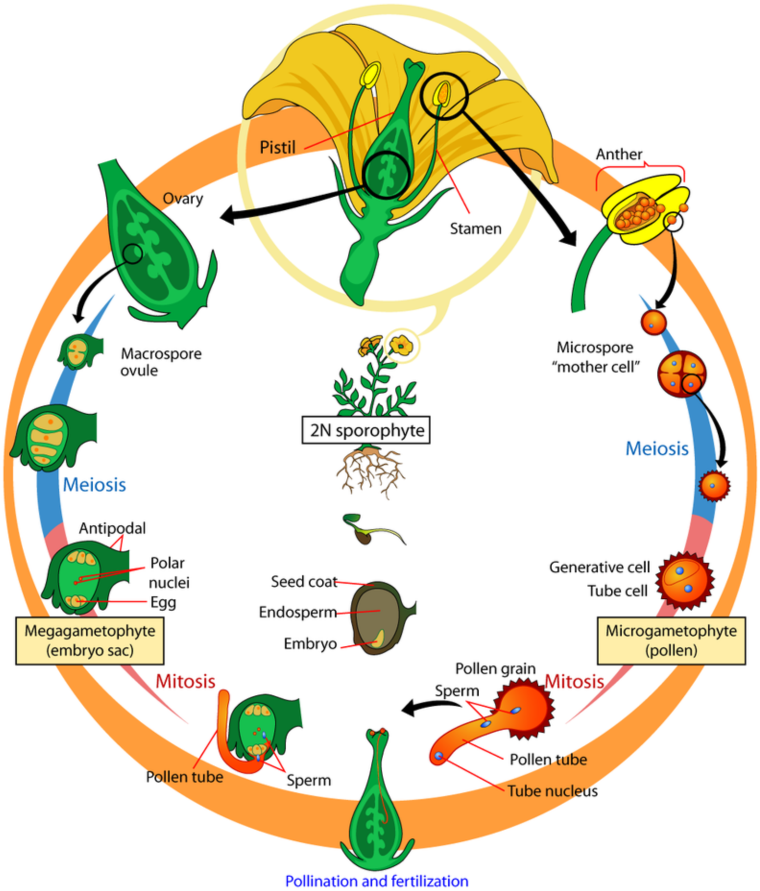

FIGURE 2.22
Life cycle of an angiosperm

surrounding the seed may develop into a fruit. Fruits attract animals that may disperse the seeds they contain. If a seed germinates, it may grow into a mature sporophyte plant and repeat the cycle.

Lesson Summary

- All plants have a life cycle with alternation of generations. Plants alternate between diploid sporophyte and haploid gametophyte generations, and between sexual reproduction with gametes and asexual reproduction with spores.
- In nonvascular plants, the gametophyte generation is dominant. The tiny sporophyte grows on the gametophyte plant.
- In vascular plants, the sporophyte generation is dominant. In seedless vascular plants such as ferns, the sporophyte releases spores from the undersides of leaves. The spores develop into tiny, separate gametophytes, from which the next generation of sporophyte plants grows.
- In seed plants, the gametophyte generation takes place in a cone or flower, which forms on the mature sporophyte plant. Each male gametophyte is just a few cells inside a grain of pollen. Each female gametophyte produces an egg inside an ovule. Pollination must occur for fertilization to take place. Zygotes develop into embryos inside seeds, from which the next sporophyte generation grows.

Lesson Review Questions

Recall

1. Outline the general life cycle of plants.
2. What are sporangia? What do they do?
3. Describe antheridia and archegonia and their functions.
4. What role do leaves play in the reproduction of ferns?
5. Describe how gymnosperms use cones to reproduce.
6. State the functions of flowers and fruits in angiosperm reproduction.

Apply Concepts

7. Create your own cycle diagram to represent the life cycle of a daisy.

Think Critically

8. Relate the concept of alternation of generations to the ability of plants to adapt to a diversity of habitats.
9. Compare and contrast gymnosperm and angiosperm life cycles.

Points to Consider

In this lesson, you read about many of the reproductive adaptations of plants.

- What are some other plant adaptations? For example, how have desert plants adapted to very dry conditions?
- Besides deserts, what other extreme habitats do plants occupy? What special adaptations might plants require to live in these other habitats?

2.4 Plant Adaptations and Responses

Lesson Objectives

- Explain how plants have adapted to a diversity of environments.
- Identify types of plant responses to environmental stimuli.

Vocabulary

- epiphyte
- tropism
- xerophyte

Introduction

Plants live just about everywhere on Earth. To live in so many different habitats, they have evolved adaptations that allow them to survive and reproduce under a diversity of conditions.

Plant Adaptations

All plants are adapted to live on land. Or are they? All living plants today have terrestrial ancestors, but some plants now live in the water. They have had to evolve new adaptations for their watery habitat.

Adaptations to Water

Aquatic plants are plants that live in water. Living in water has certain advantages for plants. One advantage is, well, the water. There's plenty of it and it's all around. Therefore, most aquatic plants do not need adaptations for absorbing, transporting, and conserving water. They can save energy and matter by not growing extensive root systems, vascular tissues, or thick cuticles on leaves. Support is also less of a problem because of the buoyancy of water. As a result, adaptations such as strong woody stems and deep anchoring roots are not necessary for most aquatic plants.

Living in water does present challenges to plants, however. For one thing, pollination by wind or animals isn't feasible under water, so aquatic plants may have adaptations that help them keep their flowers above water. For instance, water lilies have bowl-shaped flowers and broad, flat leaves that float. This allows the lilies to collect the maximum amount of sunlight, which does not penetrate very deeply below the surface. Plants that live in moving water, such as streams and rivers, may have different adaptations. For example, cattails have narrow, strap-like leaves that reduce their resistance to the moving water (see **Figure** 2.23).

FIGURE 2.23
Water lilies and cattails have different adaptations for life in the water. Compare the leaves of the two kinds of plants. How do the leaves help the plants adapt to their watery habitats?

Adaptations to Extreme Dryness

Plants that live in extremely dry environments have the opposite problem: how to get and keep water. Plants that are adapted to very dry environments are called **xerophytes**. Their adaptations may help them increase water intake, decrease water loss, or store water when it is available.

The saguaro cactus pictured in **Figure** 2.24 has adapted in all three ways. When it was still a very small plant, just a few inches high, its shallow roots already reached out as much as 2 meters (7 feet) from the base of the stem. By now, its root system is much more widespread. It allows the cactus to gather as much moisture as possible from rare rainfalls. The saguaro doesn't have any leaves to lose water by transpiration. It also has a large, barrel-shaped stem that can store a lot of water. Thorns protect the stem from thirsty animals that might try to get at the water inside.

FIGURE 2.24
The saguaro cactus has many adaptations for extreme dryness. How does it store water?

Adaptations to Air

Plants called **epiphytes** grow on other plants. They obtain moisture from the air and make food by photosynthesis. Most epiphytes are ferns or orchids that live in tropical or temperate rainforests (see **Figure** 2.25). Host trees provide

support, allowing epiphyte plants to obtain air and sunlight high above the forest floor. Being elevated above the ground lets epiphytes get out of the shadows on the forest floor so they can get enough sunlight for photosynthesis. Being elevated may also reduce the risk of being eaten by herbivores and increase the chance of pollination by wind.

FIGURE 2.25
These Elkhorn and Staghorn ferns are growing on a rainforest tree as epiphytes.

Epiphytes don't grow in soil, so they may not have roots. However, they still need water for photosynthesis. Rainforests are humid, so the plants may be able to absorb the water they need from the air. However, many epiphytes have evolved modified leaves or other structures for collecting rainwater, fog, or dew. The leaves of the bromeliad shown in **Figure** 2.26 are rolled into funnel shapes to collect rainwater. The base of the leaves forms a tank that can hold more than 8 liters (2 gallons) of water. Some insects and amphibians may spend their whole life cycle in the pool of water in the tank, adding minerals to the water with their wastes. The tissues at the base of the leaf are absorbent, so they can take in both water and minerals from the tank.

FIGURE 2.26
The leaves of this bromeliad are specialized to collect, store, and absorb rainwater.

Plant Responses

Like all organisms, plants detect and respond to stimuli in their environment. Unlike animals, plants can't run, fly, or swim toward food or away from danger. They are usually rooted to the soil. Instead, a plant's primary means of response is to change how it is growing. Plants also don't have a nervous system to control their responses. Instead, their responses are generally controlled by hormones, which are chemical messenger molecules.

Plant Tropisms

As you read earlier in this chapter, plant roots always grow downward because specialized cells in root caps detect and respond to gravity. This is an example of a tropism. A **tropism** is a turning toward or away from a stimulus in the environment. Growing toward gravity is called geotropism. Plants also exhibit phototropism, or growing toward a light source. This response is controlled by a plant growth hormone called auxin. As shown in **Figure** 2.27, auxin stimulates cells on the dark side of a plant to grow longer. This causes the plant to bend toward the light.

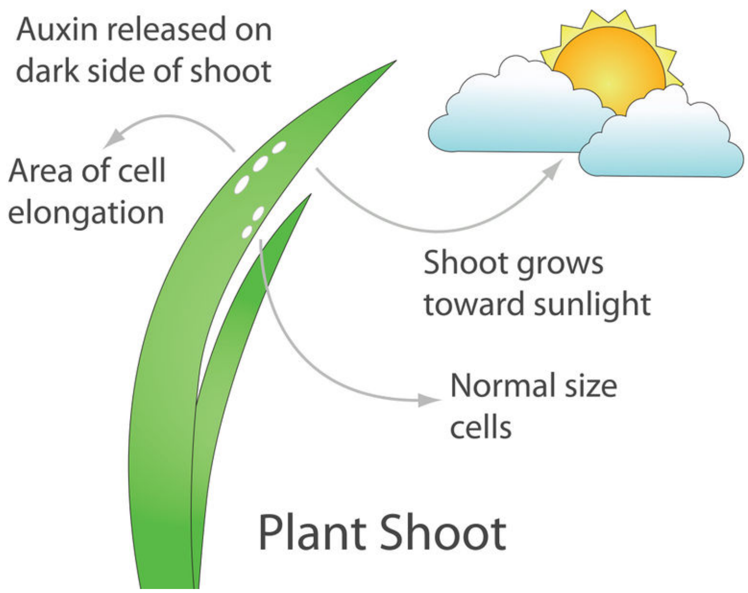

FIGURE 2.27
Phototropism is controlled by the growth hormone auxin.

Daily and Seasonal Responses

Plants also detect and respond to the daily cycle of light and darkness. For example, some plants open their leaves during the day to collect sunlight and then close their leaves at night to prevent water loss. Environmental stimuli that indicate changing seasons trigger other responses. Many plants respond to the days growing shorter in the fall by going dormant. They suspend growth and development in order to survive the extreme cold and dryness of winter. Dormancy ensures that seeds will germinate and plants will grow only when conditions are favorable.

Responses to Disease

Plants don't have immune systems, but they do respond to disease. Typically, their first line of defense is the death of cells surrounding infected tissue. This prevents the infection from spreading. Many plants also produce hormones and toxins to fight pathogens. For example, willow trees produce salicylic acid to kill bacteria. The same compound

is used in many acne products for the same reason. Exciting new research suggests that plants may even produce chemicals that warn other plants of threats to their health, allowing the plants to prepare for their own defense. As these and other responses show, plants may be rooted in place, but they are far from helpless.

KQED: Plant Plague: Sudden Oak Death

Devastating over one million oak trees across Northern California in the past ten years, Sudden Oak Death is a killer with no cure. But biologists now are looking to the trees' genetics for a solution. See http://www.kqed.org/quest/television/plant-plague-sudden-oak-death for more information.

Lesson Summary

- Plants live just about everywhere on Earth, so they have evolved adaptations that allow them to survive and reproduce under a diversity of conditions. Various plants have evolved adaptations to live in the water, in very dry environments, or in the air as epiphytes.
- Like all organisms, plants detect and respond to stimuli in their environment. Their main response is to change how they grow. Their responses are controlled by hormones. Some plant responses are tropisms. Plants also respond to daily and seasonal cycles and to disease.

Lesson Review Questions

Recall

1. List special challenges that aquatic plants face.
2. What are xerophytes? Give an example.
3. Identify three general ways that plants can adapt to extreme dryness.
4. Describe how epiphytes can absorb moisture without growing roots in soil.
5. What is the primary way that plants respond to environmental stimuli? What controls their responses?
6. Define tropism. Name one example in plants.
7. State ways that plants respond to disease.

Apply Concepts

8. Apply the concept of symbiosis to epiphytes and their host plants. Do you think they have a symbiotic relationship? If so, which type of symbiotic relationship do you think they have? Explain your answer.

Think Critically

9. Why are epiphytes found mainly in rainforest ecosystems?
10. Why is it adaptive for plants to detect and respond to daily and seasonal changes?

EOL Research

11. Bromeliads are some of the most common epiphytes. Research bromeliads at EOL and discuss the evolution of these species. See the *Communities and Populations* chapter for information about EOL.

Points to Consider

In this chapter you read about the cells, tissues, and organs that make up plants. You also read about plant life cycles. Like plants, animals are complex organisms with tissues and organs. Animals also have life cycles.

- How do the cells of animals differ from those of plants? What tissues and organs might be found in animals?
- What is the general animal life cycle? How does it differ from the general life cycle of plants?

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CHAPTER 3 Introduction to Animals

Chapter Outline

Do you know what these greenish, blob-like shapes are? Would it surprise you to learn that they are animals? They don't look anything like the animals you are probably familiar with—animals such as dogs and deer, fish and frogs. But the greenish blobs are animals nonetheless. They belong to a phylum called Cnidaria, but you may know them as jellyfish. They are very simple animals and not fish at all.

How can an organism as simple as a jellyfish be considered an animal? How are animals defined? What traits must an organism have to be classified in the animal kingdom? In this chapter, you will learn the answers to these questions. You will find out just what it means to be an animal.

3.1 Overview of Animals

Lesson Objectives

- Identify characteristics that all animals share.
- Give an overview of animal classification.
- Outline major trends in animal evolution.

Vocabulary

- amniote
- animal
- exoskeleton
- invertebrate
- notochord
- vertebral column
- vertebrate

Introduction

There is great variation among species that make up the animal kingdom. Some of this variation is shown in **Figure** 3.1. Despite the variation, there are a number of traits that are shared by all animals. The fact that all animals have certain traits in common shows that they share a common ancestor. How did such a diverse group of organisms evolve? What traits do all animals share? Read on to find out.

Characteristics of Animals

Animals are a kingdom of multicellular eukaryotes. They cannot make their own food. Instead, they get nutrients by eating other living things. Therefore, animals are heterotrophs.

Animal Cells

Like the cells of all eukaryotes, animal cells have a nucleus and other membrane-bound organelles (see **Figure** 3.2). Unlike the cells of plants and fungi, animal cells lack a cell wall. This gives animal cells flexibility. It lets them take on different shapes so they can become specialized to do particular jobs. The human nerve cell shown in **Figure** 3.3 is a good example. Its shape suits it for its function of transmitting nerve impulses over long distances. A nerve cell would be unable to take this shape if it were surrounded by a rigid cell wall.

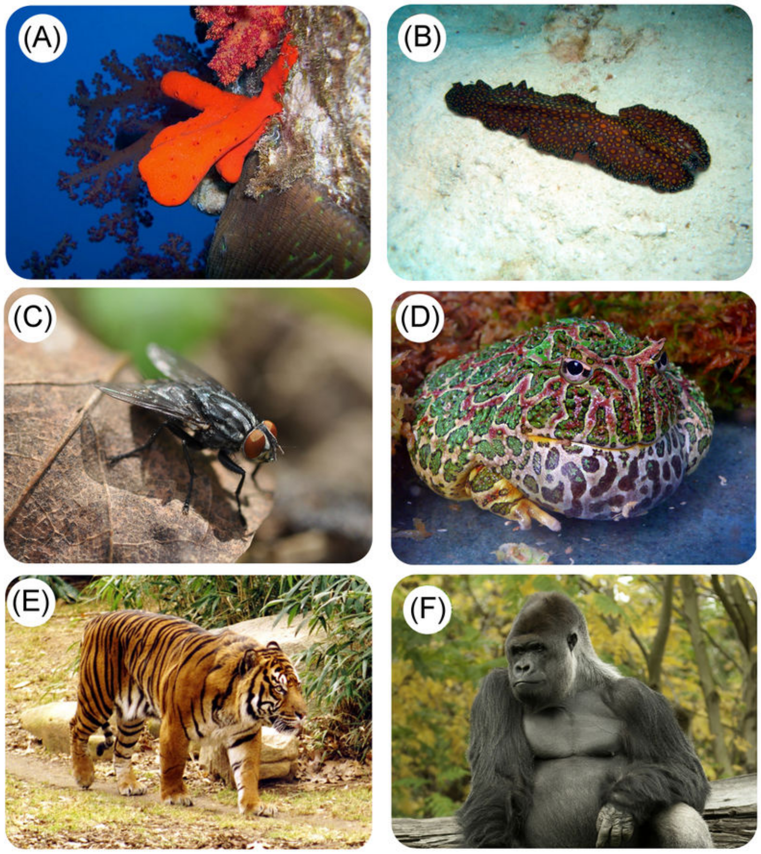


FIGURE 3.1
Diversity of Animals. These photos give just an inkling of the diversity of organisms that belong to the animal kingdom. (A) Sponge (B) Flatworm (C) Flying Insect (D) Frog (E) Tiger (F) Gorilla.

Animal Structure and Function

Animals not only have specialized cells. Most animals also have tissues and organs. In many animals, organs form organ systems, such as a nervous system. Higher levels of organization allow animals to perform many complex functions. What can animals do that most other living things cannot? Here are some examples. All of them are illustrated in **Figure** 3.4.

- Animals can detect environmental stimuli, such as light, sound, and touch. Stimuli are detected by sensory nerve cells. The information is transmitted and processed by the nervous system. The nervous system, in turn, may direct the body to respond.
- All animals can move, at least during some stage of their life cycle. Muscles and nerves work together to allow movement. Being able to move lets animals actively search for food and mates. It also helps them escape from predators.
- Virtually all animals have internal digestion of food. Animals consume other organisms and may use special tissues and organs to digest them. (Many other organisms absorb nutrients directly from the environment.)

Animal Life Cycle and Reproduction

Many animals have a relatively simple life cycle. A general animal life cycle is shown in **Figure** 3.5. Most animals spend the majority of their life as diploid organisms. Just about all animals reproduce sexually. Diploid adults undergo meiosis to produce sperm or eggs. Fertilization occurs when a sperm and an egg fuse. The zygote that forms develops into an embryo. The embryo eventually develops into an adult.

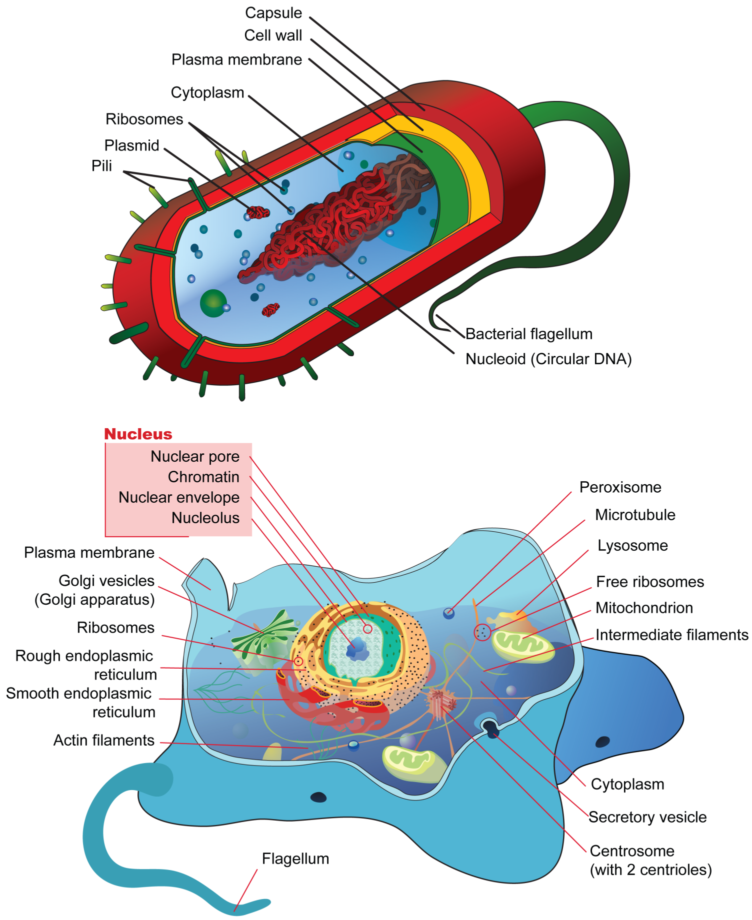


FIGURE 3.2

Animal Cell. The shape of an animal cell is not constrained by a rigid cell wall. A bacterial cell is shown above for comparison.

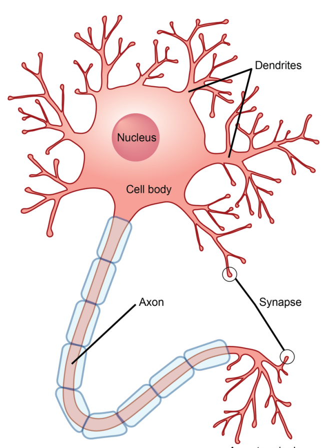


FIGURE 3.3

Human Nerve Cell. A human nerve cell is specialized to transmit nerve impulses. How do you think the cell's shape helps it perform this function?

Classification of Animals

All animals share basic traits. But animals also show a lot of diversity. They range from simple sponges to complex humans.

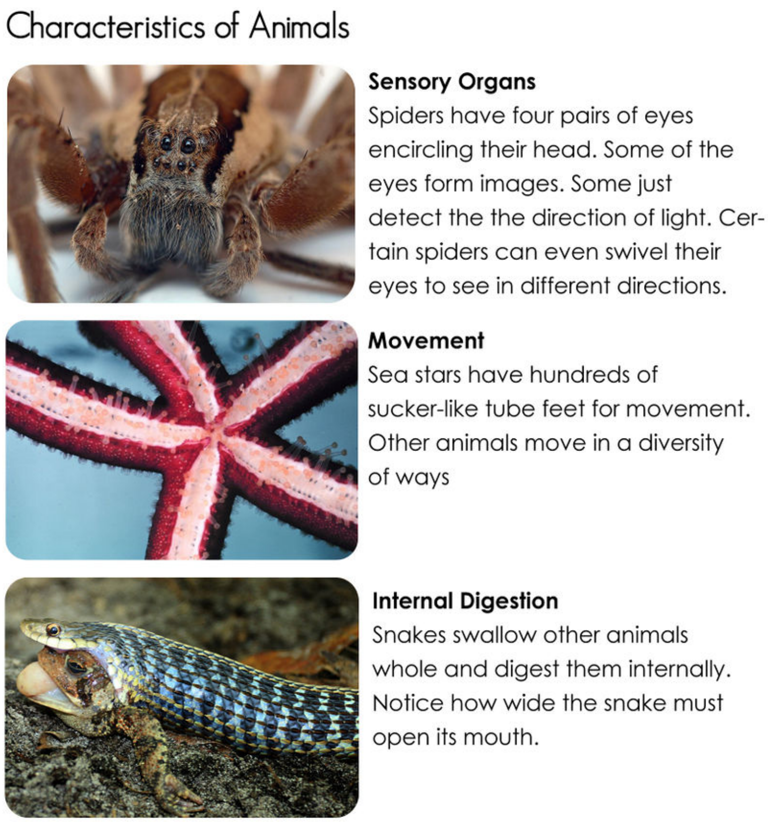


FIGURE 3.4
Characteristics of Animals. Most animals share these characteristics: sensory organs, movement, and internal digestion.

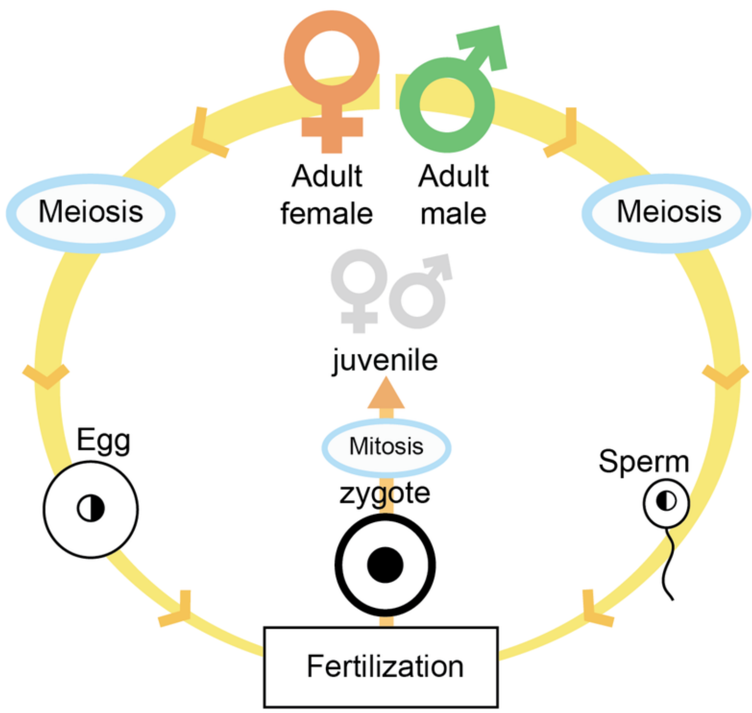


FIGURE 3.5
Animal Life Cycle. An animal life cycle that includes only sexual reproduction is shown here. Some animals also reproduce asexually. How does the animal life cycle compare with the life cycle of a plant?

Major Animal Phyla

Members of the animal kingdom are divided into more than 30 phyla. **Table** 3.1 lists the 9 phyla with the greatest number of species. Each of the animal phyla listed in the table have at least 10,000 species.

TABLE 3.1: Major Phyla of the Animal Kingdom

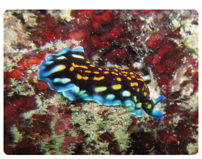
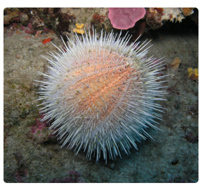
	Phylum	Animals It Includes
	Porifera	sponges
	Cnidaria	jellyfish, corals
	Platyhelminthes	flatworms, tapeworms, flukes
	Nematoda	roundworms
	Mollusca	snails, clams, squids

TABLE 3.1: (continued)

	Phylum	Animals It Includes
	Annelida	earthworms, leeches, marine worms
	Arthropoda	insects, spiders, crustaceans, centipedes
	Echinodermata	sea stars, sea urchins, sand dollars, sea cucumbers
	Chordata	tunicates, lancelets, fish, amphibians, reptiles, birds, mammals

Invertebrate vs. Vertebrate

The first eight phyla listed in **Table** 3.1 include only invertebrate animals. **Invertebrates** are animals that lack a **vertebral column**, or backbone. The last phylum in the table, the Chordata, also includes many invertebrate species. Tunicates and lancelets are both invertebrates. Altogether, invertebrates make up at least 95 percent of all animal species. The remaining animals are vertebrates. **Vertebrates** are animals that have a backbone. All vertebrates belong to the phylum Chordata. They include fish, amphibians, reptiles, birds, and mammals.

Major Trends in Animal Evolution

The oldest animal fossils are about 630 million years old. By 500 million years ago, most modern phyla of animals had evolved. **Figure** 3.6 shows when some of the major events in animal evolution took place.

Animal Origins

Who were the ancestors of the earliest animals? They may have been marine protists that lived in colonies. Scientists think that cells of some protist colonies became specialized for different jobs. After a while, the specialized cells

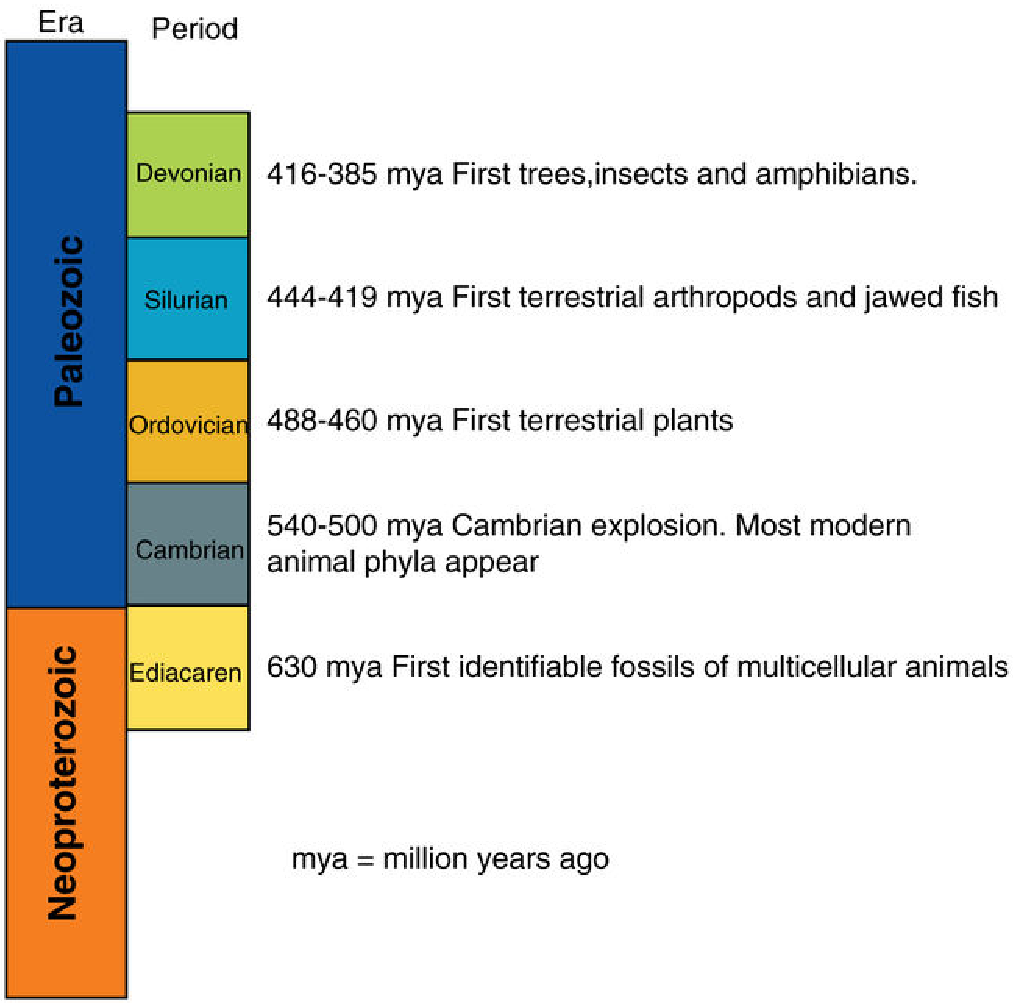


FIGURE 3.6

Partial Geologic Time Scale. This portion of the geologic time scale shows major events in animal evolution.

came to need each other for survival. Thus, the first multicellular animal evolved. Look at the cells in **Figure** 3.7. One type of sponge cell, the choanocyte, looks a lot like the protist cell. How does this support the hypothesis that animals evolved from protists?

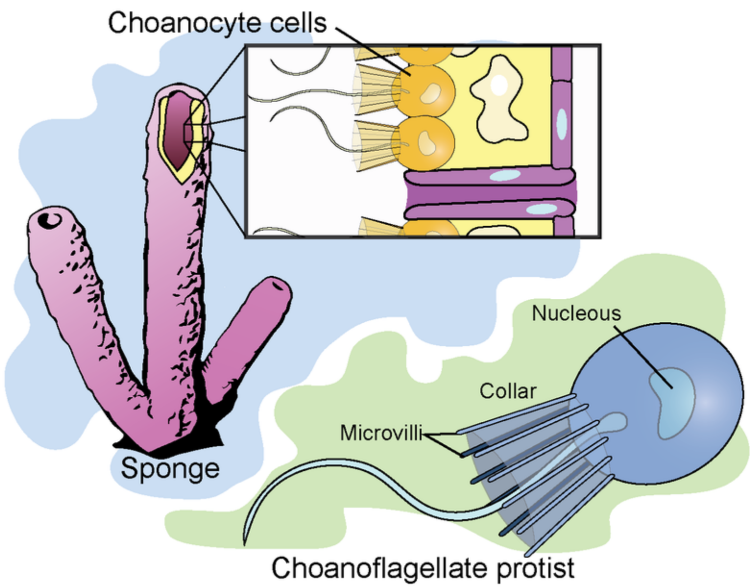


FIGURE 3.7
Choanoflagellate Protist and Choanocyte Cells in Sponges. Sponge choanocytes look a lot like choanoflagellate protists.

Evolution of Invertebrates

Many important animal adaptations evolved in invertebrates. Without these adaptations, vertebrates would not have been able to evolve. They include:

- Tissues, organs, and organ systems.
- A symmetrical body.
- A brain and sensory organs.
- A fluid-filled body cavity.
- A complete digestive system.
- A body divided into segments.

You can read about all of these adaptations in the next lesson.

Moving from Water to Land

When you think of the first animals to colonize the land, you may think of amphibians. It's true that ancestors of amphibians were the first vertebrates to move to land. However, the very first animals to go ashore were invertebrates, most likely arthropods.

The move to land required new adaptations. For example, animals needed a way to keep their body from drying out. They also needed a way to support their body on dry land without the buoyancy of water. One way early arthropods solved these problems was by evolving an **exoskeleton.** This is a non-bony skeleton that forms on the outside of the body. It supports the body and helps retain water. The video *Walking with Monsters* is a depiction of the evolution of life from water onto land: http://www.youtube.com/watch?v=gytrNU3iwvM (4:43).

Evolution of Chordates

Another major step in animal evolution was the evolution of a notochord. A **notochord** is a rigid rod that runs the length of the body. It supports the body and gives it shape (see **Figure** 3.8). It also provides a place for muscles to

anchor, and counterbalances them when they contract. Animals with a notochord are called chordates. They also have a hollow nerve cord that runs along the top of the body. Gill slits and a tail are two other chordate features. Many modern chordates have some of these structures only as embryos.

FIGURE 3.8
Primitive Chordate: Tunicate. This tunicate is a primitive, deep-sea chordate. It is using its notochord to support its head, while it waits to snatch up prey in its big mouth.

Evolution of Vertebrates

Vertebrates evolved from primitive chordates. This occurred about 550 million years ago. The earliest vertebrates may have been jawless fish, like the hagfish in **Figure** 3.9. Vertebrates evolved a backbone to replace the notochord after the embryo stage. They also evolved a cranium, or bony skull, to enclose and protect the brain.

FIGURE 3.9
Primitive Vertebrate: Hagfish. Hagfish are very simple vertebrates.

As early vertebrates evolved, they became more complex. Around 365 million years ago, they finally made the transition from water to land. The first vertebrates to live on land were amphibians. They evolved from lobe-finned fish. You can compare a lobe-finned fish and an amphibian in **Figure** 3.10.

Evolution of Amniotes

Amphibians were the first animals to have true lungs and limbs for life on land. However, they still had to return to water to reproduce. That's because their eggs lacked a waterproof covering and would dry out on land. The first fully terrestrial vertebrates were amniotes. **Amniotes** are animals that produce eggs with internal membranes. The

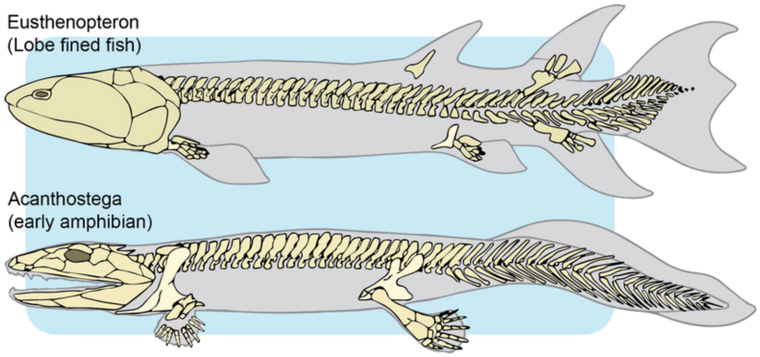


FIGURE 3.10
From Lobe-Finned Fish to Early Amphibian. Lobe-finned fish evolved into the earliest amphibians. A lobe-finned fish could breathe air for brief periods of time. It could also use its fins to walk on land for short distances. What similarities do you see between the lobe-finned fish and the amphibian?

membranes let gases but not water pass through. Therefore, in an amniotic egg, an embryo can breathe without drying out. Amniotic eggs were the first eggs that could be laid on land.

The earliest amniotes evolved about 350 million years ago. They may have looked like the animal in **Figure** 3.11. Within a few million years, two important amniote groups evolved: synapsids and sauropsids. Synapsids evolved into mammals. The sauropsids gave rise to reptiles, dinosaurs, and birds.

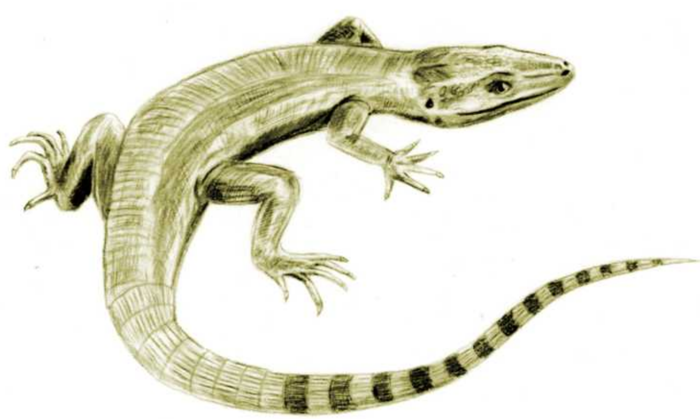


FIGURE 3.11
Early Amniote. The earliest amniotes probably looked something like this. They were reptile-like, but not actually reptiles. Reptiles evolved somewhat later.

Lesson Summary

- Animals are multicellular eukaryotes that lack cell walls. All animals are heterotrophs. They have sensory organs, the ability to move, and internal digestion. They also have sexual reproduction.
- Vertebrates have a backbone, but invertebrates do not. Except for the chordates, all animal phyla consist only of invertebrates. Chordates include both vertebrates and invertebrates.
- The earliest animals evolved from colonial protists more than 600 million years ago. Many important animal adaptations evolved in invertebrates, including tissues and a brain. The first animals to live on land were invertebrates. Amphibians were the first vertebrates to live on land. Amniotes were the first animals that could reproduce on land.

Review Questions

Recall

1. Identify traits that characterize all animals.
2. State one way that animal cells differ from the cells of plants and fungi. What is the significance of this difference?
3. Describe a general animal life cycle.
4. State how the phylum Chordata differs from other animal phyla.
5. List three traits that evolved in invertebrate animals.

Apply Concepts

6. Assume that a new species of animal has been discovered. It is an egg-laying animal that lives and reproduces on land. Explain what you know about its eggs without ever seeing them.

Think Critically

7. Compare and contrast invertebrates and vertebrates.
8. Relate similarities between choanoflagellates and choanocytes to animal origins.

Points to Consider

Vertebrates are the animals with which we are most familiar. But there are far more invertebrates than vertebrates on the planet. The next lesson provides an overview of invertebrate animals.

- Before reading the next lesson, think about what you now know about invertebrates. Can you identify some invertebrate traits?
- Invertebrates are sometimes referred to as "lower" animals. This is because they evolved earlier and are simpler than vertebrates. Do you think invertebrates are also less adapted to their environments than vertebrates? Why or why not?

3.2 Overview of Invertebrates

Lesson Objectives

- Describe general characteristics of invertebrates.
- Outline major events in invertebrate evolution.
- Give an overview of invertebrate classification.

Vocabulary

- bilateral symmetry
- cephalization
- coelom
- complete digestive system
- ectoderm
- endoderm
- hydrostatic skeleton
- incomplete digestive system
- larva (plural, larvae)
- mesoderm
- pseudocoelom
- radial symmetry
- segmentation

Introduction

The majority of animals today are invertebrates. They have a wide range of physical traits and ways of life. Modern invertebrates include animals as different as the sponge and tarantula shown in **Figure** 3.12. Why are both of these animals classified as invertebrates? What traits do they have common?

Characteristics of Invertebrates

One trait the sponge and tarantula share is lack of a backbone. In fact, they don't have any bones at all. These are defining traits of all invertebrates. Some invertebrates have a skeleton, but it isn't made of bone. Many other traits of invertebrates show considerable diversity.

FIGURE 3.12
Examples of Invertebrates. Both a sponge (left) and tarantula (right) are invertebrates. Can you identify any traits they share?

Digestion

Invertebrates have one of two types of digestive system. They are called incomplete and complete digestive systems. Both are shown in **Figure** 3.13. An **incomplete digestive system** consists of a digestive cavity with one opening. The single opening serves as both mouth and anus. A **complete digestive system** consists of a digestive tract with two openings. One opening is the mouth. The other is the anus.

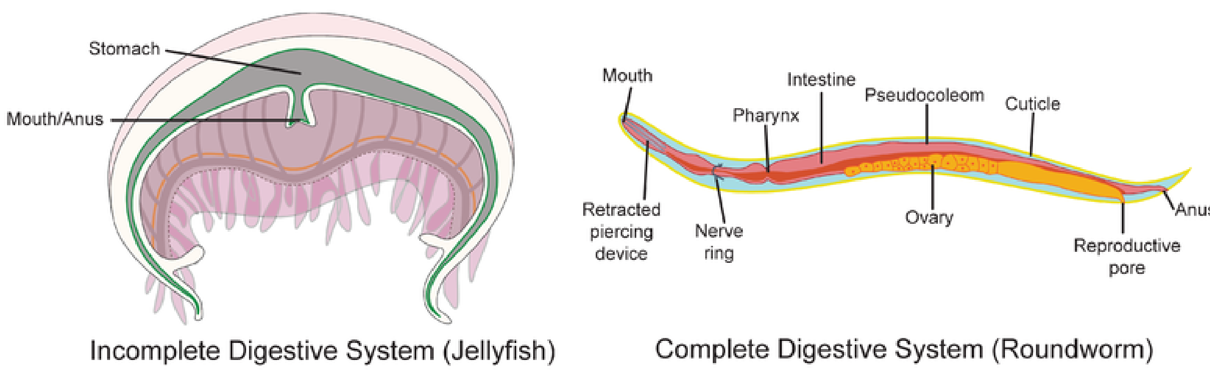


FIGURE 3.13
Two Types of Digestive Systems in Invertebrates. On the left is an incomplete digestive system, found in a jellyfish; on the right is the complete digestive system of a roundworm. Invertebrates may have either of these two types of digestive system. Find the parts of each digestive system in each drawing. How do the two systems differ?

Movement

All invertebrates can move on their own during at least some stage of their life cycle. However, they may differ in how they move. Several ways are described below.

- Some invertebrates are simply carried along by water currents. They cannot control their movement in a particular direction. An example is a jellyfish.
- Other invertebrates can contract muscles to move independently of water currents or on solid surfaces. They can also control the direction in which they move. An example is a roundworm. It can move forward and to the left or right.
- Still other invertebrates have specialized appendages for movement. For example, they may have jointed legs for walking or climbing or wings for flying. An example is an insect such as a fly.

Nervous System

Most invertebrates have a nervous system. The nervous system allows them to sense and respond to their environment. The simplest invertebrate nervous system is just a network of nerves that can sense touch (see **Figure** 3.14). Most invertebrates have a more complex nervous system. It may include a brain and several different sense organs.

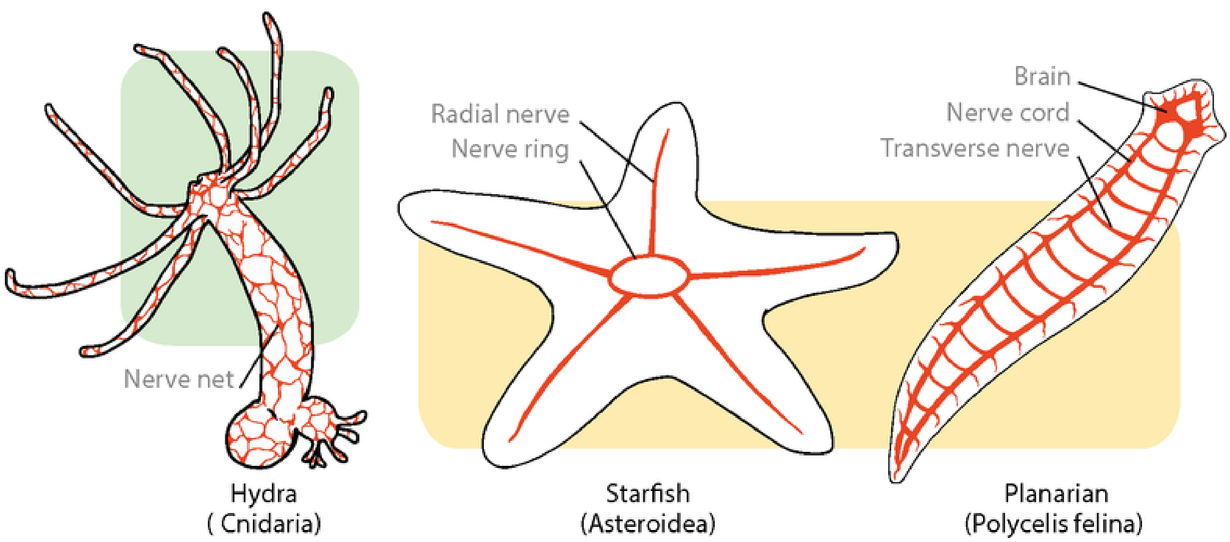


FIGURE 3.14
The nervous system of invertebrates.

Reproduction

Most invertebrates reproduce sexually. Diploid adults produce haploid gametes (sperm and eggs). In some species, the same individuals produce both sperm and eggs. In other species, sperm and eggs are produced by separate male and female individuals. Fertilization occurs when a sperm and an egg fuse to form a diploid zygote. The zygote develops into an embryo and eventually into a new adult organism. On the way, it may pass through one or more larval stages. A **larva** (plural, larvae) is a juvenile, or immature, stage of an animal. It is generally quite different in form and function from the adult form of the species. For example, the larva may be able to swim freely, whereas the adult must remain permanently attached to a solid surface.

Some invertebrates can also reproduce asexually. This may occur by fission or budding. Fission takes place when an animal simply divides into two parts. Each part then regrows the missing part. The result is two whole organisms.

Budding may take place when a parent forms a small bump, or bud. The bud remains attached to the parent while it develops into a new individual.

Invertebrate Evolution

Invertebrates evolved several important traits before vertebrates even appeared. These traits are now found in just about all animals.

Multicellularity

The first animal trait to evolve was multicellularity. This was highly adaptive. Multiple cells could do different jobs. They could evolve special adaptations that allowed them to do their job really well. However, the first invertebrates still lacked tissues. Sponges represent the first organism at this stage of invertebrate evolution.

Tissues

Living cnidarians, such as jellyfish, represent the next stage of invertebrate evolution. This was the evolution of tissues. It was the first step in the evolution of organs and organ systems. At first, invertebrates developed tissues from just two embryonic cell layers. There was an outer cell layer called **ectoderm** and an inner cell layer called **endoderm.** The two cell layers allowed different types of tissues to form.

Radial Symmetry

Another trait that evolved early on was symmetry. To understand symmetry, you need to see an animal that lacks symmetry. A sponge, like the one in **Figure** 3.15, lacks symmetry. This means it cannot be divided into two identical halves. A symmetrical organism, in contrast, can be divided into two identical halves. Both the coral polyp and the beetle in **Figure** 3.15 have symmetry.

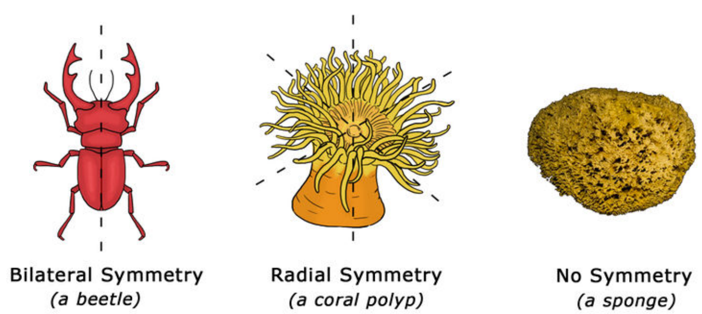


FIGURE 3.15

Symmetry in Invertebrates. Sponges lack symmetry. Radial symmetry evolved first. This was followed by bilateral symmetry. How do the two types of symmetry differ?

The coral polyp in **Figure** 3.15 has **radial symmetry.** This was the first type of symmetry to evolve. The coral has a distinct top and bottom but not distinct ends. It can be divided into identical halves like a pie, but not into right and left halves. Animals with radial symmetry have no sense of directions such as forward and backward or left and right. This makes controlled movement in these directions impossible.

Cephalization

Flatworms represent the next stage of invertebrate evolution. They evolved **cephalization.** This is the concentration of nerve tissue at one end of the body, forming a head region. This is highly adaptive. It allows central control of the entire organism. Cephalization was first step in the evolution of a brain.

Bilateral Symmetry

An outcome of cephalization was **bilateral symmetry.** This is demonstrated by the beetle in **Figure** 3.15. With concentrated nerve tissue at the head but not at the tail end, the two ends of the body are distinct from each other. The animal can be divided down the middle to form identical right and left halves. It allows the animal to tell front from back and left from right. This is needed for controlled movements in these directions.

Mesoderm

Ancestors of flatworms also evolved **mesoderm.** This is a third layer of cells between the ectoderm and the endoderm (see **Figure** 3.16). Evolution of this new cell layer allowed animals to develop new types of tissues, such as muscle.

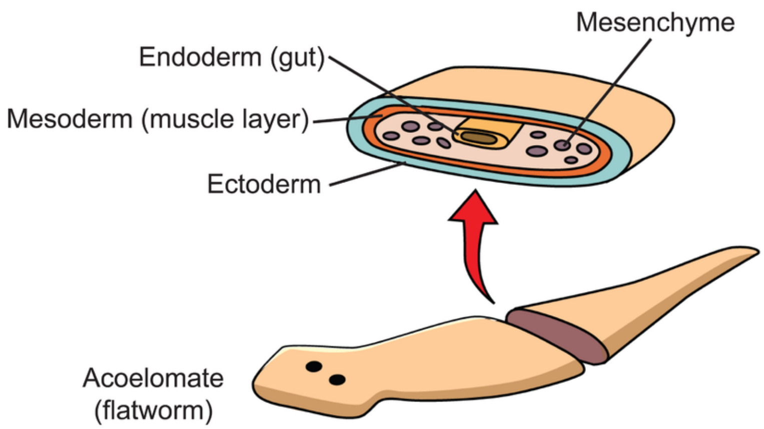


FIGURE 3.16

Three Cell Layers in a Flatworm. A flatworm has three cell layers.

Complete Digestive System

Early invertebrates had an incomplete digestive system. There was just one opening for the mouth and anus. Ancestors of modern roundworms were the first animals to evolve a complete digestive system. With a separate mouth and anus, food could move through the body in just one direction. This made digestion more efficient. An animal could keep eating while digesting food and getting rid of waste. Different parts of the digestive tract could also become specialized for different digestive functions. This led to the evolution of digestive organs.

Pseudocoelom and Coelom

Ancestors of roundworms also evolved a **pseudocoelom.** This is a partial body cavity that is filled with fluid. It allows room for internal organs to develop. The fluid also cushions the internal organs. The pressure of the fluid within the cavity provides stiffness. It gives the body internal support, forming a **hydrostatic skeleton.** It explains why roundworms are round and flatworms are flat. Later, a true **coelom** evolved. This is a fluid-filled body

cavity, completely enclosed by mesoderm. It lies between the digestive cavity and body wall (see **Figure** 3.17). Invertebrates with a true coelom include mollusks and annelids.

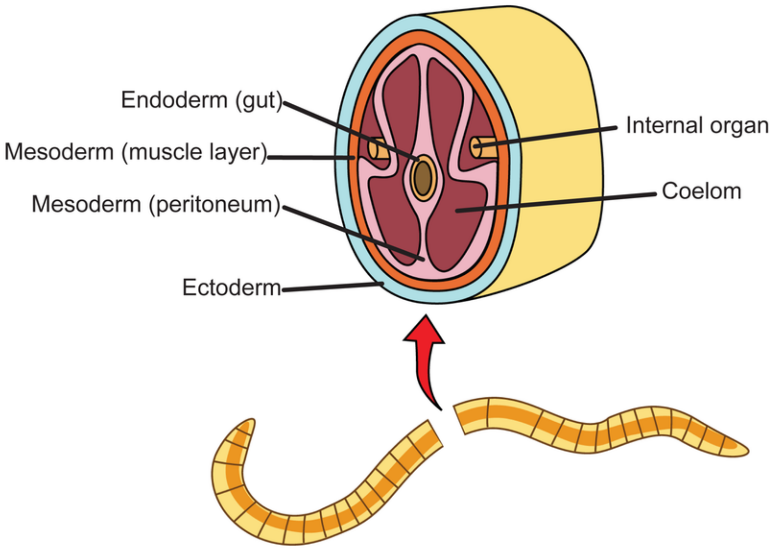


FIGURE 3.17
Cross Section of an Invertebrate with a Coelom. The coelom forms within the mesoderm.

Segmented Body

Segmentation evolved next. This is a division of the body into multiple segments. Both the earthworm and ant pictured in **Figure** 3.18 have segmented bodies. This trait increases flexibility. It permits a wider range of motion. All annelids and arthropods are segmented. Arthropods also evolved jointed appendages. For example, they evolved jointed legs for walking and "feelers" (antennae) for sensing.

FIGURE 3.18
Segmented Invertebrates. Earthworm (Annelid) and Black Ant (Arthropod). An earthworm consists of many small segments. An ant has three larger segments. Notice the ants jointed legs and "feelers."

Notochord

Some invertebrates evolved a notochord. This is the stiff support rod in a chordate. The first chordates were probably similar to modern invertebrate chordates. The sea squirt in **Figure** 3.19 is an example. Later, some invertebrate chordates evolved into vertebrates.

FIGURE 3.19
Notochord. A sea squirt is an invertebrate with a notochord.

Classification of Invertebrates

Eight major phyla contain the majority of invertebrate species.

Major Invertebrate Phyla

Table 3.2 gives an overview of the eight invertebrate phyla with the greatest number of species. The next chapter describes each phylum in greater detail.

TABLE 3.2: Major Invertebrate Phyla

Phylum (includes)	Notable Characteristics	Example
Porifera (sponges)	multicellularity, specialized cells but no tissues, asymmetry, incomplete digestive system	sponges
Cnidaria (jellyfish, corals)	radial symmetry, true tissues, incomplete digestive system	jellyfish
Platyhelminthes (flatworms, tapeworms, flukes)	cephalization, bilateral symmetry, mesoderm, complete digestive system	flatworm
Nematoda (roundworms)	pseudocoelom, complete digestive system	roundworm
Mollusca (snails, clams, squids)	true coelom, organ systems, some with primitive brain	snail
Annelida (earthworms, leeches, marine worms)	segmented body, primitive brain	earthworm
Arthropoda (insects, spiders, crustaceans, centipedes)	segmented body, jointed appendages, exoskeleton, brain	insect (dragonfly)

TABLE 3.2: (continued)

Phylum (includes)	Notable Characteristics	Example
Echinodermata (sea stars, sea urchins, sand dollars, sea cucumbers)	complete digestive system, coelom, spiny internal skeleton	sea urchin

Protostomes and Deuterostomes

Most invertebrates (and higher animals) can also be placed in one of two groups based on how they develop as embryos. The two groups are called protostomes and deuterostomes. As shown in **Figure** 3.20, organisms in the two groups have different ways of forming the coelom and mouth, among other differences.

Mollusks, annelids, and arthropods are protostomes. Echinoderms and chordates are deuterostomes. This distinction is important. Why does it matter? It shows that echinoderms are more closely related to chordates than are the other invertebrate phyla. This is not apparent based on other, more obvious traits.

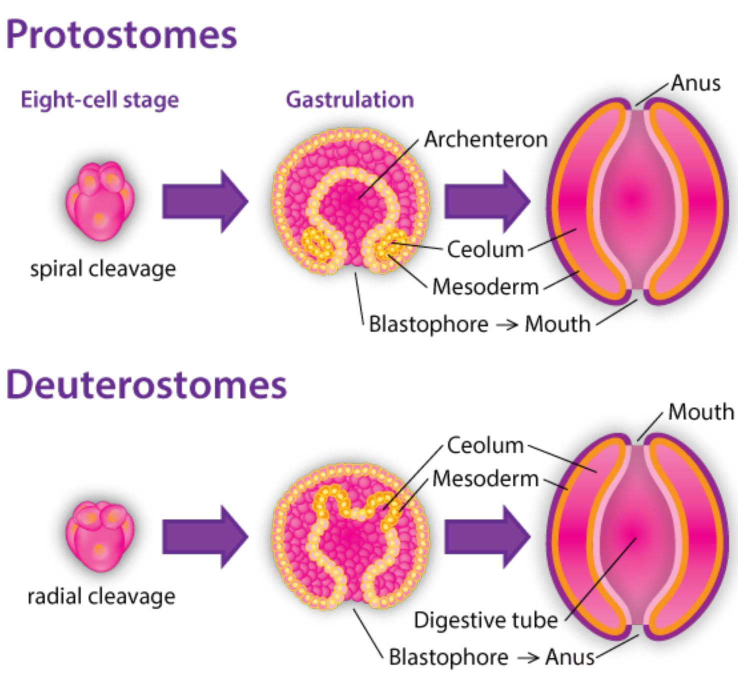


FIGURE 3.20

Protostomes vs. Deuterostomes. In protostomes such as mollusks, the coelom forms within the mesoderm. In deuterostomes such as echinoderms, the coelom forms from a pouch of endoderm. How does the formation of the mouth differ in these two groups of animals?

Lesson Summary

- The majority of living animals are invertebrates. Invertebrates lack a backbone. They may have an incomplete or a complete digestive system. They vary in how they move and in the complexity of their nervous system. Most invertebrates reproduce sexually. After hatching, many invertebrates pass through one or more larval stages that are different from the adult stage.
- Many important traits evolved in invertebrates. They include: multicellularity, tissues and organs, radial and bilateral symmetry, cephalization, mesoderm, complete digestive system, coelom, segmented body, and

notochord.
- Eight invertebrate phyla contain most invertebrate species. Invertebrates (and higher animals) can also be placed in one of two groups based on how they develop as embryos.

Lesson Review Questions

Recall

1. Describe the range of variation in the nervous systems of invertebrates.

2. Distinguish among asymmetry, radial symmetry, and bilateral symmetry.

3. Define cephalization. What is its relationship to bilateral symmetry?

4. What is mesoderm? Name an invertebrate with mesoderm.

5. Define coelom. How is the coelom related to the hydrostatic skeleton?

6. What is segmentation? Why is it adaptive?

7. Describe evidence showing that echinoderms are more closely related to chordates than are other invertebrate phyla.

Apply Concepts

8. Create a diagram to show the life cycle of an invertebrate with a larval stage. Include simple sketches of the adult and larval stages of the animal.

9. Assume you have discovered a new invertebrate. It has a segmented body, a brain, and jointed appendages. In which phylum would you place it? Why?

Think Critically

10. Compare and contrast incomplete and complete digestive systems. Why is a complete digestive system more efficient?

11. Explain how invertebrate movement is related to body symmetry.

Points to Consider

This chapter presents an overview of invertebrate phyla. The next chapter describes invertebrate phyla in greater detail.

- What questions do you have about invertebrate phyla now? For example, do you wonder where organisms in the different phyla live or what they eat?
- Invertebrates evolved hundreds of millions of years ago. Which invertebrate phylum do you think has the greatest number of species today?

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3.3 References

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Chapter 4 From Sponges to Invertebrate Chordates

Chapter Outline

This may look like a scary creature from your worst nightmare, but it wouldn't hurt a fly. In fact, it is a fly! The picture shows the charming portrait of a horsefly, up close and personal. Those big, striped, colorful orbs are its eyes. Did you ever look through a kaleidoscope? If so, then you have an idea of what the world looks like to a horsefly.

What other organs do insects like this horsefly have? Besides sensing their environment, what other functions do their organs serve? In this chapter, you will find out. You will read not only about fly eyes. You'll also read about octopus ink, spider fangs, and other fascinating features of invertebrates.

4.1 Sponges, Cnidarians, Flatworms, and Roundworms

Lesson Objectives

- Describe invertebrates in the phylum Porifera.
- Outline characteristics of cnidarians.
- Give an overview of the platyhelminths.
- Summarize traits of nematode invertebrates.

Vocabulary

- Cnidaria
- endoskeleton
- filter feeder
- medusa (plural, medusae)
- Nematoda
- Platyhelminthes
- polyp
- Porifera
- sessile

Introduction

Invertebrates are animals without a backbone. They are the most numerous animals on Earth. Most invertebrates are insects. However, simpler invertebrates evolved before insects. Some—like the sponges you will read about next—have existed virtually unchanged for hundreds of millions of years. Their continued existence is evidence that they are well adapted for their habitats. They also evolved some of the most important traits that are found in almost all animals today. Without the traits that evolved in sponges and other simple invertebrates, you would not exist.

Sponges

Sponges are aquatic invertebrates that make up the phylum **Porifera.** The word *porifera* means pore-bearing. The phylum is aptly named. As you can see from **Figure** 4.1, a sponge has a porous body. There are at least 5,000 living species of sponges. Almost all of them inhabit the ocean, living mainly on coral reefs or the ocean floor.

FIGURE 4.1
Sponge on a Coral Reef. This orange sponge is covered with pores. Can you predict the function of the pores?

Structure and Function of Sponges

Sponges come in a variety of shapes and sizes. For example, they may be shaped like tubes, fans, cones, or just blobs. They range in diameter from about a centimeter (0.4 inches) to over a meter (3.3 feet). Many species live in colonies that may be quite large. Adult sponges are **sessile**. This means they are unable to move from place to place. Root-like projections anchor them to solid surfaces such as rocks and reefs.

Sponges have an internal skeleton that gives them support and protection. An internal skeleton is called an **endoskeleton**. A sponge endoskeleton consists of short, sharp rods called spicules (see **Figure** 4.2). Spicules are made of silica, calcium carbonate, or spongin, a tough protein. They grow from specialized cells in the body of the sponge.

Sponges are **filter feeders.** They pump water into their body through their pores. The water flows through a large central cavity called the spongocoel (see **Figure** 4.2). As the water flows by, specialized collar cells filter out food particles such as bacteria. Collar cells have tiny hairs that trap the particles. They also have a flagellum that whips the water and keeps it moving. Once the food is trapped, the collar cells digest it (see **Figure** 4.3). Cells called amebocytes also help digest the food. They distribute the nutrients to the rest of the body as well. Finally, the water flows back out of the body through an opening called the osculum. As water flows through the sponge, oxygen diffuses from the water to the sponge's cells. The cells also expel wastes into the water for removal through the osculum.

Sponge Reproduction

Sponges reproduce both asexually and sexually. Asexual reproduction occurs by budding. **Figure** 4.4 shows the sponge life cycle when sexual reproduction is involved. Adult sponges produce eggs and sperm. In many species, the same individuals produce both. However, they don't produce eggs and sperm at the same time. As a result, self-fertilization is unlikely to occur. What is an advantage of avoiding self-fertilization?

Sperm are released into the surrounding water through the osculum. If they enter a female sponge through a pore, they may be trapped by collar cells. Trapped sperm are delivered to eggs inside the female body, where fertilization takes place. The resulting zygote develops into a larva. Unlike the adult, the larva is motile. It is covered with cilia that propel it through the water. As the larva grows, it becomes more similar to an adult sponge and loses its ability to swim.

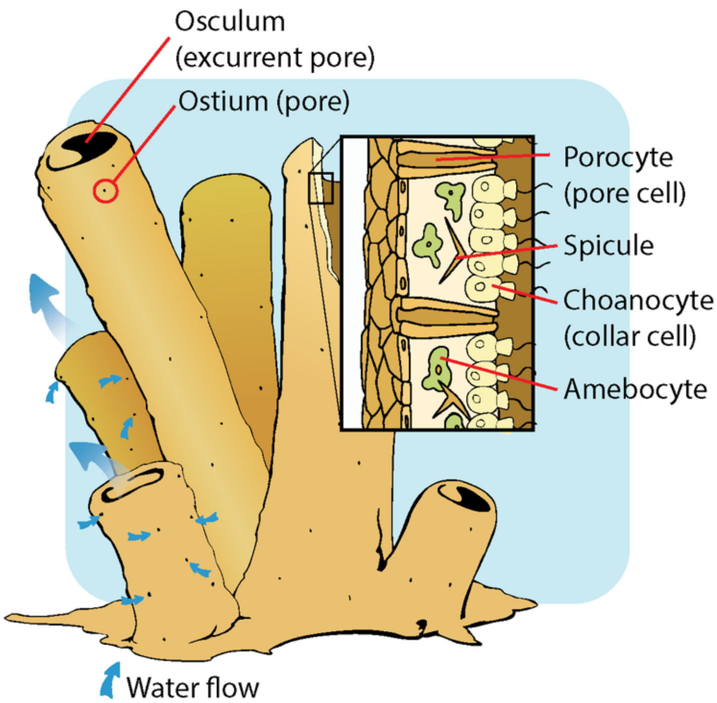


FIGURE 4.2
Sponge Anatomy. A sponge lacks tissues and organs, but it has several types of specialized cells.

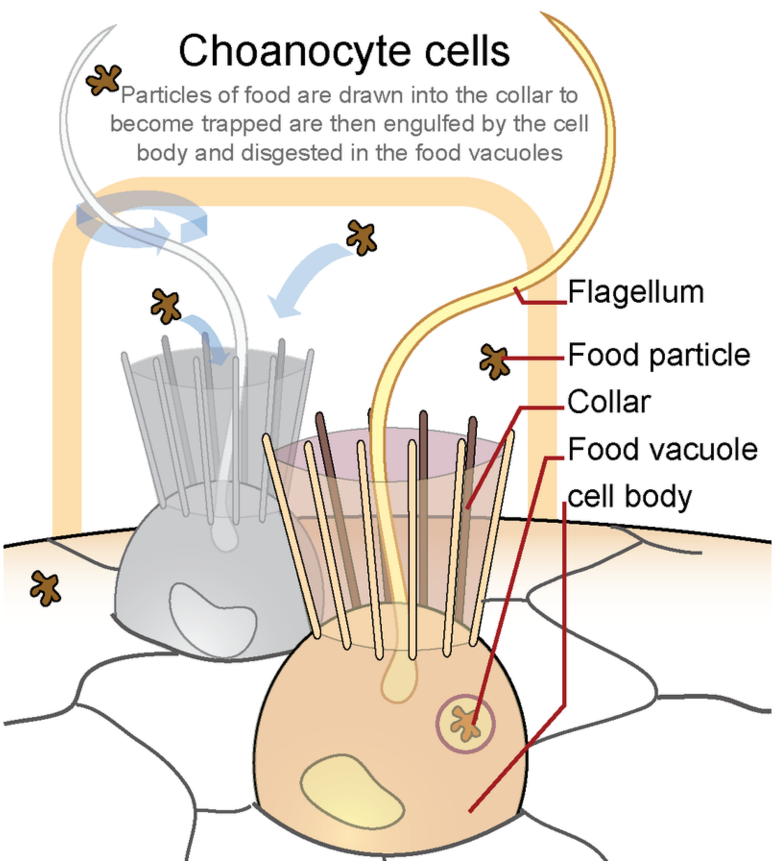


FIGURE 4.3
Collar Cell. The collar cells of sponges trap and digest food.

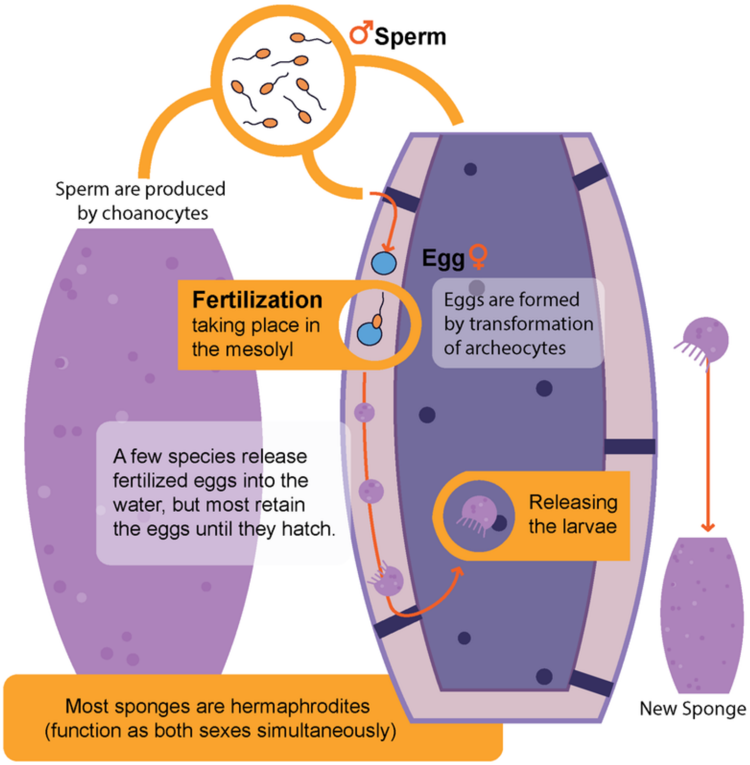


FIGURE 4.4
The sponge life cycle includes sexual reproduction. Sponges may also reproduce asexually.

Ecology of Sponges

Sponges that live on coral reefs have symbiotic relationships with other reef species. They provide shelter for algae, shrimp, and crabs. In return, they get nutrients from the metabolism of the organisms they shelter. Sponges are a source of food for many species of fish. Because sponges are sessile, they cannot flee from predators. Their sharp spicules provide some defense. They also produce toxins that may poison predators that try to eat them.

Cnidarians

Cnidarians are invertebrates such as jellyfish and corals. They belong to the phylum **Cnidaria.** All cnidarians are aquatic. Most of them live in the ocean. Cnidarians are a little more complex than sponges. They have radial symmetry and tissues. There are more than 10,000 cnidarian species. They are very diverse, as shown in **Figure** 4.5.

Structure and Function of Cnidarians

All cnidarians have something in common. It's a nematocyst, like the one shown in **Figure** 4.6. A nematocyst is a long, thin, coiled stinger. It has a barb that may inject poison. These tiny poison *darts* are propelled out of special cells. They are used to attack prey or defend against predators.

There are two basic body plans in cnidarians. They are called the polyp and medusa. Both are shown in **Figure** 4.7. The **polyp** has a tubular body and is usually sessile. The **medusa** (plural, medusae) has a bell-shaped body and is typically motile. Some cnidarian species alternate between polyp and medusa forms. Other species exist in just one form or the other.

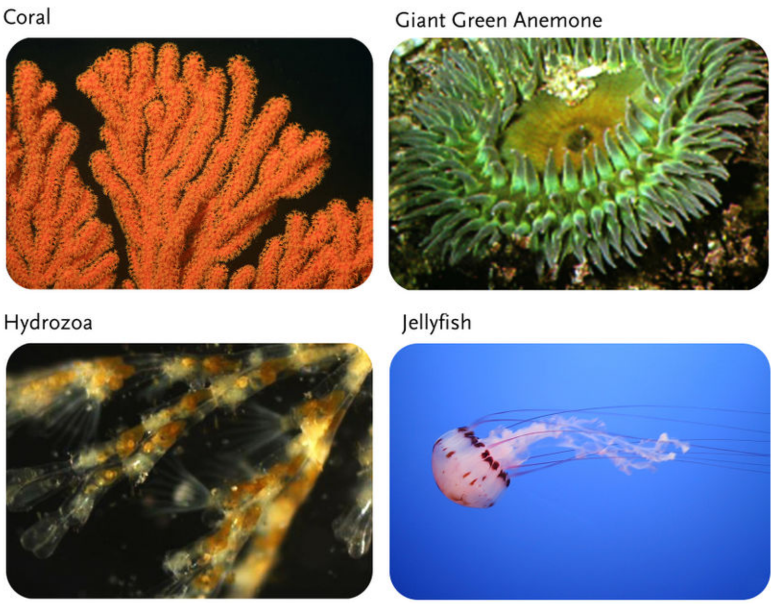


FIGURE 4.5
Cnidarian Diversity. Cnidarians show a lot of variability.

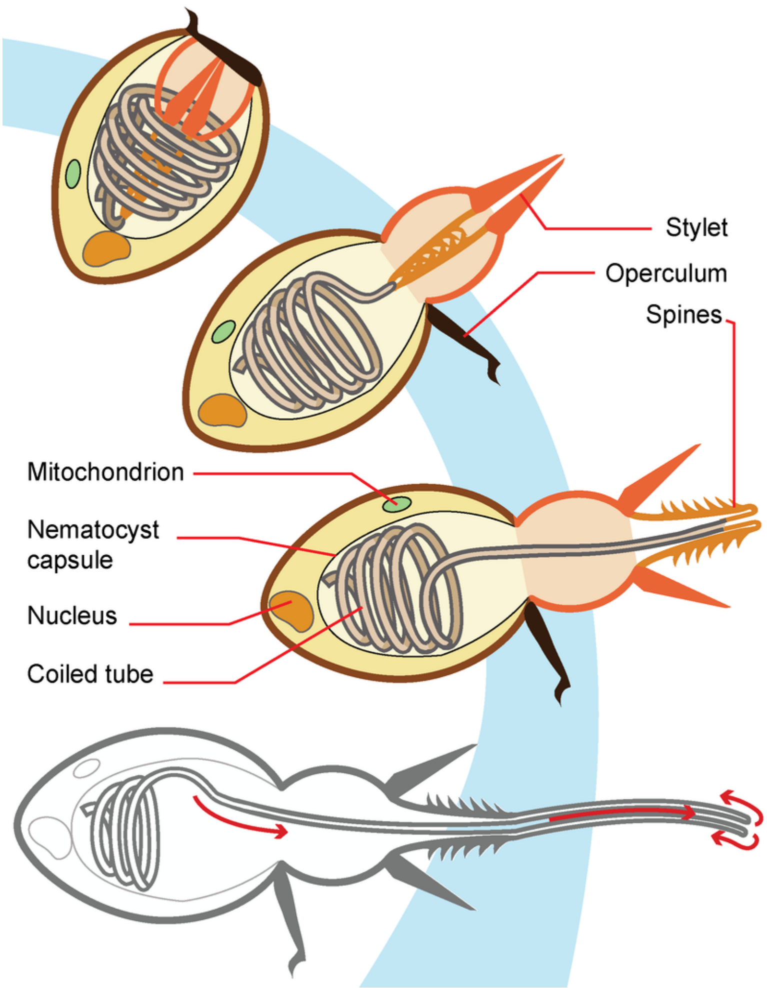


FIGURE 4.6
Cnidarian Nematocyst. A cnidarian nematocyst is like a poison dart. It is ejected from a specialized cell.

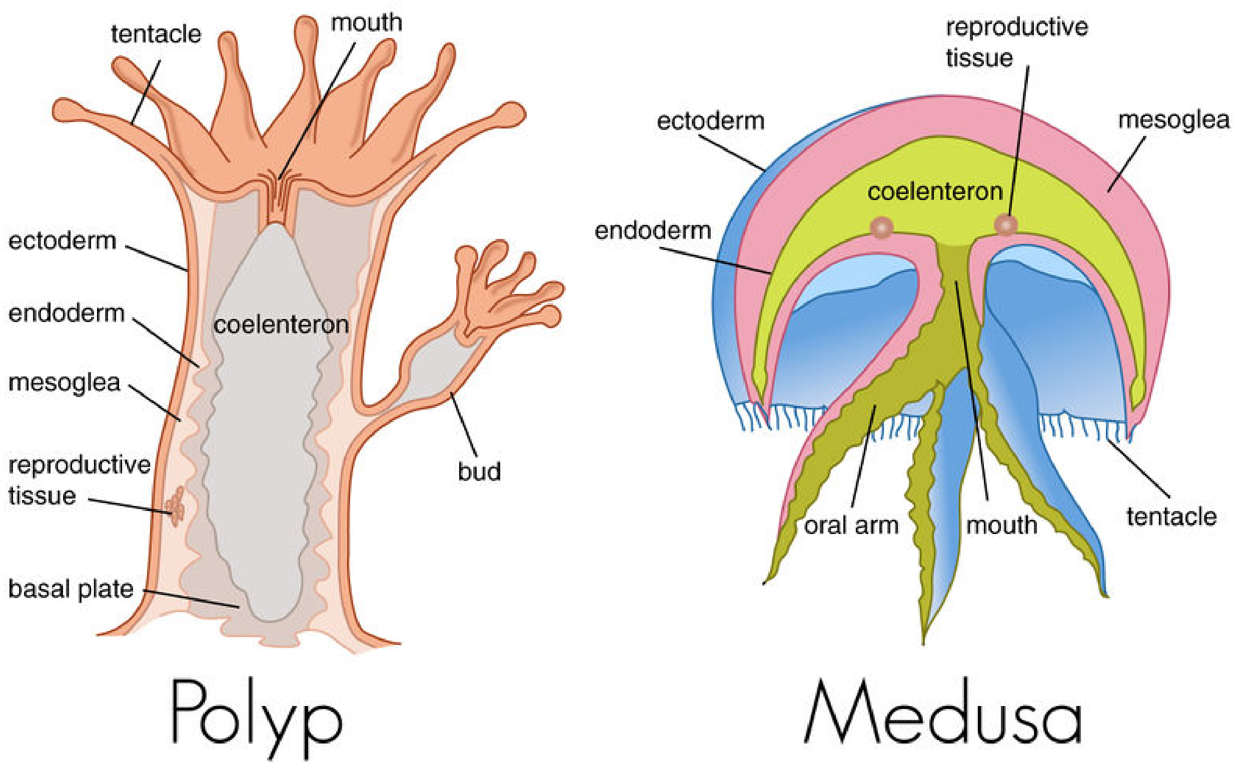


FIGURE 4.7

Cnidarian Body Plans. Cnidarians may exist in the polyp (left) or medusa (right) form.

The body of a cnidarian consists of two cell layers, ectoderm and endoderm. The cells surround a digestive cavity called the coelenteron (see **Figure** 4.8). Cnidarians have a simple digestive system. The single opening is surrounded by tentacles, which are used to capture prey. The tentacles are covered with nematocyst cells. Digestion takes place in the coelenteron. Nutrients are absorbed and gases exchanged through the cells lining this cavity. Fluid in the coelenteron creates a hydrostatic skeleton.

Cnidarians have a simple nervous system consisting of a nerve net that can detect touch. They may also have other sensory structures. For example, jellyfish have light-sensing structures and gravity-sensing structures. These senses give them a sense of up versus down. It also helps them balance.

Cnidarian Reproduction

Figure 4.8 shows a general cnidarian life cycle. Polyps usually reproduce asexually. One type of asexual reproduction in polyps leads to the formation of new medusae. Medusae usually reproduce sexually. Sexual reproduction forms a zygote. The zygote develops into a larva called a planula. The planula, in turn, develops into a polyp. There are many variations on the general life cycle. Obviously, species that exist only as polyps or medusae have a life cycle without the other form.

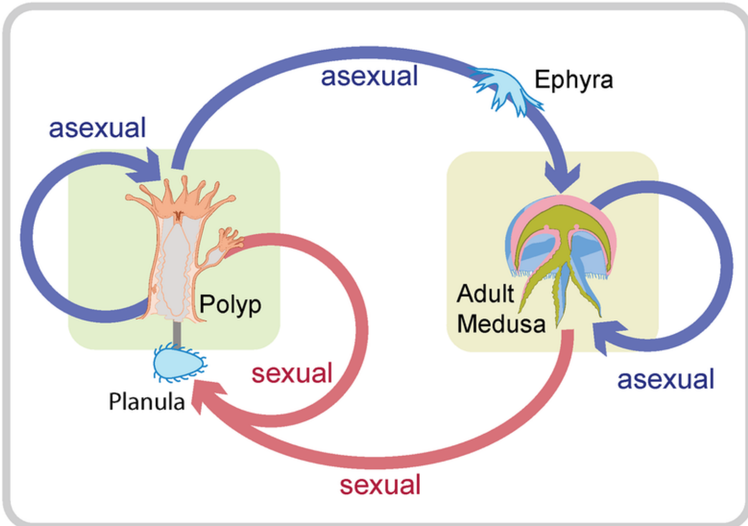


FIGURE 4.8
General Cnidarian Life Cycle. Cnidarians may reproduce both asexually and sexually.

Ecology of Cnidarians

Cnidarians can be found in almost all ocean habitats. They may live in water that is shallow or deep, warm or cold. A few species live in freshwater. Some cnidarians live alone, while others live in colonies.

Corals form large colonies in shallow tropical water. They are confined to shallow water because they have a mutualistic relationship with algae that live inside them. The algae need sunlight for photosynthesis, so they must be relatively close to the surface of the water. Corals exist only as polyps. They catch plankton with their tentacles. Many secrete a calcium carbonate exoskeleton. Over time, this builds up to become a coral reef (see **Figure** 4.9). Coral reefs provide food and shelter to many ocean organisms. They also help protect shorelines from erosion by absorbing some of the energy of waves. Coral reefs are at risk of destruction today.

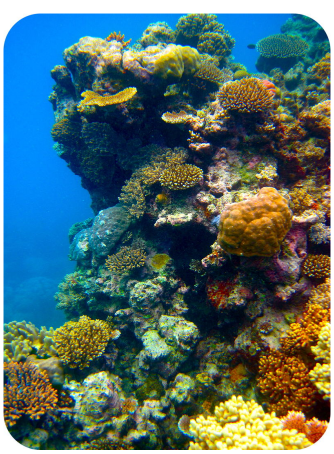
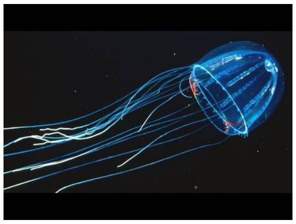


FIGURE 4.9
Great Barrier Reef. The Great Barrier Reef is a coral reef off the coast of Australia.

Unlike corals, jellyfish spend most of their lives as medusae. They live virtually everywhere in the ocean. They are typically carnivores. They prey on zooplankton, other invertebrates, and the eggs and larvae of fish.

KQED: Amazing Jellies

Jellyfish. They are otherworldly creatures that glow in the dark, without brains or bones, some more than 30 meters (100 feet) long. And there are many different types. Jellyfish are free-swimming members of the phylum Cnidaria. Jellyfish are found in every ocean, from the surface to the deep sea. To find out more about jellyfish, see http://www.kqed.org/quest/television/amazing-jellies–siphonophores2 .



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Flatworms

Flatworms belong to the phylum **Platyhelminthes.** Examples of flatworms are shown in **Figure** 4.10. There are more than 25,000 species in the flatworm phylum.

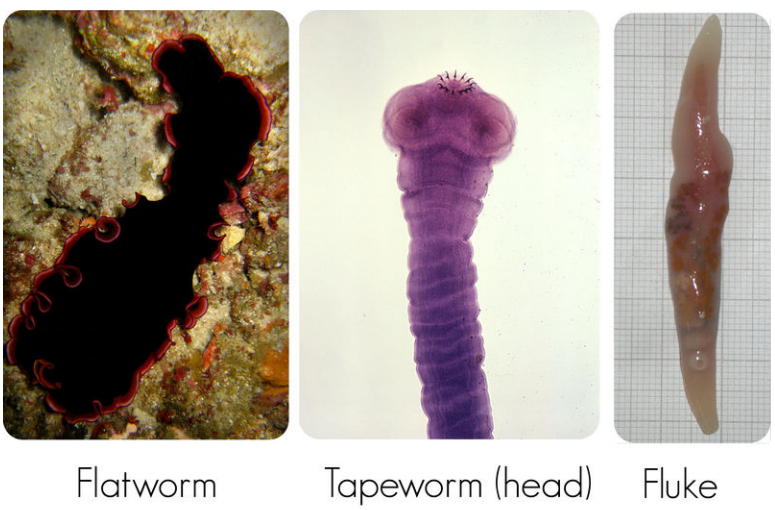

FIGURE 4.10

Platyhelminthes. Platyhelminths include flatworms, tapeworms, and flukes.

Structure and Function of Flatworms

Flatworms range in length from about 1 millimeter (0.04 inches) to more than 20 meters (66 feet). They have a flat body because they do not have a coelom or even a pseudocoelom. They also lack a respiratory system. Instead, their cells exchange gases by diffusion directly with the environment. Their digestive system is incomplete.

Flatworms reflect several major evolutionary advances in invertebrates. They have three embryonic cell layers, including mesoderm. The mesoderm layer allows them to develop organ systems. For example, they have muscular and excretory systems. The muscular system allows them to move from place to place over solid surfaces. The excretory system lets them maintain a proper balance of water and salts. Flatworms also show cephalization and bilateral symmetry.

Flatworm Reproduction

Flatworms reproduce sexually. In most species, the same individuals produce both eggs and sperm. After fertilization occurs, the fertilized eggs pass out of the adult's body and hatch into larvae. There may be several different larval stages. The final larval stage develops into the adult form, and the life cycle repeats.

Ecology of Flatworms

Both flukes and tapeworms are parasites with vertebrate hosts, including human hosts. Flukes live in the host's circulatory system or liver. Tapeworms live in the host's digestive system. Usually, more than one type of host is required to complete the parasite's life cycle. Look at the life cycle of the liver fluke in **Figure** 4.11. As an adult, the fluke has a vertebrate host. As a larva, it has an invertebrate host. If you follow the life cycle, you can see how each host becomes infected so the fluke can continue its life cycle.

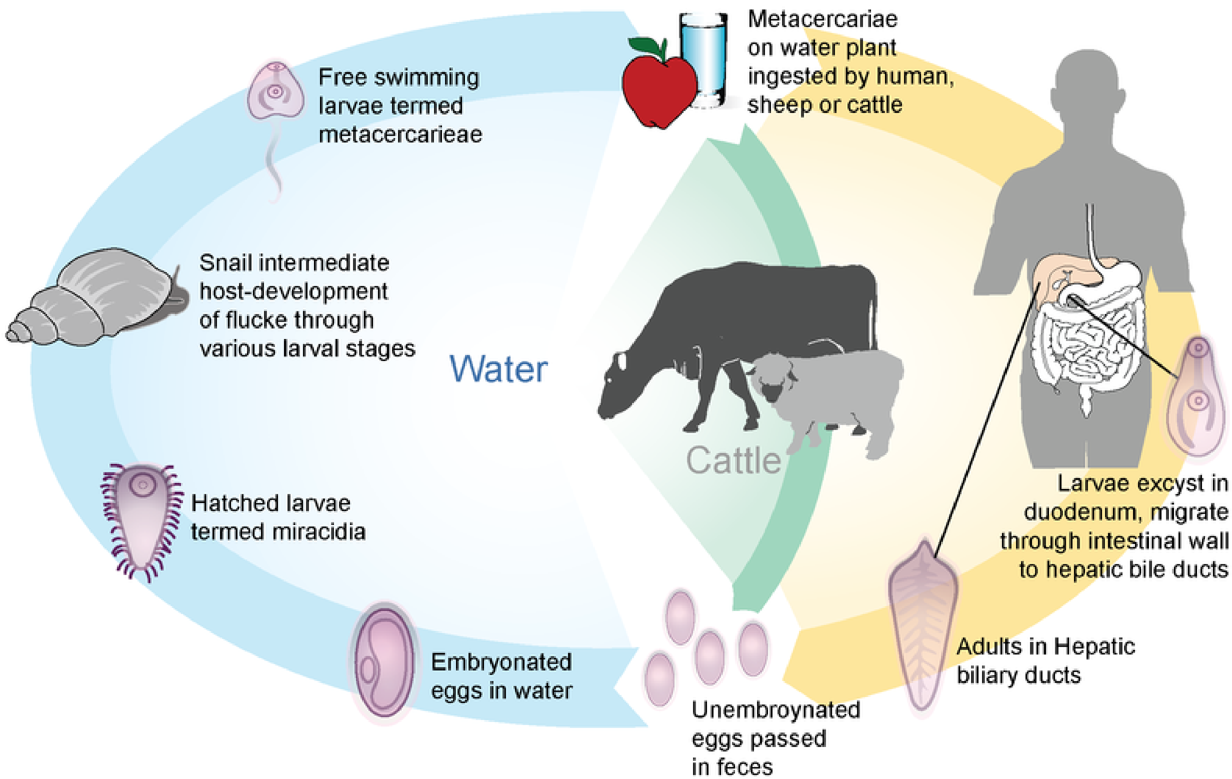

FIGURE 4.11
Life Cycle of the Sheep Liver Fluke. The sheep liver fluke has a complicated life cycle with two hosts. How could such a complicated way of life evolve?

Tapeworms and flukes have suckers and other structures for feeding on a host. Tapeworms also have a ring of hooks on their head to attach themselves to the host (see **Figure** 4.12). Unlike other invertebrates, tapeworms lack a mouth and digestive system. Instead, they absorb nutrients directly from the host's digestive system with their suckers.

Not all flatworms are parasites. Some are free-living carnivores. They eat other small invertebrates and decaying animals. Most of the free-living species live in aquatic habitats, but some live in moist soil.

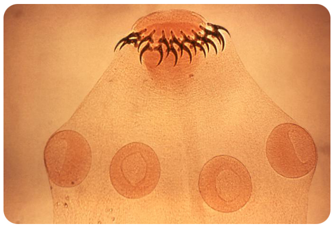

FIGURE 4.12
Tapeworm Suckers and Hooks. The head of a tapeworm has several suckers. At the very top of the head is a "crown" of hooks called a scolex.

Roundworms

Roundworms make up the phylum **Nematoda.** This is a very diverse animal phyla. It has more than 80,000 known species.

Structure and Function of Roundworms

Roundworms range in length from less than 1 millimeter (0.04 inches) to over 7 meters (23 feet) in length. As their name suggests, they have a round body. This is because they have a pseudocoelom. This is one way they differ from flatworms. Another way is their complete digestive system. It allows them to take in food, digest food, and eliminate wastes all at the same time.

Roundworms have a tough covering of cuticle on the surface of their body. It prevents their body from expanding. This allows the buildup of fluid pressure in the pseudocoelom. As a result, roundworms have a hydrostatic skeleton. This provides a counterforce for the contraction of muscles lining the pseudocoelom. This allows the worms to move efficiently along solid surfaces.

Roundworm Reproduction

Roundworms reproduce sexually. Sperm and eggs are produced by separate male and female adults. Fertilization takes place inside the female organism. Females lay huge numbers of eggs, sometimes as many as 100,000 per day! The eggs hatch into larvae, which develop into adults. Then the cycle repeats.

Ecology of Roundworms

Roundworms may be free-living or parasitic. Free-living worms are found mainly in freshwater habitats. Some live in soil. They generally feed on bacteria, fungi, protozoans, or decaying organic matter. By breaking down organic matter, they play an important role in the carbon cycle.

Parasitic roundworms may have plant, vertebrate, or invertebrate hosts. Several species have human hosts. For example, hookworms, like the one in **Figure** 4.13, are human parasites. They infect the human intestine. They are named for the hooks they use to grab onto the host's tissues. Hookworm larvae enter the host through the skin. They migrate to the intestine, where they mature into adults. Adults lay eggs, which pass out of the host in feces. Then the cycle repeats.

Tiny pinworms are the most common roundworm parasites of people in the U.S. In some areas, as many as one out of three children are infected. Humans become infected when they ingest the nearly microscopic pinworm eggs. The eggs hatch and develop into adults in the host's digestive tract. Adults lay eggs that pass out of the host's body to continue the cycle. Pinworms have a fairly simple life cycle with only one host.

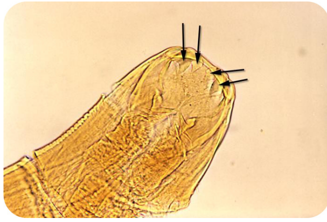

FIGURE 4.13
Hookworm Parasite. Hookworms like this one are common human parasites.

Lesson Summary

- Sponges are aquatic invertebrates. They make up the phylum Porifera. Sponges have specialized cells and an endoskeleton. They lack tissues and body symmetry. Adult sponges are sessile filter feeders. Sponge larvae have cilia for swimming.
- Cnidarians include jellyfish and corals. They are aquatic invertebrates. They have tissues and radial symmetry. They also have tentacles with stingers. There are two cnidarian body plans: the polyp and the medusa. They differ in several ways. Many corals secrete an exoskeleton that builds up to become a coral reef.
- Platyhelminths are flatworms such as tapeworms and flukes. They have a mesoderm cell layer and simple organ systems. They also show cephalization and bilateral symmetry. Many flatworms are parasites with vertebrate hosts. Some are free-living carnivores that live mainly in aquatic habitats.
- Roundworms make up the phylum Nematoda. They have a pseudocoelom and hydrostatic skeleton. Their body is covered with tough cuticle. Free-living roundworms are found mainly in freshwater habitats. Parasitic roundworms have a variety of hosts, including humans.

Lesson Review Questions

Recall

1. Define sessile. Name an invertebrate with a sessile adult stage.

2. Describe the skeleton of a sponge.

3. Sponges have specialized cells called collar cells. Describe how collar cells are specialized for the functions they serve.

4. What is a nematocyst? What is its function?

5. How do coral reefs form?

6. Describe specialized feeding structures of parasitic platyhelminths.

7. How do free-living nematodes contribute to the carbon cycle?

Apply Concepts

8. Create a diagram of an adult sponge body plan that shows how sponges obtain food.

9. Apply what you know about pinworms to develop one or more recommendations for preventing pinworm infections in humans.

Think Critically

10. Compare and contrast cnidarian polyps and medusae.

11. Platyhelminths and nematodes are both worms. Justify classifying them in different invertebrate phyla.

12. Some parasitic flatworms have a very complicated life cycle with more than one host. Infer why this might be adaptive.

Points to Consider

In this lesson, you read about flatworms and roundworms. In the next lesson, you'll read about worms called annelids. Mollusks such as snails are also described in the next lesson.

- How are annelids different from flatworms and roundworms?
- Why do you think annelids are placed in a lesson with mollusks instead of with flatworms and roundworms?

4.2 Mollusks and Annelids

Lesson Objectives

- Describe invertebrates in the phylum Mollusca.
- Summarize the characteristics of annelids.

Vocabulary

- Annelida
- deposit feeder
- gills
- heart
- mantle
- Mollusca
- regeneration

Introduction

Mollusks are invertebrates such as the common snail. Most mollusks have shells. Annelids are worms such as the familiar earthworm. They have segmented bodies. Annelids look like roundworms on the outside, but on the inside they are more like mollusks.

Mollusks

Have you ever been to the ocean or eaten seafood? If you have, then you probably have encountered members of the phylum **Mollusca.** Mollusks include snails, scallops, and squids, as shown in **Figure** 4.14. There are more than 100,000 known species of mollusks. About 80 percent of mollusk species are gastropods.

Structure and Function of Mollusks

Mollusks are a very diverse phylum. Some mollusks are nearly microscopic. The largest mollusk, a colossal squid, may be as long as a school bus and weigh over half a ton! The basic body plan of a mollusk is shown in **Figure** 4.15. The main distinguishing feature is a hard outer shell. It covers the top of the body and encloses the internal organs. Most mollusks have a distinct head region. The head may have tentacles for sensing the environment and grasping food. There is generally a muscular foot, which may be used for walking. However, the foot has evolved modifications in many species to be used for other purposes.

FIGURE 4.14
This figure shows some of the more common and familiar mollusks.

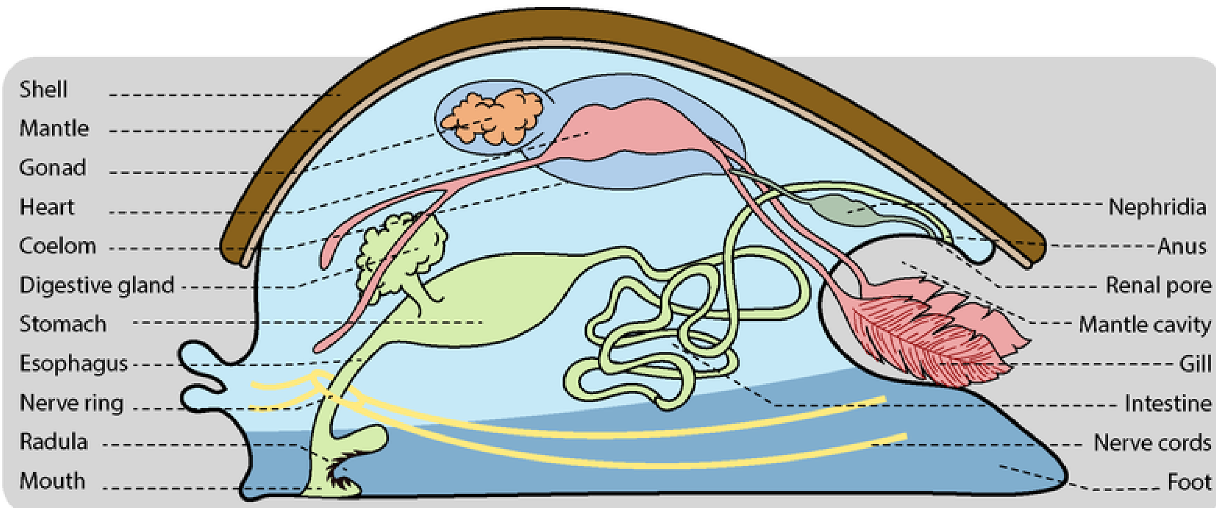

FIGURE 4.15
Basic Mollusk Body Plan. The basic body plan shown here varies among mollusk classes. For example, several mollusk species no longer have shells. Do you know which ones?

Two unique features of mollusks are the mantle and radula (see **Figure** 4.15). The **mantle** is a layer of tissue that lies between the shell and the body. It secretes calcium carbonate to form the shell. It forms a cavity, called the mantle cavity, between the mantle and the body. The mantle cavity pumps water for filter feeding. The radula is a feeding organ with teeth made of chitin. It is located in front of the mouth in the head region. Herbivorous mollusks use the radula to scrape food such as algae off rocks. Predatory mollusks use the radula to drill holes in the shells of their prey.

Mollusks have a coelom and a complete digestive system. Their excretory system consists of tube-shaped organs called nephridia (see **Figure** 4.15). The organs filter waste from body fluids and release the waste into the coelom. Terrestrial mollusks exchange gases with the surrounding air. This occurs across the lining of the mantle cavity.

Aquatic mollusks "breathe" under water with gills. **Gills** are thin filaments that absorb gases and exchange them between the blood and surrounding water.

Mollusks have a circulatory system with one or two hearts that pump blood. The **heart** is a muscular organ that pumps blood through the circulatory system when its muscles contract. The circulatory system may be open or closed, depending on the species.

The major classes of mollusks vary in structure and function. You can read about some of their differences in **Figure** 4.16.

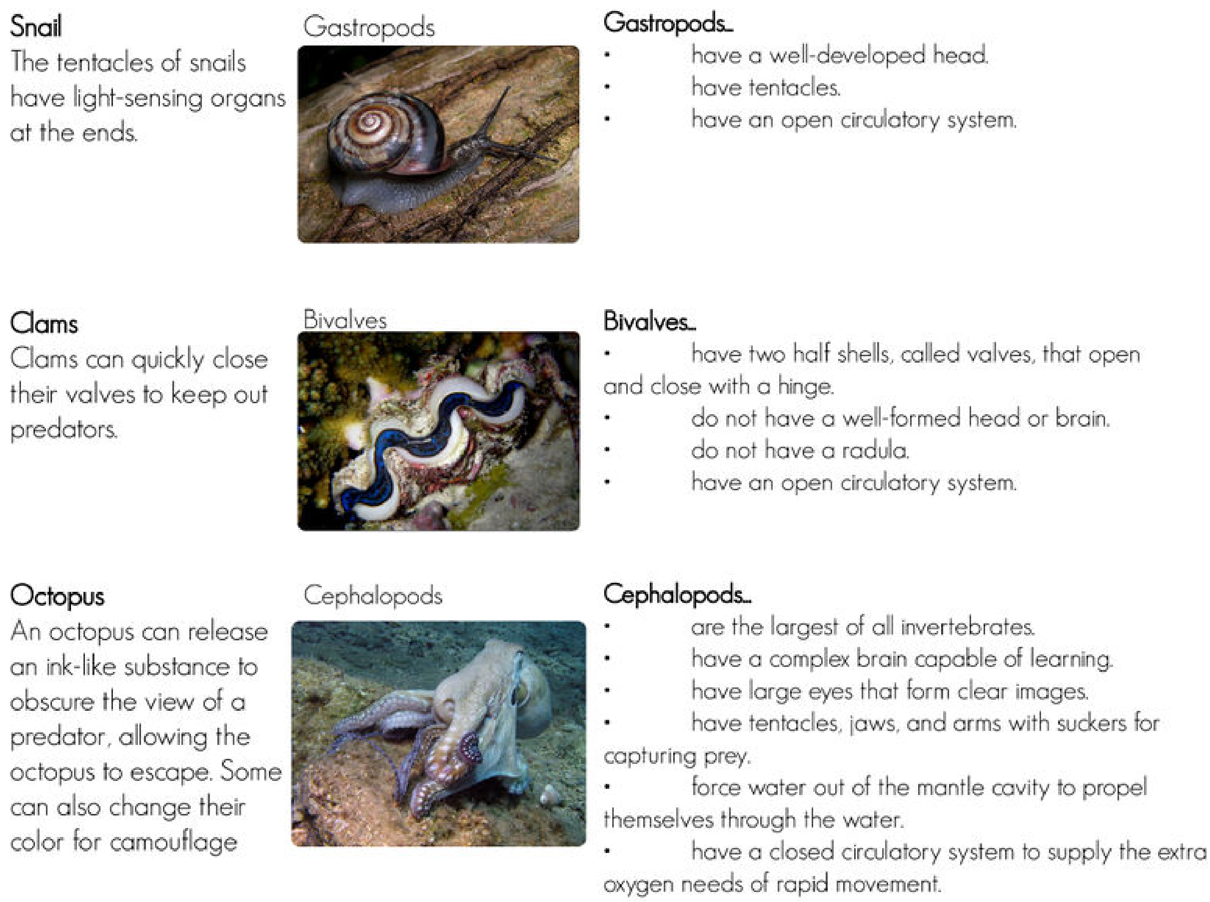

FIGURE 4.16

Use this figure to compare and contrast gastropods, bivalves, and cephalopods

Mollusk Reproduction

Mollusks reproduce sexually. Most species have separate male and female sexes. Gametes are released into the mantle cavity. Fertilization may be internal or external, depending on the species. Fertilized eggs develop into larvae. There may be one or more larval stages. Each one is different from the adult stage. Mollusks (and annelids) have a unique larval form called a trochophore. It is a tiny organism with cilia for swimming.

Ecology of Mollusks

Mollusks live in most terrestrial, freshwater, and marine habitats. However, the majority of species live in the ocean. They can be found in both shallow and deep water and from tropical to polar latitudes. Mollusks are a major food source for other organisms, including humans. You may have eaten mollusks such as clams, oysters, scallops, or mussels.

The different classes of mollusks have different ways of obtaining food.

- Gastropods may be herbivores, predators, or internal parasites. They live in both aquatic and terrestrial habitats. Marine species live mainly in shallow coastal waters. Gastropods use their foot to crawl slowly over rocks, reefs, or soil, looking for food.
- Bivalves are generally sessile filter feeders. They live in both freshwater and marine habitats. They use their foot to attach themselves to rocks or reefs or to burrow into mud. Bivalves feed on plankton and nonliving organic matter. They filter the food out of the water as it flows through their mantle cavity.
- Cephalopods are carnivores that live only in marine habitats. They may be found in the open ocean or close to shore. They are either predators or scavengers. They generally eat other invertebrates and fish.

KQED: Cool Critters: Dwarf Cuttlefish

What's the coolest critter in the ocean under 4 inches long? The Dwarf Cuttlefish! Cuttlefish are marine animals that belong to the class Cephalopoda. Despite their name, cuttlefish are not fish but molluscs. Recent studies indicate that cuttlefish are among the most intelligent invertebrates, with one of the largest brain-to-body size ratios of all invertebrates. Cuttlefish have an internal shell called the cuttlebone and eight arms and two tentacles furnished with denticulated suckers, with which they secure their prey. For more information on the cuttlefish, see http://www.kqed.org/quest/television/cool-critters-dwarf-cuttlefish .

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KQED: The Fierce Humboldt Squid

The Humboldt squid is a large, predatory invertebrate found in the Pacific Ocean. A mysterious sea creature up to 7 feet long, with 10 arms, a sharp beak and a ravenous appetite, packs of fierce Humboldt Squid attack nearly everything they see, from fish to scuba divers. Traveling in groups of 1,000 or more and swimming at speeds of more than 15 miles an hour, these animals hunt and feed together, and use jet propulsion to shoot out of the water to escape predators. Humboldt squid live at depths of between 600 and about 2,000 feet, coming to the surface at night to feed. They live for approximately two years and spend much of their short life in the ocean's oxygen-minimum zone, where very little other life exists. Because they live at such depths, little is known about these mysterious sea creatures. The Humboldt squid usually lives in the waters of the Humboldt Current, ranging from the southern tip of South America north to California, but in recent years, this squid has been found as far north as Alaska. Marine biologists are working to discover why they have headed north from their traditional homes off South America. See http://www.kqed.org/quest/television/the-fierce-humboldt-squid for additional information.

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Where's the Octopus?

When marine biologist Roger Hanlon captured the first scene in this video he started screaming. Hanlon, senior scientist at the Marine Biological Laboratory in Woods Hole, studies camouflage in cephalopods–squid, cuttlefish and octopus. They are masters of optical illusion. The video at http://www.sciencefriday.com/videos/watch/10397 shows some of Hanlon's top video picks of sea creatures going in and out of hiding.

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Annelids

The phylum **Annelida** is made up of segmented worms such as earthworms. Segmented worms are divided into many repeating segments. There are roughly 15,000 species of annelids. Most belong to one of three classes. A species in each class is pictured in **Figure** 4.17.

Structure and Function of Annelids

Annelids range in length from less than 1 millimeter (0.04 inches) to over 3 meters (10 feet). They never attain the large size of some mollusks. Like mollusks, however, they have a coelom. In fact, the annelid coelom is even larger, allowing greater development of internal organs. Annelids have other similarities with mollusks, including:

- A closed circulatory system (like cephalopods).
- An excretory system consisting of tubular nephridia.
- A complete digestive system.
- A brain.
- Sensory organs for detecting light and other stimuli.
- Gills for gas exchange (but many exchange gas through their skin).

The segmentation of annelids is highly adaptive. For one thing, it allows more efficient movement. Each segment generally has its own nerve and muscle tissues. Thus, localized muscle contractions can move just those segments needed for a particular motion. Segmentation also allows an animal to have specialized segments to carry out particular functions. This allows the whole animal to be more efficient. Annelids have the amazing capacity to regrow segments that break off. This is called **regeneration.**

Annelids have a variety of structures on the surface of their body for movement and other functions. These vary, depending on the species. Several of the structures are described in **Figure** 4.18.

FIGURE 4.17

Classes of Annelids. The majority of annelids are polychaetes. They live on the ocean floor, so you may not be familiar with them.

Annelid Reproduction

Most species of annelids can reproduce both asexually and sexually. However, leeches can reproduce only sexually. Asexual reproduction may occur by budding or fission. Sexual reproduction varies by species.

- In some species, the same individual produces both sperm and eggs. But worms mate to exchange sperm, rather than self-fertilizing their own eggs. Fertilized eggs are deposited in a mucous cocoon. Offspring emerge from the cocoon looking like small adults. They grow to adult size without going through a larval stage.
- In polychaete species, there are separate sexes. Adult worms go through a major transformation to develop reproductive organs. This occurs in many adults at once. Then they all swim to the surface and release their gametes in the water, where fertilization takes place. Offspring go through a larval stage before developing into adults.

Ecology of Annelids

Annelids live in a diversity of freshwater, marine, and terrestrial habitats. They vary in what they feed on and how they obtain their food.

- Earthworms are **deposit feeders.** They burrow through the ground, eating soil and extracting organic matter from it. Earthworm feces, called worm casts, are very rich in plant nutrients. Earthworm burrows help aerate soil, which is also good for plants.
- Polychaete worms live on the ocean floor. They may be sedentary filter feeders or active predators or scavengers. Active species crawl along the ocean floor in search of food.
- Leeches are either predators or parasites. As predators, they capture and eat other invertebrates. As parasites, they feed off the blood of vertebrate hosts. They have a tubular organ, called a proboscis, for feeding.

FIGURE 4.18

Annelid External Structures. Many annelids have bristles and other types of external structures. Each structure is not present in all species.

Lesson Summary

- Mollusks are invertebrates such as snails, scallops, and squids. They have a hard outer shell. There is a layer of tissue called the mantle between the shell and the body. Most mollusks have tentacles for feeding and sensing, and many have a muscular foot. Mollusks also have a coelom, a complete digestive system, and specialized organs for excretion. The majority of mollusks live in the ocean. Different classes of mollusks have different ways of obtaining food.

- Annelids are segmented worms such as earthworms and leeches. Annelids have a coelom, closed circulatory system, excretory system, and complete digestive system. They also have a brain. Earthworms are important deposit feeders that help form and enrich soil. Leeches are either predators or parasites. Parasitic leeches feed off the blood of vertebrate hosts.

Lesson Review Questions

Recall

1. Describe the basic body plan of a mollusk.

2. What are gills? What is their function?

3. What is the difference between an open and a closed circulatory system?

4. What is a radula? What is it used for?

5. Define regeneration.

Apply Concepts

6. Create a Venn diagram to show important similarities and differences among the three major classes of mollusks.

Think Critically

7. Explain the advantages of a segmented body.

8. Polychaete worms have an interesting reproductive strategy. Describe this strategy and infer its adaptive significance.

Points to Consider

Most invertebrates you have read about so far live in aquatic habitats. Many of those that are not aquatic live inside other organisms as parasites. In the next lesson you will read about invertebrates that live mainly on land. They are the arthropods, such as insects.

- Compared with aquatic invertebrates, what challenges do you think terrestrial invertebrates might face?
- How might terrestrial invertebrates meet these challenges? What special tissues, organs, or appendages might they have evolved to adapt to life on land?

4.3 Arthropods and Insects

Lesson Objectives

- Give an overview of the phylum Arthropoda.
- Outline the characteristics and importance of insects.

Vocabulary

- arthropod
- metamorphosis
- molting
- pupa
- trilobite

Introduction

Arthropods are not only the largest phylum of invertebrates. They are by far the largest phylum of the animal kingdom. Some 80 percent of all species living on Earth today are arthropods. Obviously, arthropods have been extremely successful. What accounts for their success? In this lesson, you will find out.

Arthropods

There are more than a million known species of arthropods. There may actually be ten times that many. Arthropods include insects, spiders, lobsters, and centipedes. The arthropods pictured in **Figure** 4.19 give just a hint of the phylum's diversity.

Structure and Function of Arthropods

Arthropods range in length from about 1 millimeter (0.04 inches) to 4 meters (about 13 feet). They have a segmented body with a hard exoskeleton. They also have jointed appendages. The body segments are the head, thorax, and abdomen (see **Figure** 4.20). In some arthropods, the head and thorax are joined together as a cephalothorax.

The arthropod exoskeleton consists of several layers of cuticle. The exoskeleton prevents water loss and gives support and protection. It also acts as a counterforce for the contraction of muscles. The exoskeleton doesn't grow as the animal grows. Therefore, it must be shed and replaced with a new one periodically through life. This is called **molting**.

FIGURE 4.19
Arthropod Diversity. Dust mites are among the smallest of arthropods. Japanese spider crabs are the largest. Besides size, what other differences among arthropods do you see in these photos?

The jointed appendages of arthropods may be used as legs for walking. Being jointed makes them more flexible. Try walking or climbing stairs without bending your knees, and you'll see why joints are helpful. In most arthropods, the appendages on the head have been modified for other functions. **Figure** 4.21 shows some of the head appendages found in arthropods. Sensory organs such as eyes are also found on the head.

Some arthropods have special excretory structures. They are called coxal glands and Malphigian tubules. Coxal glands collect and concentrate liquid waste from blood. They excrete the waste from the body through a pore. Malphigian tubules carry waste from the digestive tract to the anus. The waste is excreted through the anus.

Like mollusks and annelids, aquatic arthropods may have gills to exchange gases with the water (discussed below). Terrestrial arthropods, on the other hand, have special respiratory structures to exchange gases with the air. These are described in **Figure** 4.22.

Underwater Spiders

In the ponds of northern Europe lives a tiny brown spider that spends its entire life underwater. But just like land spiders, it needs oxygen to breathe. So, how does this spider breath? Does it use book lungs? No. In fact, aquatic spiders, known as *diving bell spiders*, have gills, and every so often, the spider leaves its underwater web to visit the surface and bring back a bubble of air that sticks to its hairy abdomen. It deposits the bubble into a little silk air tank. This *diving bell* is a gill that sucks oxygen from the water, allowing the spider to stay underwater for up to 24 hours. For additional information and pictures see http://news.sciencemag.org/sciencenow/2011/06/spiders.html?ref=hp .

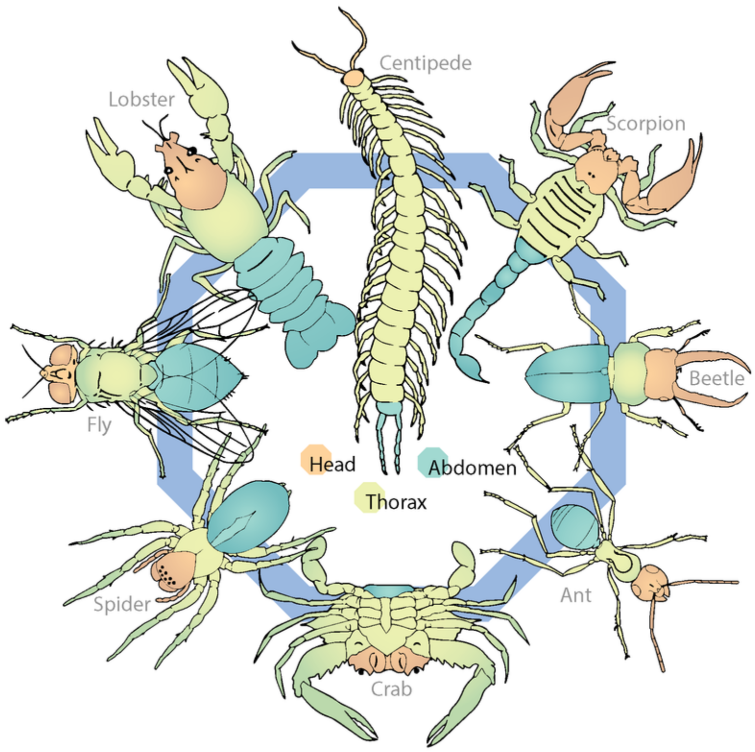

FIGURE 4.20
Arthropod Body Plan. Notice the three body segments of each organism.

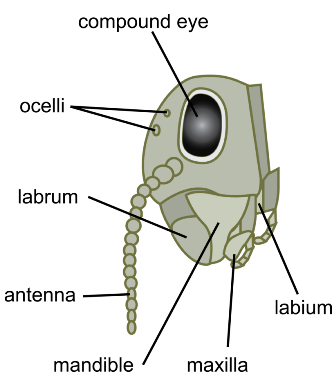

FIGURE 4.21
Arthropod Head. Arthropods have evolved a variety of specialized appendages and other structures on their head.

To see these spiders in action, watch this video: http://www.youtube.com/watch?v=GidrcvjoeKE

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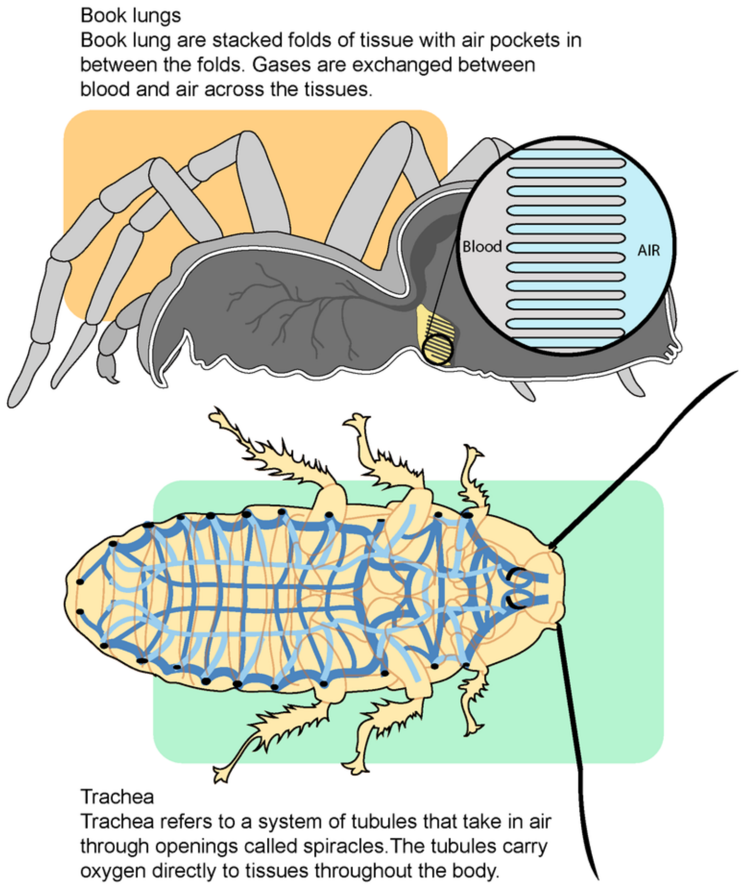


FIGURE 4.22
How Terrestrial Arthropods Breathe Air. Terrestrial arthropods have respiratory structures that let them breathe air.

Arthropod Reproduction

Arthropods have a life cycle with sexual reproduction. Most species go through larval stages after hatching. The larvae are very different from the adults. They change into the adult form in a process called **metamorphosis**. This may take place within a cocoon. A familiar example of metamorphosis is the transformation of a caterpillar (larva) into a butterfly (adult). Other arthropod species, in contrast, hatch young that look like small adults. These species lack both larval stages and metamorphosis.

Evolution of Arthropods

The oldest known arthropods are **trilobites**. A fossil trilobite is shown in **Figure** 4.23. Trilobites were marine arthropods. They had many segments with paired appendages for walking. As arthropods continued to evolve, segments fused. Eventually, arthropods with three major segments evolved. Appendages were also lost or modified during the course of arthropod evolution.

Arthropods were the first animals to live on land. The earliest terrestrial arthropods were probably millipedes. They moved to land about 430 million years ago. Early land arthropods evolved adaptations such as book lungs or trachea to breathe air. The exoskeleton was another important adaptation. It prevents an animal from drying out. It also provides support in the absence of buoyant water.

FIGURE 4.23
Trilobite Fossil. This trilobite fossil represents the earliest arthropods. Trilobites first appeared more than 500 million years ago. They lived for at least 200 million years before going extinct. They left behind large numbers of fossils.

Classification of Arthropods

Living arthropods are divided into four subphyla. They are described in **Table** 4.1. The Hexapoda subphylum includes mainly insects. There are so many insects and they are so important that they are described in greater detail below.

TABLE 4.1: Classification of Living Arthropods

Subphylum (includes)	Description	Example
Myriapoda (centipedes, millipedes)	terrestrial; herbivores or predators; 10–400 walking legs; poison claws for hunting	centipede 
Chelicerata (spiders, scorpions, mites, ticks, horseshoe crabs, sea spiders)	mainly terrestrial; predators or parasites; 8 walking legs; appendages called chelicerae for grasping prey; poison fangs for killing prey; no mandibles, maxillae, antennae; two body segments	spider 

TABLE 4.1: (continued)

Subphylum (includes)	Description	Example
Crustacea (lobsters, crabs, shrimp, barnacles, krill)	mainly aquatic, predators, scavengers, or filter feeders; two pairs of antennae and claws for hunting; unique larval stage (called "nauplius") with head appendages for swimming	lobster 
Hexapoda (ants, flies, grasshoppers, beetles, butterflies, moths, bees, springtails)	mainly terrestrial or aerial; herbivores, predators, parasites, scavengers, or decomposers; 6 walking legs; many modified appendages, such as wings for flying	beetle 

Insects

Most members of the subphylum Hexapoda are insects (class Insecta). In fact, more than half of all known organisms are insects. There may be more than 10 million insect species in the world, most of them yet to be identified. It's clear that insects, and not humans, dominate life on Earth.

Structure and Function of Insects

Insects range in length from less than a millimeter to about the length of your arm. They can be found in most habitats, but they are mainly terrestrial. Many can fly, so they are also aerial. Like other arthropods, insects have a head, thorax, and abdomen. They have a wide variety of appendages, including six legs attached to the thorax.

Insects have a pair of antennae for "smelling" and "tasting" chemicals. Some insects can also use their antennae to detect sound. Other sensory organs on the head include several simple eyes and a pair of compound eyes. The compound eyes let insects see images. Butterflies and bees can even see in color. For feeding, the head contains one pair of mandibles and two pairs of maxillae. Insects consume a wide range of foods, and their mouthparts have become specialized. Several variations are shown in **Figure** 4.24.

An insect's abdomen contains most of the internal organs. Like other arthropods, insects have a complete digestive system. They also have an open circulatory system and central nervous system. Like other terrestrial arthropods, they have trachea for breathing air and Malphigian tubules for excretion.

Insect Flight

The main reason that insects have been so successful is their ability to fly. Insects are the only invertebrates that can fly and the first animals to evolve flight. Flight has important advantages. It's a guaranteed means of escape from nonflying predators. It also aids in the search for food and mates.

Insects generally have two pairs of wings for flight. Wings are part of the exoskeleton and attached to the thorax. Insect wings show a lot of variation. As you can see in **Figure** 4.25, butterfly wings are paper-thin, whereas beetle wings are like armor. Not all insect wings work the same way, either. They differ in how the muscles are attached and whether the two pairs of wings work independently or together. Besides flight, wings serve other functions.

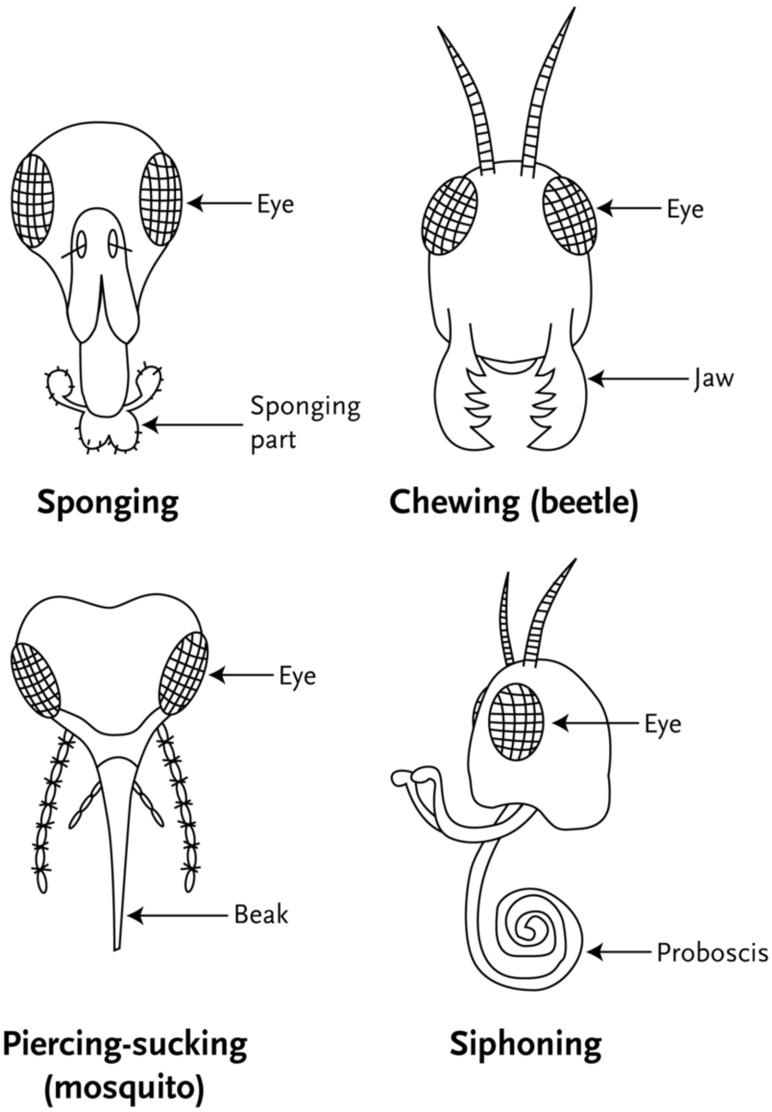


FIGURE 4.24
Mouthpart Specialization in Insects. The mouthparts of insects are adapted for different food sources. How do you think the different mouthparts evolved?

They may protect the body (beetles), communicate visually with other insects (butterflies), or produce sounds to attract mates (katydids).

Insect Reproduction

Nearly all insects reproduce sexually. Some can also reproduce asexually. An example of an insect life cycle is shown in **Figure** 4.26.

When an insect egg hatches, a larva emerges. The larva eats and grows and then enters the pupa stage. The **pupa** is immobile and may be encased in a cocoon. During the pupa stage, the insect goes through metamorphosis. Tissues and appendages of the larva break down and reorganize into the adult form. How did such an incredible transformation evolve? Metamorphosis is actually very advantageous. It allows functions to be divided between life stages. Each stage can evolve adaptations to suit it for its specific functions without affecting the adaptations of the other stage.

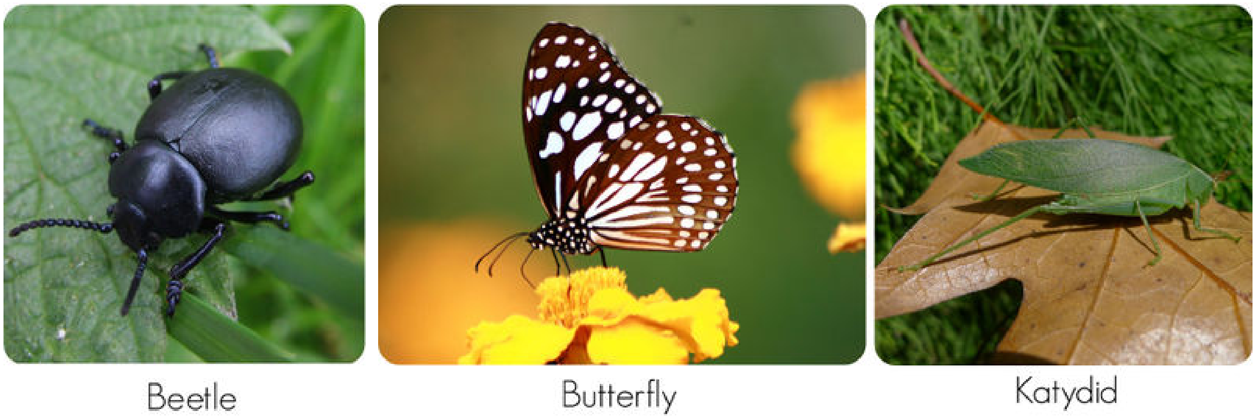


FIGURE 4.25

Form and Function in Insect Wings. Beetles, butterflies, and katydids all have two pairs of wings that they use for flight. However, the wings are very different because they have other functions as well.

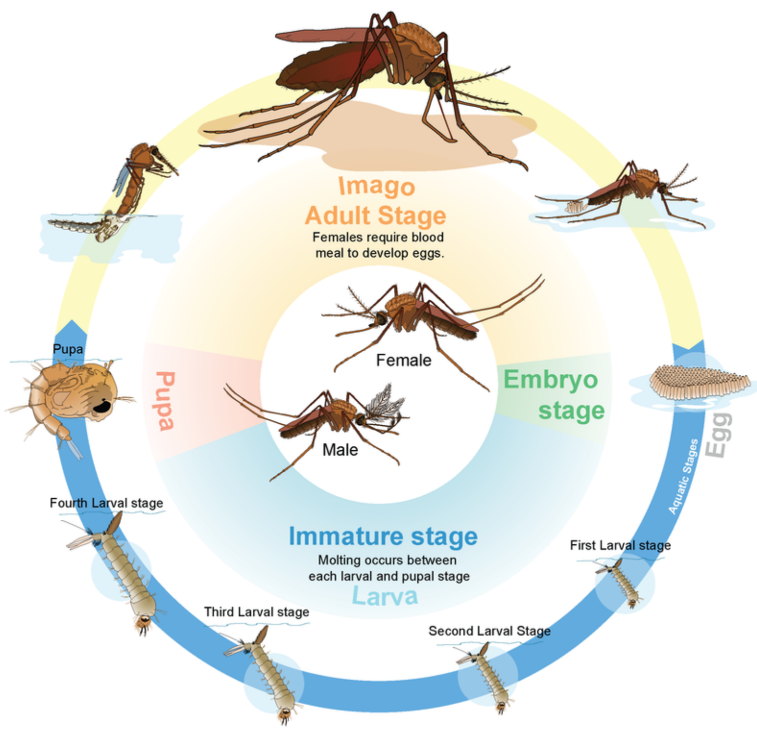


FIGURE 4.26

Insect Life Cycle. This diagram represents the life cycle of a mosquito. Most insects have a similar life cycle.

Insect Behavior

Insects are capable of a surprising range of behaviors. Most of their behaviors, such as flying and mating, are instinctive. These are behaviors that don't need to be learned. They are largely controlled by genes. However, some insect behaviors are learned. For example, ants and bees can learn where food is located and keep going back for more.

Many species of insects have evolved complex social behaviors. They live together in large, organized colonies (see **Figure** 4.27). This is true of ants, termites, bees, and wasps. Colonies may include millions of individual insects. Colony members divide up the labor of the colony. Different insects are specialized for different jobs. Some reproduce, while others care for the young. Still others get food or defend the nest.

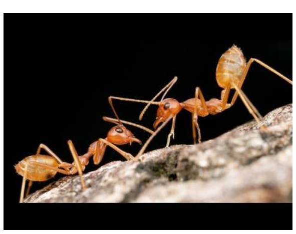
FIGURE 4.27

Termite Nest. This cathedral-like structure is the nest of a huge colony of termites in Australia. In fact, it is the world's largest known termite nest. It towers 7.5 meters (25 feet) above the ground and houses millions of termites.

Living in a large colony requires good communication. Ants communicate with chemicals called pheromones. For example, an ant deposits pheromones on the ground as it returns to the nest from a food source. It is marking the path so other ants can find the food. Honeybees communicate by doing a "waggle dance."

KQED: Ants: The Invisible Majority

Most of us think ants are just pests. But not Brian Fisher. Known as "The Ant Guy," he's on a mission to show the world just how important and amazing these little creatures are and in the process, catalog all of the world's 30,000 ant species before they become casualties of habitat loss. For more information see http://www.kqed.org/quest/television/ants-the-invisible-majority2 .



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KQED: Landbugs: A Population of Millions

Ladybugs, also known as ladybird beetles, have a life cycle of four to six weeks. In one year, as many as six generations of ladybird beetles may hatch. In the spring, each adult female lays up to 300 eggs in small clusters on plants where aphids are present. After a week, the wingless larvae hatch. Both the ladybird beetle larvae and adults are active predators, eating only aphids, scales, mites and other plant-eating insects. The ladybugs live on the vegetation where their prey is found, which includes roses, oleander, milkweed and broccoli. Adult ladybugs don't taste very good. A bird careless enough to try to eat one will not swallow it.

By late May to early June, when the larvae have depleted the food supply, the adults migrate to the mountains. There, they eat mainly pollen. The ladybugs gain fat from eating the pollen and this tides them over their nine-month hibernation. Thousands of adults hibernate over winter in tight clusters, called aggregates, under fallen leaves and ground litter near streams. In the clear, warmer days of early spring, the ladybugs break up the aggregates and begin several days of mating. You can learn more about ladybugs at this link: http://www.kqed.org/quest/television/ladybug-pajama-party .

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Insects and Humans

Most humans interact with insects every day. Many of these interactions are harmless and often go unnoticed. However, insects cause humans a lot of harm. They spread human diseases. For example, the deadly bubonic plague of the middle ages was spread by fleas. Today, millions of people die each year from malaria, which is spread by mosquitoes. Insects also eat our crops. Sometimes they travel in huge swarms that completely strip the land of all plant material (see **Figure** 4.28). On the other hand, we depend on insects for the very food we eat. Without insects to pollinate them, flowering plants—including many food crops—could not reproduce.

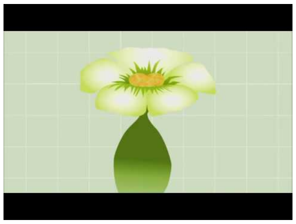
FIGURE 4.28

Locust Swarm. A swarm of locusts in the African country of Mauritania darkens the mid-day sky. The hungry insects will eat virtually all the plants in their path.

KQED: Better Bees: Super Bee and Wild Bee

Honeybees are one of the most well-known insects on the planet. Bees are naturalized on every continent except Antarctica. Honeybees have a highly developed social structure and depend on their community, or colony, for survival, with a colony containing up to 20,000 bees. When bees search plants for nectar, pollen sticks to the fuzzy hairs that cover their hind legs. At the next flower, some of the pollen rubs off and fertilizes that flower. In this way, bees help improve fruit production. Bees pollinate an estimated 130 different varieties of fruit, flowers, nuts and

vegetables in the United States alone. Farmers obviously depend on bees to pollinate crops, such as fruit and nuts, but in recent years thousands of bee colonies have disappeared. This could be a devastating issue for farmers. Can anything be done? Meet two Northern California researchers looking for ways to make sure we always have bees to pollinate our crops at http://www.kqed.org/quest/television/better-bees-super-bee-and-wild-bee .



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Lesson Summary

- Arthropods are the largest phylum in the animal kingdom. Most arthropods are insects. The phylum also includes spiders, centipedes, and crustaceans. The arthropod body consists of three segments with a hard exoskeleton and jointed appendages. Terrestrial arthropods have adaptations for life on land, such as trachea or book lungs for breathing air. The earliest arthropods were trilobites. The earliest land arthropods were millipedes.
- Insects are arthropods in the class Hexapoda. They are the most numerous organisms in the world. Most are terrestrial, and many are aerial. Insects have six legs and a pair of antennae for sensing chemicals. They also have several eyes and specialized mouthparts for feeding. Insects are the only invertebrates that can fly. Flight is the main reason for their success. Insects may live in large colonies and have complex social behaviors. Insects spread disease and destroy crops. However, they are essential for pollinating flowering plants.

Lesson Review Questions

Recall

1. Identify distinguishing traits of most arthropods.

2. What is molting? Why does it occur?

3. Name three arthropod head appendages and state their functions.

4. Describe two structures that allow arthropods to breathe air.

5. List several traits that characterize insects.

6. State two important advantages of flight in insects.

7. Give examples of insect behavior.

Apply Concepts

8. Assume you see a "bug" crawling over the ground. It has two body segments and lacks antennae. Which arthropod subphylum does the "bug" belong to? Explain your answer.

9. Create a timeline of arthropod evolution.

Think Critically

10. Present facts and a logical argument to support the following statement: Insects dominate life on Earth.
11. Relate form to function in the mouthparts of insects.
12. Explain why distinctive life stages and metamorphosis are adaptive.

Points to Consider

The invertebrates described so far in this chapter are protostomes. They differ from the other major grouping of animals, the deuterostomes, in how their embryos develop. The next lesson describes invertebrates that are deuterostomes. These invertebrates are more closely related to vertebrates such as humans. Some of these invertebrates are even placed in the chordate phylum.

- What traits do you think might characterize deuterostome invertebrates?
- How might chordate invertebrates differ from nonchordate invertebrates?

4.4 Echinoderms and Invertebrate Chordates

Lesson Objectives

- Summarize traits of echinoderm invertebrates.
- Outline the characteristics and classification of chordates.
- Describe the two subphyla of invertebrate chordates.

Vocabulary

- chordates
- echinoderms
- lancelets
- tunicates

Introduction

The invertebrate phyla described in the first three lessons of this chapter are all nonchordates. They don't have a notochord, and they are not closely related to chordates. In this lesson, you will read about invertebrates that are closely related to chordates—including you.

Echinoderms

Echinoderms are marine organisms that make up the phylum Echinodermata. They can be found in the ocean from the equator to the poles. There are roughly 6000 living species of echinoderms. They are among the most distinctive organisms within the animal kingdom. Members of the phylum include sea stars (starfish), sand dollars, and feather stars, all shown in **Figure** 4.29.

Structure and Function of Echinoderms

Echinoderms are named for their "spiny skin." However, the spines aren't on their skin. They are part of the endoskeleton. The endoskeleton consists of calcium carbonate plates and spines, covered by a thin layer of skin. Adult echinoderms have radial symmetry. This is easy to see in the sea star and sand dollar in **Figure** 4.29. However, echinoderms evolved from an ancestor with bilateral symmetry. Evidence for this is the bilateral symmetry of their larvae.

A unique feature of echinoderms is their water vascular system. This is a network of canals that extends along each body part. In most echinoderms, the canals have external projections called tube feet (see **Figure** 4.30). The feet have suckers on the ends. Muscle contractions force water into the feet, causing them to extend outward. As the

FIGURE 4.29
Examples of Echinoderms. You may have seen sea stars and sand dollars at the beach because they live in shallow water near the shore. Other echinoderms, such as feather stars, are less commonly seen because they live in the deep ocean.

feet extend, they attach their suckers to new locations, farther away from their previous points of attachment. This results in a slow but powerful form of movement. The suckers are very strong. They can even be used to pry open the shells of prey.

FIGURE 4.30
Tube Feet of a Sea Star. The tube feet of a sea star (in white) are part of its water vascular system. There is a sucker on the end of each foot that allows the animal to "walk" slowly over a surface. The suckers are strong enough to pry open shells.

Echinoderms lack respiratory and excretory systems. Instead, the thin walls of their tube feet allow oxygen to diffuse in and wastes to diffuse out. Echinoderms also lack a centralized nervous system. They have an open circulatory system and lack a heart. On the other hand, echinoderms have a well-developed coelom and a complete digestive system. Echinoderms use pheromones to communicate with each other. They detect the chemicals with sensory cells on their body's surface. Some echinoderms also have simple eyes (ocelli) that can sense light. Like annelids, echinoderms have the ability to regenerate a missing body part.

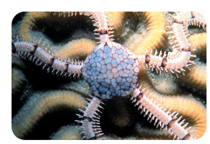
Echinoderm Reproduction

Some echinoderms can reproduce asexually by fission, but most echinoderms reproduce sexually. They generally have separate sexes and external fertilization. Eggs hatch into free-swimming larvae. The larvae undergo metamorphosis to change into the adult form. During metamorphosis, their bilateral symmetry changes to radial symmetry.

Echinoderm Classification

Living echinoderms are placed in five classes. These five classes show many similarities. Organisms in each class are described in **Table** 4.2.

TABLE 4.2: Classes of Living Echinoderms

Class (includes)	Description	Example
Crinoidea • feathers stars • sea lilies	fewer than 100 species; many have more than five arms; earliest and most primitive echinoderms; live on the ocean floor, mainly in deep water; filter feeders	feather star 
Asteroidea • sea stars	almost 2000 species; most have five arms; many are brightly colored; live on the ocean floor, mainly in shallow water; predators or scavengers	sea star 
Ophiuroidea • brittle stars	about 2000 species; central disk distinct from arms; move by flapping their arms, which lack suckers; live on the ocean floor in shallow or deep water; predators, scavengers, deposit feeders, or filter feeders	brittle star 
Echinoidea • sea urchins • sand dollars • sea biscuits • heart urchins	about 100 species; do not have arms but do have tube feet; have a specialized mouth part with teeth to scrape food from rocks; live on the ocean floor in shallow or deep water; predators, herbivores, or filter feeders	sea urchin 
Holothuroidea • sea cucumbers	about 1000 species; long body without arms; unlike other echinoderms, have a respiratory system; live on the ocean floor in shallow or deep water; deposit feeders, or filter feeders	sea cucumber 

Introduction to Chordates

The phylum Chordata consists of both invertebrate and vertebrate **chordates**. It is a large and diverse phylum. It includes some 60,000 species. Chordates range in length from about a centimeter (0.4 inches) to over 30 meters (100 feet). They live in marine, freshwater, terrestrial, and aerial habitats. They can be found from the equator to the poles. Several examples of chordates are pictured in **Figure** 4.31.

FIGURE 4.31

Diversity of Chordates. These six species illustrate the diversity of the phylum Chordata.

Characteristics of Chordates

Chordates have three embryonic cell layers. They also have a segmented body with a coelom and bilateral symmetry. Chordates have a complete digestive system and a closed circulatory system. Their nervous system is centralized. There are four additional traits that are unique to chordates. These four traits, shown in **Figure** 4.32, define the chordate phylum.

- Post-anal tail: The tail is opposite the head and extends past the anus.
- Dorsal hollow nerve cord: The nerve cord runs along the top, or dorsal, side of the animal. (In nonchordate animals, the nerve cord is solid and runs along the bottom).
- Notochord: The notochord lies between the dorsal nerve cord and the digestive tract. It provides stiffness to counterbalance the pull of muscles.
- Pharyngeal slits: Pharyngeal slits are located in the pharynx. This is the tube that joins the mouth to the digestive and respiratory tracts.

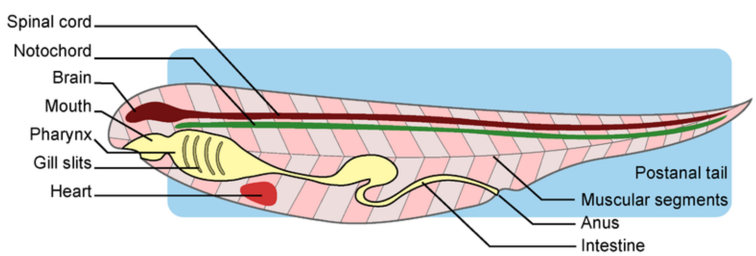


FIGURE 4.32
Body Plan of a Typical Chordate. The body plan of a chordate includes a post-anal tail, notochord, dorsal hollow nerve cord, and pharyngeal slits.

In some chordates, all four traits persist throughout life and serve important functions. However, in many chordates, including humans, all four traits are present only during the embryonic stage. After that, some of the traits disappear or develop into other organs. For example, in humans, pharyngeal slits are present in embryos and later develop into the middle ear.

Classification of Chordates

Living species of chordates are classified into three major subphyla: Vertebrata, Urochordata, and Cephalochordata. Vertebrates are all chordates that have a backbone. The other two subphyla are invertebrate chordates that lack a backbone.

Invertebrate Chordates

Members of the subphylum Urochordata are **tunicates** (also called sea squirts). Members of the subphylum Cephalochordata are **lancelets**. Both tunicates and lancelets are small and primitive. They are probably similar to the earliest chordates that evolved more than 500 million years ago.

Tunicates

There are about 3,000 living species of tunicates (see **Figure** 4.33). They inhabit shallow marine waters. Larval tunicates are free-swimming. They have all four defining chordate traits. Adult tunicates are sessile. They no longer have a notochord or post-anal tail.

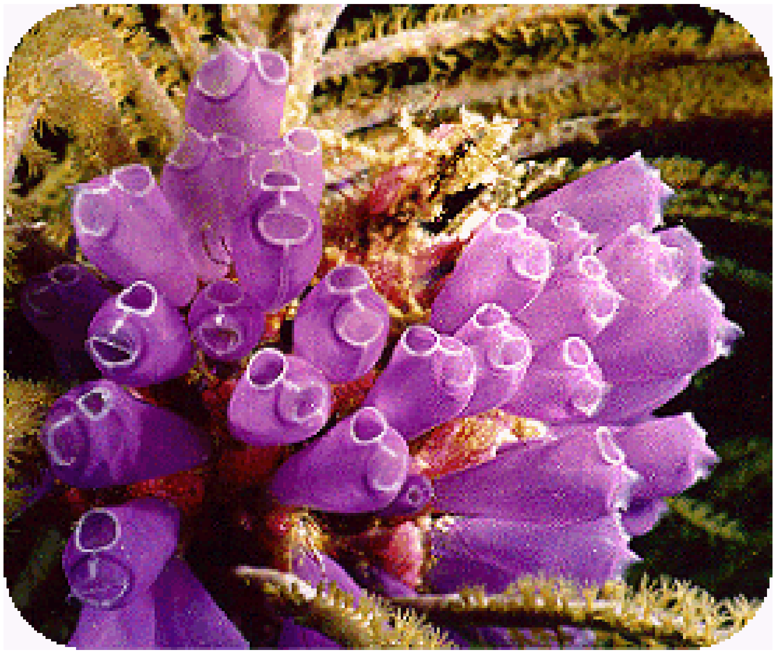


FIGURE 4.33
Tunicates (Urochordata). Tunicates are one of two subphyla of invertebrate chordates.

Adult tunicates are barrel-shaped. They have two openings that siphon water into and out of the body. The flow of water provides food for filter feeding. Tunicates reproduce sexually. Each individual produces both male and female gametes. However, they avoid self-fertilization. Tunicates can also reproduce asexually by budding.

Lancelets

There are only about 25 living species of lancelets. They inhabit the ocean floor where the water is shallow. Lancelet larvae are free-swimming. The adults can swim but spend most of their time buried in the sand. Like tunicates, lancelets are filter feeders. They take in water through their mouth and expel it through an opening called the atriopore (see **Figure** 4.34). Lancelets reproduce sexually and have separate sexes.

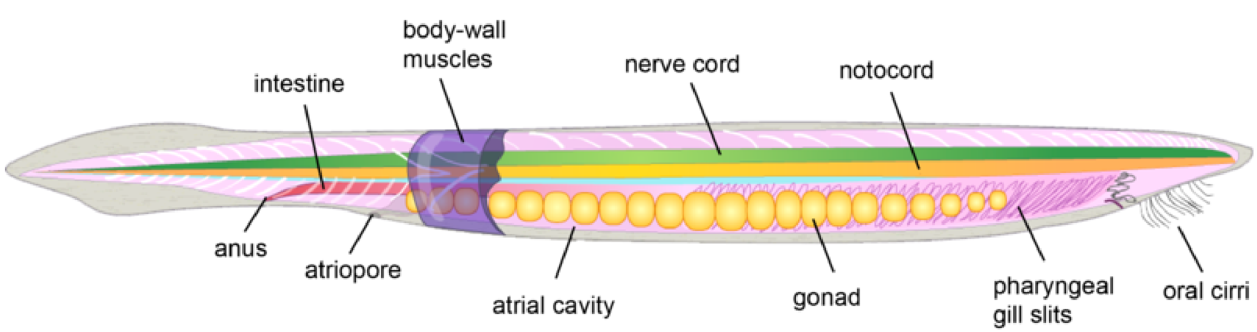


FIGURE 4.34
Lancelet (Cephalochordata). Unlike tunicates, lancelets retain all four defining chordate traits in the adult stage. Can you find them?

Lesson Summary

- Echinoderms are marine invertebrates. They include sea stars, sand dollars, and feather stars. They have a spiny endoskeleton. They have radial symmetry as adults but bilateral symmetry as larvae. Echinoderms have a unique water vascular system with tube feet. This allows slow but powerful movement.
- Chordates include vertebrates and invertebrates that have a notochord. Chordates also have a post-anal tail, dorsal hollow nerve cord, and pharyngeal slits. Vertebrate chordates have a backbone, while invertebrate chordates do not. Invertebrate chordates include tunicates and lancelets; both are primitive marine organisms.

Lesson Review Questions

Recall

1. Describe the echinoderm endoskeleton.
2. Give an example of an organism in each class of living echinoderms.
3. Identify the four defining traits of chordates.
4. Name and describe the two subphyla of invertebrate chordates.

Apply Concepts

5. Create a labeled drawing that explains how the tube feet of echinoderms allow them to "walk."

Think Critically

6. Adult sea stars and other echinoderms have obvious radial symmetry. What evidence supports the claim that echinoderms evolved from an ancestor with bilateral symmetry?
7. Adult humans lack the defining traits of chordates. Why are humans still classified in the chordate phylum?

Points to Consider

This chapter and the chapter before it describe the amazing diversity of invertebrates. The remaining chapters are devoted to vertebrates.

- How do vertebrates differ from invertebrates? What is the main distinguishing feature of vertebrates?
- Many traits that evolved in invertebrates characterize all vertebrate animals as well. Which invertebrate traits do you think are also found in vertebrates such as humans?

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31. Tunicate: Chika Watanabe; Rhinoceros: Brian Snelson; Kangaroo: Subhash Chandra; Shark: Terry Goss; Cormorant: Linda Tanner; Whale: Courtesy of US National Oceanic and Atmospheric Administration. Tunicate: http://www.flickr.com/photos/chikawatanabe/61157859/; Rhinoceros: http://www.flickr.com/photos/exfordy/2961323775/; Kangaroo: http://www.flickr.com/photos/ysc/2179798100/; Shark: http://commons.wikimedia.org/wiki/File:White_shark.jpg; Cormorant: http://www.flickr.com/photos/goingslo/2306021399/in/photostream/; Whale: http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/bluewhale.htm . Tunicate, Rhinoceros, Kangaroo, Shark, Cormorant: CC BY 2.0; Whale: Public Domain
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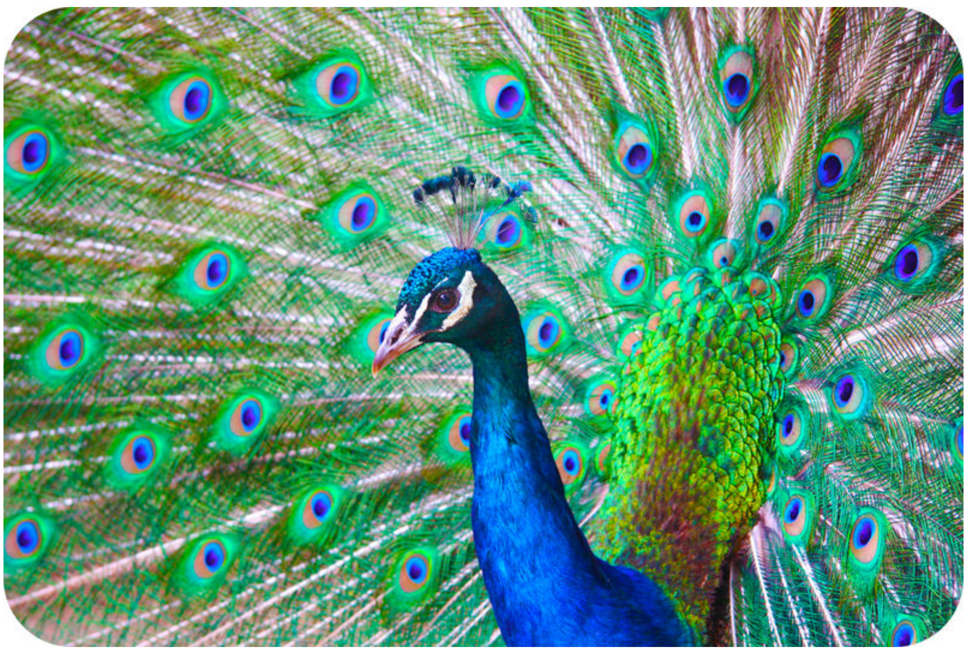
CHAPTER 5 From Fish to Birds

Chapter Outline



This stunning bird is a peacock. Do you know why he is spreading out his big, colorful tail feathers like a fan? He is trying to attract a female for mating. Both the feathers and the behavior evolved because they increase the chances that males of the species will reproduce and pass their genes to the next generation. Many other vertebrates have similar behaviors for attracting mates. Even fish display some remarkably sophisticated mating behaviors.

Fish and birds are both vertebrates. Vertebrates are a diverse and fascinating group of animals. In many ways, they are very different from the invertebrates described in previous chapters. Elaborate mating behaviors are just one way they differ. This chapter describes many other differences between vertebrates and invertebrates. It also describes in detail the classes of vertebrates from fish to birds.

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5.1 Overview of Vertebrates

Lesson Objectives

- List the characteristics of vertebrates.
- Explain how vertebrates reproduce.
- Identify the nine classes of vertebrates.
- Give an overview of vertebrate evolution.

Vocabulary

- bone
- cartilage
- cranium
- ectothermy
- endothermy
- immune system
- kidney
- ovipary
- ovovivipary
- vertebrae (singular, vertebra)
- vivipary

Introduction

Vertebrates are a subphylum of the phylum Chordata. Like all chordates, vertebrates have a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail. What other characteristics do vertebrates have? What traits set them apart from invertebrate chordates?

Characteristics of Vertebrates

The main distinguishing feature of vertebrates is their vertebral column, or backbone (see **Figure** 5.1). The backbone runs from the head to the tail along the dorsal (top) side of the body. The vertebral column is the core of the endoskeleton. It allows a vertebrate to hold its shape. It also houses and protects the spinal (nerve) cord that passes through it. The vertebral column is made up of repeating units called **vertebrae** (singular, vertebra). In many species, there are shock-absorbing discs between the vertebrae to cushion them during movement.

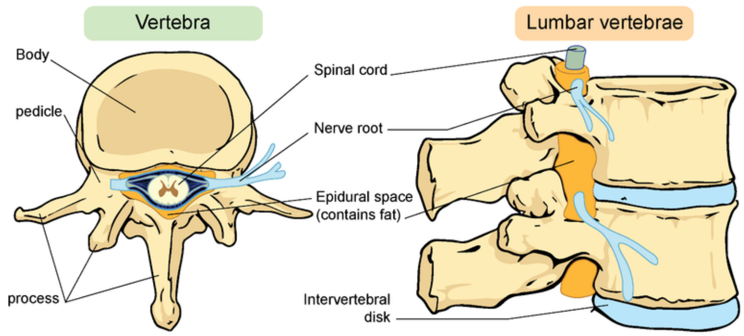


FIGURE 5.1

Human Vertebral Column and Vertebrae. The human vertebral column consists of 33 vertebrae. Two vertebrae are shown here enlarged.

Vertebrate Endoskeleton

Another distinguishing feature of vertebrates is an endoskeleton made of bone or cartilage. **Cartilage** is a tough tissue that contains a protein called collagen. **Bone** is a hard tissue that consists of a collagen matrix, or framework, filled in with minerals such as calcium. Bone is less flexible than cartilage but stronger. An endoskeleton made of bone rather than cartilage allows animals to grow larger and heavier. Bone also provides more protection for soft tissues and internal organs.

As shown in **Figure** 5.2, the vertebrate endoskeleton includes a **cranium,** or skull, to enclose and protect the brain. It also generally includes two pairs of limbs. Limb girdles (such as the human hips and shoulders) connect the limbs to the rest of the endoskeleton.

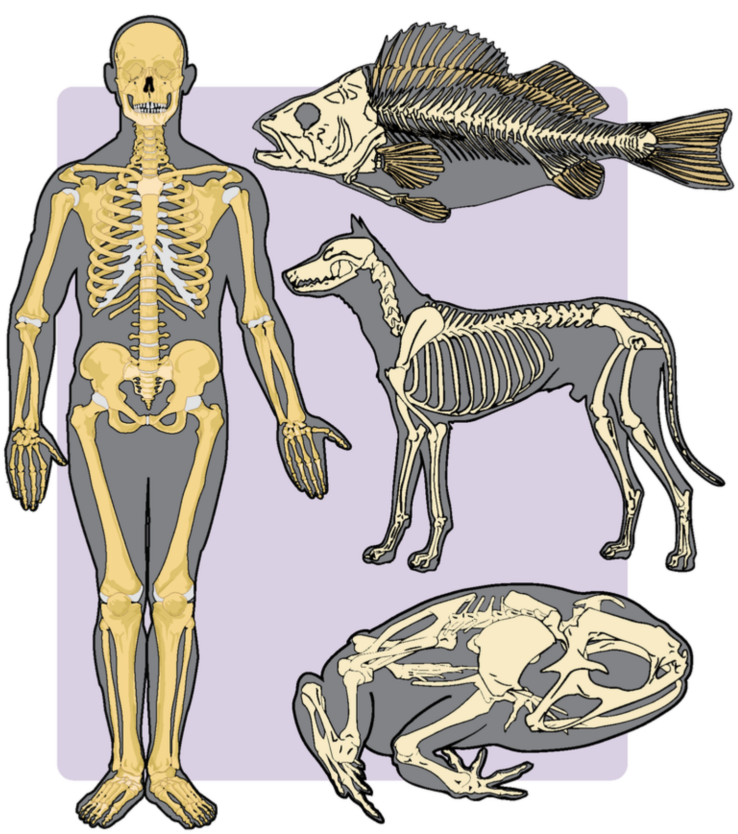


FIGURE 5.2

Vertebrate Endoskeletons. The vertebrate endoskeleton includes a vertebral column, cranium, limbs, and limb girdles. Can you find these parts in each endoskeleton shown here?

Other Vertebrate Traits

There are several additional traits found in virtually all vertebrates.

- Vertebrates have a system of muscles attached to the endoskeleton to enable movement. Muscles control movement by alternately contracting (shortening) and relaxing (lengthening). Generally, muscles work together in opposing pairs.
- Vertebrates have a closed circulatory system with a heart. Blood is completely contained within blood vessels that carry the blood throughout the body. The heart is divided into chambers that work together to pump blood. There are between two and four chambers in the vertebrate heart. With more chambers, there is more oxygen in the blood and more vigorous pumping action.
- Most vertebrates have skin covered with scales, feathers, fur, or hair. These features serve a variety of functions, such as waterproofing and insulating the body.
- Vertebrates have an excretory system that includes a pair of kidneys. **Kidneys** are organs that filter wastes from blood so they can be excreted from the body.
- Vertebrates have an endocrine system of glands that secrete hormones. Hormones are chemical messengers that control many body functions.
- Vertebrates have an adaptive immune system. The **immune system** is the organ system that defends the body from pathogens and other causes of disease. Being adaptive means that the immune system can *learn* to recognize specific pathogens. Then it can produce tailor-made chemicals called antibodies to *attack* them. This allows the immune system to launch a rapid attack whenever the pathogens invade the body again.
- Vertebrates have a centralized nervous system. As shown in **Figure** 5.3, the nervous system consists of a brain in the head region. It also includes a long spinal cord that runs from the brain to the tail end of the backbone. Long nerve fibers extend from the spinal cord to muscles and organs throughout the body.

Vertebrate Reproduction

Vertebrates reproduce sexually, and almost all of them have separate male and female sexes. Generally, aquatic species have external fertilization, whereas terrestrial species have internal fertilization. Can you think of a reason why aquatic and terrestrial vertebrates differ in this way?

Vertebrates have one of the following three reproductive strategies: ovipary, ovovivipary, or vivipary.

- **Ovipary** refers to the development of an embryo within an egg outside the mother's body. This occurs in most amphibians and reptiles and in all birds.
- **Ovovivipary** refers to the development of an embryo inside an egg within the mother's body until it hatches. The mother provides no nourishment to the developing embryo inside the egg. This occurs in some species of fish and reptiles.
- **Vivipary** refers to the development and nourishment of an embryo within the mother's body. Birth may be followed by a period of parental care of the offspring. This reproductive strategy occurs in almost all mammals.

Vertebrate Classification

There are about 50,000 vertebrate species, and they are placed in nine different classes. Five of the classes are fish. The other classes are amphibians, reptiles, birds, and mammals. **Table** 5.1 lists some of the distinguishing traits of each class.

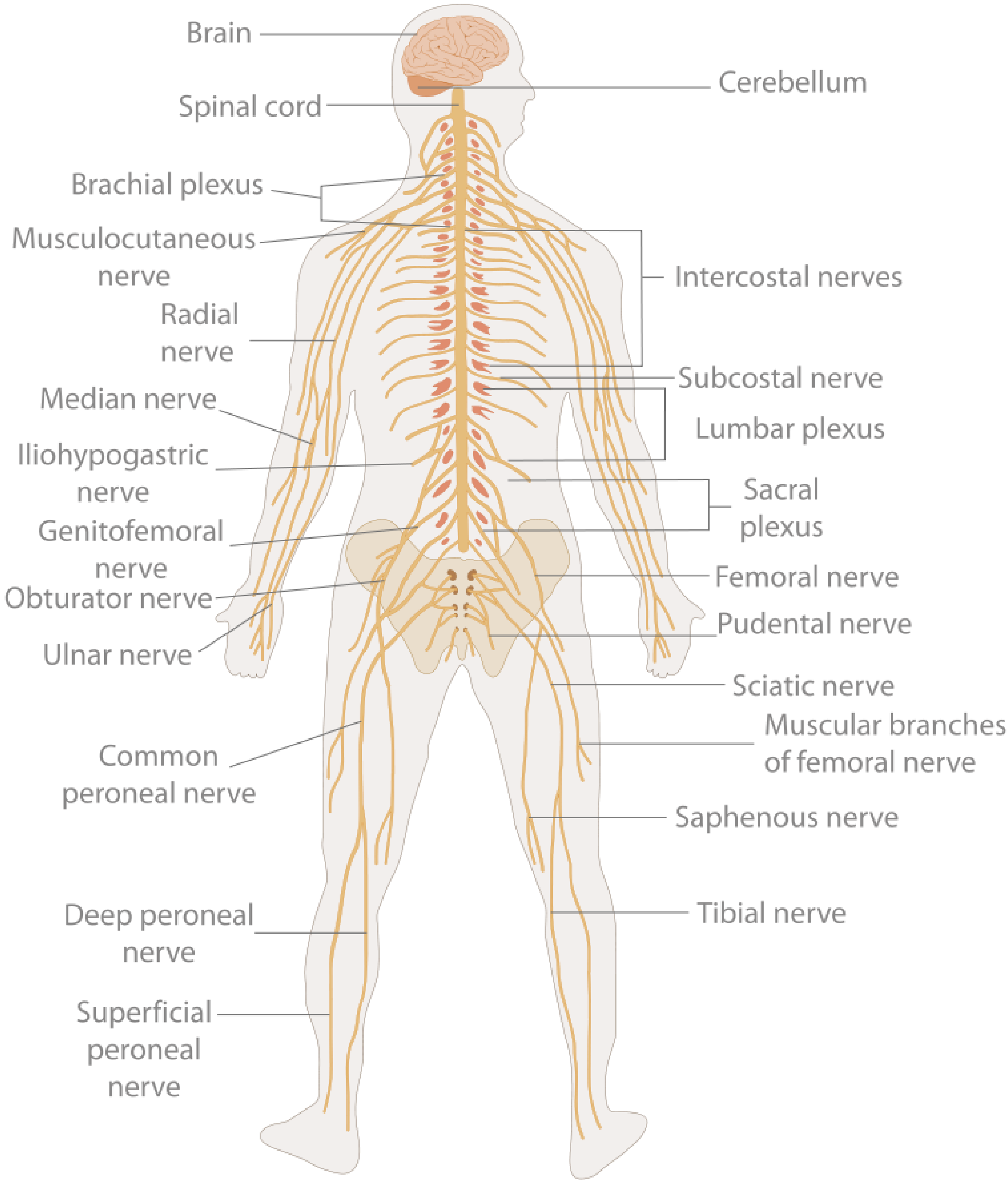


FIGURE 5.3

Nervous System (Human). The vertebrate nervous system includes a brain and spinal cord. It also includes a body-wide network of nerves, called peripheral nerves. They connect the spinal cord with the rest of the body.

TABLE 5.1: Classes of Vertebrates

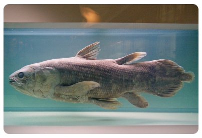
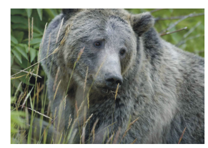
Class	Distinguishing Traits	Example
Hagfish	They have a cranium but no backbone; they do not have jaws; their endoskeleton is made of cartilage; they are ectothermic.	hagfish 
Lampreys	They have a partial backbone; they do not have jaws; their endoskeleton is made of cartilage; they are ectothermic.	lamprey 
Cartilaginous Fish	They have a complete backbone; they have jaws; their endoskeleton is made of cartilage; they are ectothermic.	shark 
Ray-Finned Fish	They have a backbone and jaws; their endoskeleton is made of bones; they have thin, bony fins; they are ectothermic.	perch 
Lobe-Finned Fish	They have a backbone and jaws; their endoskeleton is made of bones; they have thick, fleshy fins; they are ectothermic.	coelacanth 
Amphibians	They have a bony endoskeleton with a backbone and jaws; they have gills as larvae and lungs as adults; they have four limbs; they are ectothermic	frog 

TABLE 5.1: (continued)

Class	Distinguishing Traits	Example
Reptiles	They have a bony endoskeleton with a backbone and jaws; they breathe only with lungs; they have four limbs; their skin is covered with scales; they have amniotic eggs; they are ectothermic.	alligator 
Birds	They have a bony endoskeleton with a backbone but no jaws; they breathe only with lungs; they have four limbs, with the two front limbs modified as wings; their skin is covered with feathers; they have amniotic eggs; they are endothermic.	bird 
Mammals	They have a bony endoskeleton with a backbone and jaws; they breathe only with lungs; they have four limbs; their skin is covered with hair or fur; they have amniotic eggs; they have mammary (milk-producing) glands; they are endothermic.	bear 

Vertebrate Evolution

The earliest vertebrates were jawless fish, similar to living hagfish. They lived between 500 and 600 million years ago. They had a cranium but no vertebral column. The phylogenetic tree in **Figure** 5.4 gives an overview of vertebrate evolution. As more data become available, new ideas about vertebrate evolution emerge.

Evolution of Fish

Not too long after hagfish first appeared, fish similar to lampreys evolved a partial vertebral column. The first fish with a complete vertebral column evolved about 450 million years ago. These fish also had jaws and may have been similar to living sharks. Up to this point, all early vertebrates had an endoskeleton made of cartilage rather than bone. About 400 million years ago, the first bony fish appeared. A bony skeletal could support a larger body. Early bony fish evolved into modern ray-finned and lobe-finned fish.

Evolution of Other Vertebrate Classes

Amphibians, reptiles, mammals, and birds evolved after fish.

- The first amphibians evolved from a lobe-finned fish ancestor about 365 million years ago. They were the

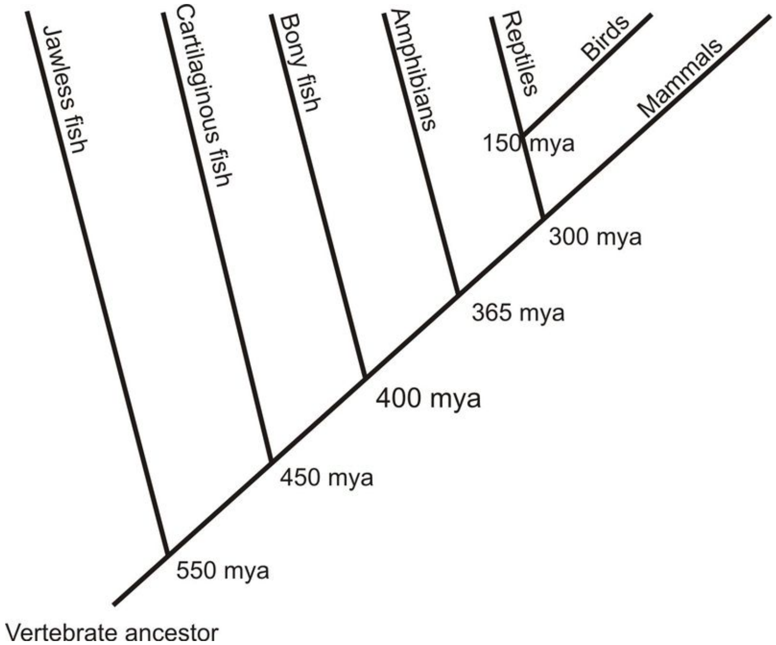


FIGURE 5.4

Phylogenetic Tree of Vertebrate Evolution. The earliest vertebrates evolved almost 550 million years ago. Which class of vertebrates evolved last?

first vertebrates to live on land, but they had to return to water to reproduce. This meant they had to live near bodies of water.

- The first reptiles evolved from an amphibian ancestor at least 300 million years ago. They laid amniotic eggs and had internal fertilization. They were the first vertebrates that no longer had to return to water to reproduce. They could live just about anywhere.
- Mammals and birds both evolved from reptile-like ancestors. The first mammals appeared about 200 million years ago and the earliest birds about 150 million years ago.

Evolution of Endothermy

Until mammals and birds evolved, all vertebrates were ectothermic. **Ectothermy** means regulating body temperature from the outside through behavioral changes. For example, an ectotherm might stay under a rock in the shade in order to keep cool on a hot, sunny day. Almost all living fish, amphibians, and reptiles are ectothermic. Their metabolic rate and level of activity depend mainly on the outside temperature. They can raise or lower their own temperature only slightly through behavior alone.

Both mammals and birds evolved endothermy. **Endothermy** means regulating body temperature from the inside through metabolic or other physical changes. On a cold day, for example, an endotherm may produce more heat by raising its metabolic rate. On a hot day, it may give off more heat by increasing blood flow to the surface of the body. Keeping body temperature stable allows cells to function at peak efficiency at all times. The metabolic rate and activity level can also remain high regardless of the outside temperature. On the other hand, maintaining a stable body temperature requires more energy—and more food.

Lesson Summary

- Vertebrates are a subphylum of chordates that have a vertebral column and an endoskeleton made of cartilage or bone. Vertebrates also have complex organ systems, including a closed circulatory system with a heart, an

excretory system with a pair of kidneys, and an adaptive immune system.
- Vertebrates reproduce sexually, and almost all have separate male and female sexes. Aquatic species generally have external fertilization, whereas terrestrial species usually have internal fertilization. Vertebrates have one of three reproductive strategies, known as ovipary, ovovivipary, or vivipary.
- The 50,000 species of living vertebrates are placed in nine classes: hagfish, lampreys, cartilaginous fish, ray-finned fish, lobe-finned fish, amphibians, reptiles, birds, and mammals.
- The earliest vertebrates resembled hagfish and lived more than 500 million years ago. As other classes of fish appeared, they evolved traits such as a complete vertebral column, jaws, and a bony endoskeleton. Amphibians were the first tetrapod vertebrates as well as the first vertebrates to live on land. Reptiles were the first amniotic vertebrates. Mammals and birds, which both descended from reptile-like ancestors, evolved endothermy, or the ability to regulate body temperature from the inside.

Lesson Review Questions

Recall

1. Describe the vertebrate vertebral column, and list its functions.

2. Contrast cartilage and bone, and state the advantages of a bony endoskeleton relative to a cartilaginous endoskeleton.

3. Identify the components of the vertebrate nervous system.

4. What is an adaptive immune system?

5. Define ovipary, ovovivipary, and vivipary. Which vertebrates use each type of reproductive strategy?

Apply Concepts

6. Create a time line of vertebrate evolution that shows how and when important vertebrate traits evolved.

Think Critically

7. Explain the significance of changes in the number of heart chambers during the course of vertebrate evolution.

8. Compare and contrast ectothermy and endothermy, including their pros and cons.

Points to Consider

The earliest and simplest vertebrates are fish. Fish also have the greatest number of vertebrate classes. Think about some of the fish you are familiar with, such as fish you eat or fish you may have seen in aquariums.

- Using the **Classes of Vertebrates Table** 5.1, which fish class or classes should these fish be placed in?
- How are all of the fish the same? In what ways do they differ?

5.2 Fish

Lesson Objectives

- Describe structure and function in fish.
- Explain how fish reproduce and develop.
- Give an overview of the five living classes of fish.
- Summarize the evolution of fish.
- Outline the ecology of the different fish classes.

Vocabulary

- fish
- spawning
- swim bladder

Introduction

Fish are aquatic vertebrates. They make up more than half of all vertebrate species. They are especially important in the study of vertebrate evolution because several important vertebrate traits evolved in fish.

Structure and Function in Fish

Fish show great diversity in body size. They range in length from about 8 millimeters (0.3 inches) to 16 meters (about 53 feet). Most are ectothermic and covered with scales. Scales protect fish from predators and parasites and reduce friction with the water. Multiple, overlapping scales provide a flexible covering that allows fish to move easily while swimming.

Adaptations for Water

Many structures in fish are adaptations for their aquatic lifestyle. Several are described below and shown in **Figure** 5.5.

- Fish have gills that allow them to "breathe" oxygen in water. Water enters the mouth, passes over the gills, and exits the body through a special opening. Gills absorb oxygen from the water as it passes over them.
- Fish have a stream-lined body. They are typically long and narrow, which reduces water resistance when they swim.

- Most fish have several fins for swimming. They use some of their fins to propel themselves through the water and others to steer the body as they swim.
- Fish have a system of muscles for movement. Muscle contractions ripple through the body in waves from head to tail. The contractions whip the tail fin against the water to propel the fish through the water.
- Most fish have a **swim bladder.** This is a balloon-like internal organ that contains gas. By changing the amount of gas in the bladder, a fish can move up or down through the water column.

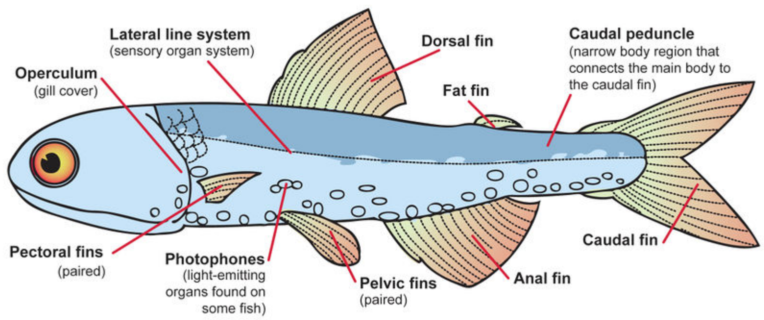


FIGURE 5.5
General Fish Body Plan. A fish has a stream-lined body with gills and fins.

Fish Organ Systems

Fish have a circulatory system with a two-chambered heart. Their digestive system is complete and includes several organs and glands. Jawed fish use their jaws and teeth to grind up food before passing it to the rest of the digestive tract. This allows them to consume larger prey.

Fish also have a centralized nervous system with a brain. Fish brains are small compared with the brains of other vertebrates, but they are large and complex compared with the brains of invertebrates. Fish also have highly developed sense organs that allow them to see, hear, feel, smell, and taste. Sharks and some other fish can even sense the very low levels of electricity emitted by other animals. This helps them locate prey.

Fish Reproduction and Development

Nearly all fish reproduce sexually, and most species have separate sexes. Those without separate sexes avoid self-fertilization by producing sperm and eggs at different times. Each fish typically produces a large number of gametes. In most fish species, fertilization takes place externally. These fish are oviparous. Eggs are laid and embryos develop outside the mother's body. In a minority of fish, including sharks, eggs develop inside the mother's body but without nourishment from the mother. These fish are ovoviviparous.

Spawning

In many species of fish, a large group of adults come together to release their gametes into the water at the same time. This is called **spawning.** It increases the chances that fertilization will take place. It also means that many embryos will form at once, which helps ensure that at least some of them will be able to escape predators.

With spawning, there is no way for fish parents to know which embryos are their own. Therefore, fish generally don't provide any care to their eggs or offspring. There are some exceptions, however, including the fish described in **Figure** 5.6.

FIGURE 5.6
Mouth Brooding. Some species of fish carry their fertilized eggs in their mouth until they hatch. This is called mouth brooding. If you look closely, you can see the eggs inside the mouth of the cardinalfish pictured here.

Fish Larvae

Fish eggs hatch into larvae that are different from the adult form of the species (see **Figure** 5.7). A larva swims attached to a large yolk sac, which provides the larva with food. The larva eventually goes through metamorphosis and changes into the adult form. However, it still needs to mature before it can reproduce.

FIGURE 5.7
Salmon Larva. This newly hatched salmon larva doesn't look very fish-like. The structure hanging from the larva is the yolk sac.

Classification of Fish

There are about 28,000 existing species of fish, and they are placed in five different classes. The classes are commonly referred to as hagfish, lampreys, cartilaginous fish, ray-finned fish, and lobe-finned fish (see **Table** 5.1 in the previous lesson).

Hagfish

Hagfish are very primitive fish. They retain their notochord throughout life rather than developing a backbone, and they lack scales and fins. They are classified as vertebrates mainly because they have a cranium. Hagfish are noted for secreting large amounts of thick, slimy mucus. The mucus makes them slippery, so they can slip out of the jaws of predators.

Lampreys

Like hagfish, lampreys also lack scales, but they have fins and a partial backbone. The most striking feature of lampreys is a large round sucker, lined with teeth, that surrounds the mouth (see **Figure** 5.8). Lampreys use their sucker to feed on the blood of other fish species.

FIGURE 5.8

Sucker Mouth of a Lamprey. The mouth of a lamprey is surrounded by a tooth-lined sucker.

Cartilaginous Fish

Cartilaginous fish include sharks, rays, and ratfish (see **Figure** 5.9). In addition to an endoskeleton composed of cartilage, these fish have a complete backbone. They also have a relatively large brain. They can solve problems and interact with other members of their species. They are generally predators with keen senses. Cartilaginous fish lack a swim bladder. Instead, they stay afloat by using a pair of muscular fins to push down against the water and create lift.

FIGURE 5.9

Cartilaginous Fish. All of these fish belong to the class of cartilaginous fish with jaws. (a) Oceanic whitetip shark (b) Ray (c) Ratfish

One of the most important traits of cartilaginous fish is their jaws. Jaws allow them to bite food and break it into

smaller pieces. This is a big adaptive advantage because it greatly expands the range of food sources they can consume. Jaws also make cartilaginous fish excellent predators. It you've ever seen the film *Jaws,* then you know that jaws make sharks very fierce predators (see also **Figure** 5.10).

FIGURE 5.10
Jaws of a Shark. Sharks have powerful jaws with multiple rows of sharp, saw-like teeth. Most other fish are no match for these powerful predators.

Ray-Finned Fish

Ray-finned fish include the majority of living fish species. including goldfish, tuna, salmon, perch, and cod. They have a bony endoskeleton and a swim bladder. Their thin fins consist of webs of skin over flexible bony rays, or spines. The fins lack muscle, so their movements are controlled by muscles in the body wall. You can compare their ray fins with the fleshy fins of lobe-finned fish in **Figure** 5.11.

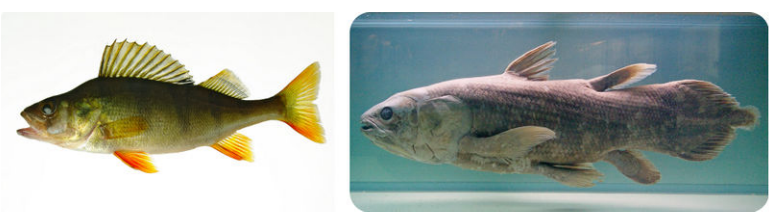


FIGURE 5.11
Fins of Bony Fish. The fins of ray-finned and lobe-finned fish are quite different. How is the form of the fins related to their different functions in the two classes of fish? Ray Fin (left), Lobe Fin (right)

Lobe-Finned Fish

Lobe-fined fish are currently far fewer in number than ray-finned fish. Their fins, like the one shown in **Figure** 5.11, contain a stump-like appendage of bone and muscle. There are two groups of lobe-finned fish still alive today: coelacanths and lungfish.

1. Coelacanths are ancient fish with just two living species. They are at risk of extinction because of their very small numbers.
2. Lungfish have a lung-like organ for breathing air. The organ is an adaptation of the swim bladder. It allows them to survive for long periods out of water.

Evolution of Fish

Invertebrate chordates use their gills to filter food out of water, not to absorb oxygen. In the early evolution of fish, there was a switch to using gills to absorb oxygen instead of to filter food. Gills consist of many thin, folded tissues that provide a large surface area for oxygen uptake. With more oxygen absorbed by the gills, fish could become much larger and more active.

Timing of Fish Evolution

Ancestors of hagfish are thought to have been the earliest vertebrates. Their fossils date back to about 550 million years ago. Fossils of cartilaginous fish with jaws, resembling living sharks, first appeared in the fossil record about 450 million years ago. They were followed about 50 million years later by the bony fish.

The Bony Fish

At first, the lobe-finned bony fish were much more common than the ray-finned bony fish that dominate today. Lobe-finned fish were also ancestral to amphibians. Their stump-like appendages and lung-like organs evolved into amphibian legs and lungs. Ray-finned bony fish may have been the first fish to evolve in freshwater. They eventually became the most diverse and dominant class of fish.

Ecology of Fish

The habitats and diets of fish are varied. They live throughout the ocean and also in freshwater lakes, ponds, rivers, and streams.

Fish Food

Most fish are predators, but the nature of their prey and how they consume it differs from one class to another and even within classes.

- Hagfish are deep-ocean bottom dwellers. They feed on other fish, either living or dead. They enter the body of their prey through the mouth or anus. Then they literally eat their prey from the inside out.
- Lampreys generally live in shallow ocean water or freshwater. They either consume small invertebrates or suck blood from larger fish with their sucker mouth.
- Cartilaginous fish such as sharks may live on the bottom of the ocean. However, most live in the water column. They prey on other fish and aquatic mammals or else consume plankton.
- Bony fish may live in salt water or freshwater. They consume a wide range of foods. For example, they may eat algae, smaller fish, detritus, or dead organisms, depending on the species of fish.

Fish at Risk

Today, more than 1,000 species of fish are at risk of extinction. This is mainly because of human actions. Specific causes include over-fishing and habitat destruction caused by water pollution, dam building, and the introduction of non-native species.

Lesson Summary

- Fish are aquatic, ectothermic vertebrates. Many structures in fish are adaptations for their aquatic lifestyle. For example, fish have a stream-lined body that reduces water resistance while swimming. They also have gills for "breathing" oxygen in water and fins for propelling and steering their body through water.
- Nearly all fish reproduce sexually and have separate sexes. Fertilization is generally external, and most fish are oviparous. Many adults of the same species may come together in a group and release gametes into the water at the same time, which is called spawning. Fish hatch into larvae that are different from the adult form of the species.
- There are about 28,000 existing species of fish, and they are placed in five classes: hagfish, lampreys, cartilaginous fish, ray-finned bony fish, and lobe-finned bony fish.
- The evolution of fish included a shift from using the gills for filtering food to using them to absorb oxygen from water. The earliest fish, resembling living hagfish, evolved about 550 million years ago. Adaptations that eventually evolved in fish include a complete vertebral column, jaws, and an endoskeleton made of bones instead of cartilage.
- Fish live throughout the ocean and in freshwater lakes and streams. Most fish are predators, but the nature of their prey and how they consume it may vary. Many species of fish are threatened by human actions, such as water pollution and over-fishing.

Lesson Review Questions

Recall

1. What are gills? What purpose do they serve in fish?
2. Describe fish scales, and state their functions.
3. Describe how fish use their muscles to swim.
4. What is a swim bladder? How is it used?
5. List two ways that fish can sense prey animals.

Apply Concepts

6. Assume that a new species of fish has been discovered deep in the ocean. It has a complete vertebral column made of cartilage. Which class should the new species be placed in? Name one other trait you would expect to find in the new species of fish. Explain your answers.

Think Critically

7. Explain why the practice of spawning is adaptive.
8. Fish with jaws may be very large. Infer how their jaws may be related to their large body size.

Points to Consider

Lobe-finned fish were the ancestors of amphibians, which were the first vertebrates to live on land.

- What are some examples of amphibians?
- How do you think amphibians might differ from lobe-finned fish? What adaptations do you think amphibians needed to evolve in order to live on land?

5.3 Amphibians

Lesson Objectives

- Describe structure and function in amphibians.
- Outline the reproduction and development of amphibians.
- Identify the three living amphibian orders.
- Describe how amphibians evolved.
- State where amphibians live and how they obtain food.

Vocabulary

- amphibian
- cloaca
- keratin
- tetrapod

Introduction

Amphibians are vertebrates that exist in two worlds. They divide their time between freshwater and terrestrial habitats. They share a number of features with air-breathing lungfish, but they also differ from lungfish in many ways. One way they differ is their appendages. Amphibians are the first true **tetrapods,** or vertebrates with four limbs. Modern amphibians include frogs, salamanders, and caecilians, as shown **Figure** 5.12.

Structure and Function in Amphibians

Amphibians have less variation in size than fish, ranging in length from 1 centimeter (2.5 inches) to 1.5 meters (about 5 feet). They generally have moist skin without scales. Their skin contains **keratin,** a tough, fibrous protein found in the skin, scales, feathers, hair, and nails of tetrapod vertebrates, from amphibians to humans. Some forms of keratin are tougher than others. The form in amphibian skin is not very tough, and it allows gases and water to pass through their skin.

Amphibian Ectothermy

Amphibians are ectothermic, so their internal body temperature is generally about the same as the temperature of their environment. When it's cold outside, their body temperature drops, and they become very sluggish. When the outside temperature rises, so does their body temperature, and they are much more active. What do you think might be some of the pros and cons of ectothermy in amphibians?

FIGURE 5.12
Examples of Living Amphibians. In what ways do these three amphibians appear to be similar? In what ways do they appear to be different?

Amphibian Organ Systems

All amphibians have digestive, excretory, and reproductive systems. All three systems share a body cavity called the **cloaca.** Wastes enter the cloaca from the digestive and excretory systems, and gametes enter the cloaca from the reproductive system. An opening in the cloaca allows the wastes and gametes to leave the body.

Amphibians have a relatively complex circulatory system with a three-chambered heart. Their nervous system is also rather complex, allowing them to interact with each other and their environment. Amphibians have sense organs to smell and taste chemicals. Other sense organs include eyes and ears. Of all amphibians, frogs generally have the best vision and hearing. Frogs also have a larynx, or voice box, to make sounds.

Most amphibians breathe with gills as larvae and with lungs as adults. Additional oxygen is absorbed through the skin in most species. The skin is kept moist by mucus, which is secreted by mucous glands. In some species, mucous glands also produce toxins, which help protect the amphibians from predators. The golden frog shown in **Figure** 5.13 is an example of a toxic amphibian.

Amphibian Reproduction and Development

Amphibians reproduce sexually with either external or internal fertilization. They attract mates in a variety of ways. For example, the loud croaking of frogs is their mating call. Each frog species has its own distinctive call that other members of the species recognize as their own. Most salamanders use their sense of smell to find a mate. The males produce a chemical odor that attracts females of the species.

FIGURE 5.13
Toxic Frog. This golden frog is only about 5 centimeters (2 inches) long, but it's the most poisonous vertebrate on Earth. One dose of its toxin can kill up to 20 humans!

Amphibian Eggs

Unlike other tetrapod vertebrates (reptiles, birds, and mammals), amphibians do not produce amniotic eggs. Therefore, they must lay their eggs in water so they won't dry out. Their eggs are usually covered in a jelly-like substance, like the frog eggs shown in **Figure** 5.14. The *jelly* helps keep the eggs moist and offers some protection from predators.

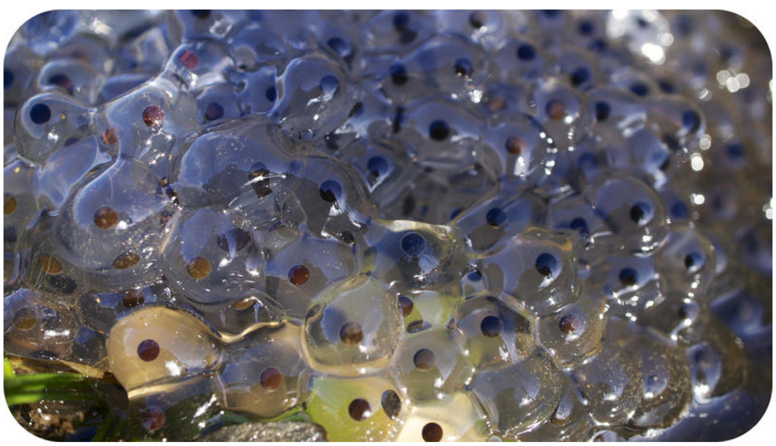


FIGURE 5.14
Frog Eggs. Frog eggs are surrounded by "jelly." What is its function?

Amphibians generally lay large number of eggs. Often, many adults lay eggs in the same place at the same time. This helps to ensure that eggs will be fertilized and at least some of the embryos will survive. Once eggs have been laid, most amphibians are done with their parenting.

Amphibian Larvae

The majority of amphibian species go through a larval stage that is very different from the adult form, as you can see from the frog in **Figure** 5.15. The early larval, or tadpole, stage resembles a fish. It lacks legs and has a long tail, which it uses to swim. The tadpole also has gills to absorb oxygen from water. As the larva undergoes metamorphosis, it grows legs, loses its tail, and develops lungs. These changes prepare it for life on land as an adult frog.

FIGURE 5.15
Frog Development: From Tadpole to Adult. A frog larva (tadpole) goes through many changes by adulthood. How do these changes prepare it for life as an adult frog?

Classification of Amphibians

There are about 6,200 known species of living amphibians. They are placed in three different orders:

1. Frogs and toads
2. Salamanders and newts
3. Caecilians

Frogs and Toads

One feature that distinguishes frogs and toads from other amphibians is lack of a tail in adulthood. Frogs and toads also have much longer back legs than other amphibians. Their back legs are modified for jumping. Frogs can jump up to 20 times their own body length. That's the same as you jumping at least 100 feet, or more than the length of a basketball court. Think how fast you could move if you could travel that far on one jump!

Frogs and toads are closely related, but they differ in several ways. Generally, frogs spend more time in water, and toads spend more time on land. As you can see from **Figure** 5.16, frogs also have smoother, moister skin than toads, as well as longer hind legs.

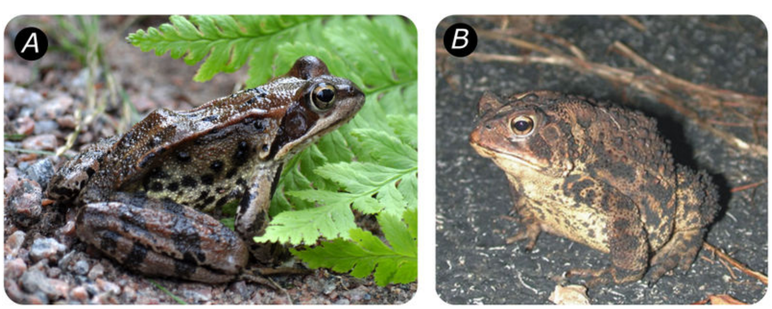


FIGURE 5.16
Frog and Toad. Frogs (a) and toads (b) are placed in the same amphibian order. What traits do they share?

Salamanders and Newts

Unlike frogs and toads, salamanders and newts keep their tails as adults (see **Figure** 5.17). They also have a long body with short legs, and all their legs are about the same length. This is because they are adapted for walking and swimming rather than jumping. An unusual characteristic of salamanders is their ability to regenerate, or regrow, legs that have been lost to predators.

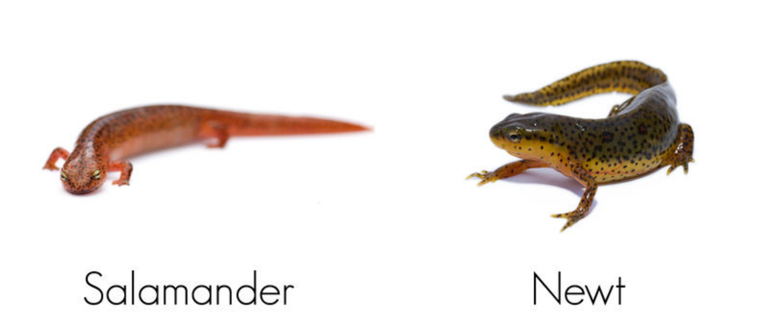


FIGURE 5.17
Salamander and Newt. Salamanders and newts can walk or swim. Salamander on a leaf (left), newt swimming in the water (right).

Caecilians

Caecilians are most closely related to salamanders. As you can see from **Figure** 5.18, they have a long, worm-like body without legs. Caecilians evolved from a tetrapod ancestor, but they lost their legs during the course of their evolution.

FIGURE 5.18
Swimming Caecilian. Caecilians are the only amphibians without legs.

Evolution of Amphibians

Fossil evidence shows that amphibians evolved about 365 million years ago from a lobe-finned lungfish ancestor. As the earliest land vertebrates, they were highly successful. Some of them were much larger than today's amphibians.

For more than 100 million years, amphibians remained the dominant land vertebrates. Then some of them evolved into reptiles. Once reptiles appeared, with their amniotic eggs, they replaced amphibians as the dominant land vertebrates.

Ecology of Amphibians

Amphibians can be found in freshwater and moist terrestrial habitats throughout the world. The only continent without amphibians is Antarctica. Amphibians are especially numerous in temperate lakes and ponds and in tropical rainforests.

Amphibians as Prey and Predators

Amphibians are an important food source for animals such as birds, snakes, raccoons, and fish. Amphibians are also important predators. As larvae, they feed mainly on small aquatic animals such as water insects. They may also feed on algae. As adults, amphibians are completely carnivorous. They may catch and eat worms, snails, and insects, as the frog in **Figure** 5.19 is doing. Unlike other amphibians, caecilians are burrowers. They use their head to dig in the soil, and they feed on earthworms and other annelids. Caecilians can be found in moist soil near rivers and streams in tropical regions.

FIGURE 5.19

Frog Predator. A frog eating its insect prey.

The Threat of Amphibian Extinction

Currently, almost one third of all amphibian species face the threat of extinction. The reasons include habitat loss, pollution, climate change, and the introduction of non-native species. Most of these problems are the result of human actions.

Amphibians have permeable skin that easily absorbs substances from the environment. This may explain why they seem to be especially sensitive to pollution. Monitoring the health and survival of amphibians may help people detect pollution early, before other organisms are affected.

Lesson Summary

- Amphibians are ectothermic vertebrates that divide their time between freshwater and terrestrial habitats. They are the first true tetrapods, or vertebrates with four limbs. Amphibians breathe with gills as larvae and with lungs as adults. They have a three-chambered heart and relatively complex nervous system.
- Amphibians reproduce sexually with either external or internal fertilization. They may attract mates with calls or scents. They do not produce amniotic eggs, so they must reproduce in water. Their larvae go through metamorphosis to change into the adult form.
- There are about 6,200 known species of living amphibians that are placed in three orders: frogs and toads, salamanders and newts, and caecilians. Frogs and toads are adapted for jumping. Salamanders and newts may walk or swim. Caecilians live in the water or soil and are the only amphibians without legs.
- Amphibians evolved about 365 million years ago from a lobe-finned fish ancestor. As the earliest land vertebrates, amphibians were highly successful for more than 100 million years until reptiles took over as the dominant land vertebrates.
- Amphibians are found throughout the world except in Antarctica and Greenland. They are important prey for animals such as birds, snakes, and raccoons. They are important predators of insects, worms, and other invertebrates. Up to one third of all amphibian species are at risk of extinction because of human actions, such as habitat destruction, climate change, and pollution.

Lesson Review Questions

Recall

1. What is a tetrapod?

2. How does the temperature of the environment affect the level of activity of an amphibian?

3. What is the cloaca? What functions does it serve in amphibians?

4. Describe three different ways that amphibians may absorb oxygen.

5. Outline the life cycle of frogs.

Apply Concepts

6. Assume that a certain species of toad appears to be dying out in a given ecosystem, perhaps because of pollution. Many people think that the toad problem is unimportant because "it's just a toad." Write a letter to a hypothetical newspaper editor in which you explain why the health and survival of amphibians such as this toad species are important to all living things in an ecosystem.

Think Critically

7. Compare and contrast the three orders of living amphibians.

8. Explain why amphibians were able to become the dominant land vertebrates for millions of years.

Points to Consider

Amphibians gave rise to reptiles, which replaced them as the dominant land vertebrates.

- Besides amniotic eggs, can you think of other ways that reptiles differ from amphibians?
- What other adaptations might reptiles have evolved that contributed to their success on land?

5.4 Reptiles

Lesson Objectives

- Give an overview of form and function in reptiles.
- Describe the amniotic egg and reptile reproduction.
- Identify the four living orders of reptiles
- Summarize how reptiles evolved.
- Describe where reptiles live and what they eat.

Vocabulary

- diaphragm
- reptile
- sauropsid
- synapsid

Introduction

Reptiles are a class of tetrapod vertebrates that produce amniotic eggs. They include crocodiles, alligators, lizards, snakes, and turtles. The reptile class is one of the largest classes of vertebrates. It consists of all amniotes except birds and mammals.

Structure and Function in Reptiles

Reptiles have several adaptations for living on dry land that amphibians lack. For example, as shown in **Figure** 5.20, the skin of most reptiles is covered with scales. The scales are made of very tough keratin, and they protect reptiles from injury, and also prevent them from losing water.

Reptile Respiration

The scales of reptiles prevent them from absorbing oxygen through their skin, as amphibians can. Instead, reptiles breathe air only through their lungs. However, their lungs are more efficient than the lungs of amphibians, with more surface area for gas exchange. This is another important reptile adaptation for life on land.

Reptiles have various ways of moving air into and out of their lungs. Lizards and snakes use muscles of the chest wall for this purpose. These are the same muscles used for running, so lizards have to hold their breath when they run. Crocodiles and alligators have a large sheet of muscle below the lungs, called a **diaphragm,** that controls their breathing. This is a structure that is also found in mammals.

FIGURE 5.20
Crocodile Scales. This crocodile is covered with tough, waterproof scales.

Ectothermy in Reptiles

Like amphibians, reptiles are ectotherms with a slow metabolic rate. Their metabolism doesn't generate enough energy to keep their body temperature stable. Instead, reptiles regulate their body temperature through their behavior. For example, the crocodile in **Figure** 5.21 is soaking up heat from the environment by basking in the sun. Because of their ectothermy, reptiles can get by with as little as one tenth the food needed by endotherms such as mammals. Some species of reptiles can go several weeks between meals.

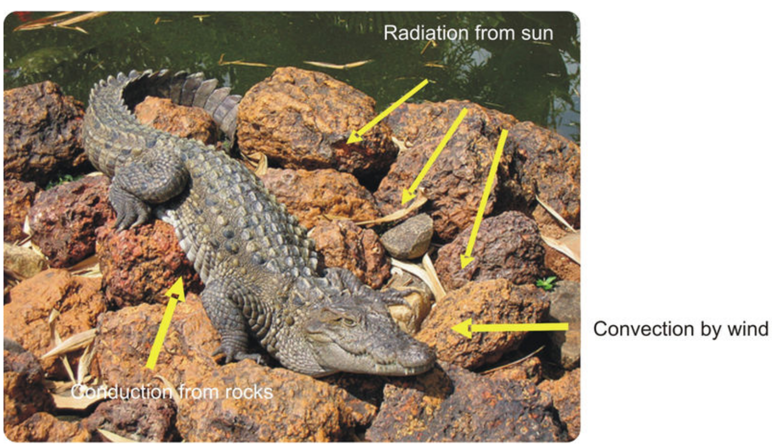


FIGURE 5.21
Heat Transfer to an Ectothermic Reptile. This crocodile is being warmed by the environment in three ways. Heat is radiating directly from the sun to the animal's back. Heat is also being conducted to the animal from the rocks it rests on. In addition, convection currents are carrying warm air from surrounding rocks to the animal's body.

Other Reptile Structures

Like amphibians, most reptiles have a heart with three chambers, although crocodiles and alligators have a four-chambered heart like birds and mammals. The reptile brain is also similar in size to the amphibian brain, taking into account overall body size. However, the parts of the reptile brain that control the senses and learned behavior are larger than in amphibians.

Most reptiles have good eyesight and a keen sense of smell. Snakes smell scents in the air using their forked tongue (see **Figure** 5.22). This helps them locate prey. Some snakes have heat-sensing organs on their head that help them

find endothermic prey, such as small mammals and birds.

FIGURE 5.22
Snake "Smelling" the Air. A snake flicks its tongue in and out to capture scent molecules in the air.

Reptile Reproduction

Most reptiles reproduce sexually and have internal fertilization. Males have one or two penises that pass sperm from their cloaca to the cloaca of a female. Fertilization occurs within the cloaca, and fertilized eggs leave the female's body through the opening in the cloaca. In a minority of species, the eggs are retained inside the female's body until they hatch. Then the offspring leave the mother's body through the cloaca opening.

Amniotic Eggs

Unlike amphibians, reptiles produce amniotic eggs (see **Figure** 5.23). The shell, membranes, and other structures of an amniotic egg protect and nourish the embryo. They keep the embryo moist and safe while it grows and develops. They also provide it with a rich, fatty food source (the yolk).

Reptile Young

Unlike amphibians, reptiles do not have a larval stage. Instead, newly hatched reptiles look like smaller versions of the adults. They are able to move about on their own, but they are vulnerable to predators. Even so, most reptile parents provide no care to their hatchlings. In fact, most reptiles don't even take care of their eggs. For example, female sea turtles lay their eggs on a sandy beach and then return to the ocean. The only exceptions are female crocodiles and alligators. They may defend their nest from predators and help the hatchings reach the water. If the young remain in the area, the mother may continue to protect them for up to a year.

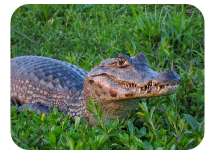
Classification of Reptiles

There are more than 8,200 living species of reptiles, with the majority being snakes or lizards. They are commonly placed in four different orders. The four orders are described in **Table** 5.2.

TABLE 5.2: Orders of Living Reptiles

Order	Characteristics	Example

TABLE 5.2: (continued)

Order	Characteristics	Example
Crocodilia: crocodiles, alligators, caimans, gharials	They have four sprawling legs that can be used to gallop; they replace their teeth throughout life; they have strong jaws and a powerful bite; they have a more advanced brain and greater intelligence than other reptiles; they have a four-chambered heart.	caiman 
Sphenodontia: tuataras	They are the least specialized of all living reptiles; their brain is very similar to the amphibian brain; they have a three-chambered heart, but it is more primitive than the heart of other reptiles.	tuatara 
Squamata: lizards, snakes	Lizards: most have four legs for running or climbing, and they can also swim; many change color when threatened; they have a three-chambered heart. Snakes: they do not have legs, although they evolved from a tetrapod ancestor; they have a very flexible jaw for swallowing large prey whole; some inject poison into their prey through fangs; they have a three-chambered heart.	lizard 
Testudines: turtles, tortoises, terrapins	They have four legs for walking; they have a hard shell covering most of their body; they have a three-chambered heart.	terrapin 

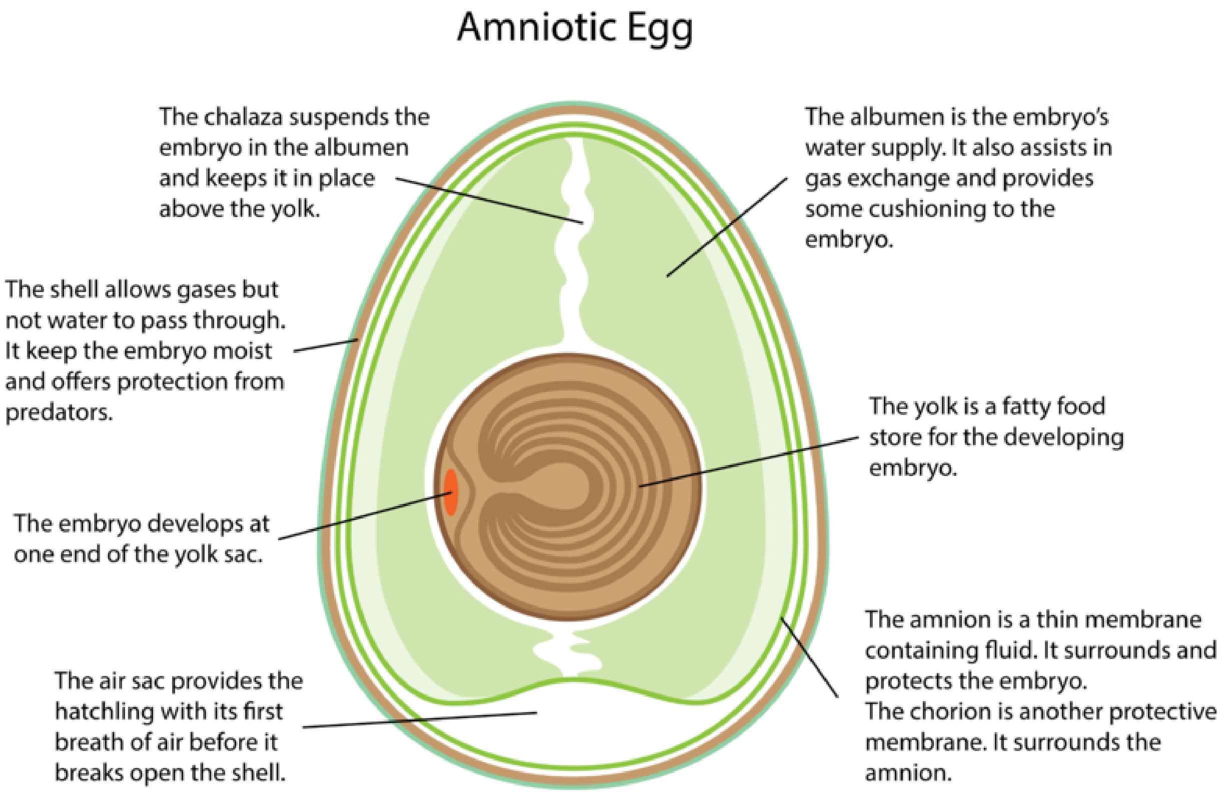


FIGURE 5.23

Amniotic Egg. The amniotic egg is an important adaptation in fully terrestrial vertebrates. It first evolved in reptiles. The shells of reptile eggs are either hard or leathery.

Evolution of Reptiles

The earliest amniotes evolved about 350 million years ago. They resembled small lizards, but they were not yet reptiles. Their amniotic eggs allowed them to move away from bodies of water and become larger. They soon became the most important land vertebrates.

Synapsids and Sauropsids

By about 320 million years ago, early amniotes had diverged into two groups, called synapsids and sauropsids. **Synapsids** were amniotes that eventually gave rise to mammals. **Sauropsids** were amniotes that evolved into reptiles, dinosaurs, and birds. The two groups of amniotes differed in their skulls. The earliest known reptile, pictured in **Figure** 5.24 dates back about 315 million years.

At first, synapsids were more successful than sauropsids. They became the most common vertebrates on land. However, during the Permian mass extinction 245 million years ago, most synapsids went extinct. Their niches were taken over by sauropsids, which had been relatively unimportant until then. This is called the "Triassic takeover."

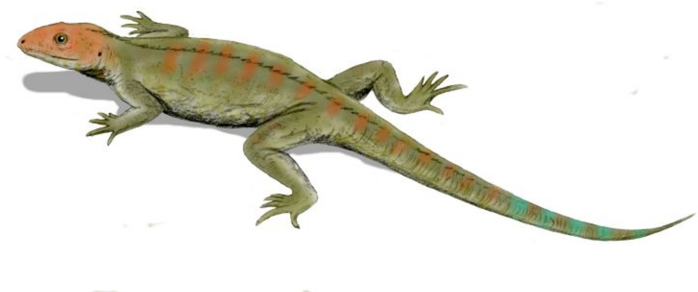


FIGURE 5.24
Earliest Reptile: Hylonomus. The earliest known reptile is given the genus name Hylonomus. It was about 20 to 30 centimeters (8 to 12 inches) long, lived in swamps, and ate insects and other small invertebrates.

Rise and Fall of the Dinosaurs

By the middle of the Triassic about 225 million years ago, sauropsids had evolved into dinosaurs. Dinosaurs became increasingly important throughout the rest of the Mesozoic Era, as they radiated to fill most terrestrial niches. This is why the Mesozoic Era is called the "Age of the Dinosaurs." During the next mass extinction, which occurred at the end of the Mesozoic Era, all of the dinosaurs went extinct. Many other reptiles survived, however, and they eventually gave rise to modern reptiles.

Evolution of Modern Reptile Orders

Figure 5.25 shows a traditional phylogenetic tree of living reptiles. Based on this tree, some of the earliest reptiles to diverge were ancestors of turtles. The first turtle-like reptiles are thought to have evolved about 250 million years ago. Ancestral crocodilians evolved at least 220 million years ago. Tuataras may have diverged from squamates (snakes and lizards) not long after that. Finally, lizards and snakes went their separate ways about 150 million years ago.

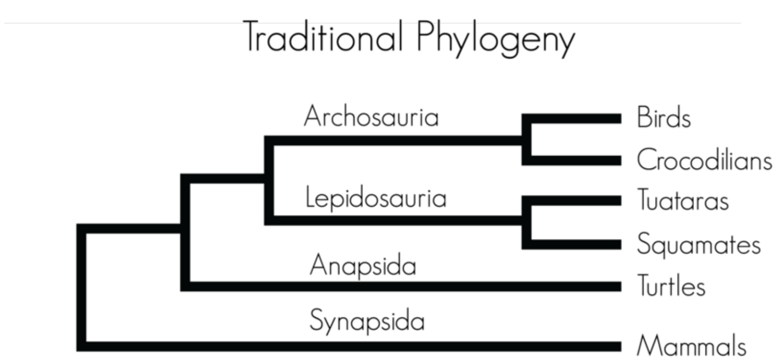


FIGURE 5.25
Traditional Reptile Phylogenetic Tree. This phylogenetic tree is based on physical traits of living and fossil reptiles. Trees based on DNA comparisons may differ from the traditional tree and from each other, depending on the DNA sequences used. Reptile evolution is currently an area of intense research and constant revision.

Ecology of Reptiles

Today, reptiles live in a wide range of habitats. They can be found on every continent except Antarctica. Many turtles live in the ocean, while others live in freshwater or on land. Lizards are all terrestrial, but their habitats may

range from deserts to rainforests, and from underground burrows to the tops of trees. Most snakes are terrestrial and live in a wide range of habitats, but some snakes are aquatic. Crocodilians live in and around swamps or bodies of freshwater or salt water.

Reptile Diets

What reptiles eat is also very diverse, but the majority of reptiles are carnivores. Large reptiles such as crocodilians are the top predators in their ecosystems, preying on birds, fish, deer, turtles, and sometimes domestic livestock. Their powerful jaws can crush bones and even turtle shells. Smaller reptiles—including tuataras, snakes, and many lizards—are also important predators, preying on insects, frogs, birds, and small mammals such as mice.

Most terrestrial turtles are herbivores. They graze on grasses, leaves, flowers, and fruits. Marine turtles and some species of lizards are omnivores, feeding on plants as well as insects, worms, amphibians, and small fish.

Reptiles at Risk

Many species of reptiles, especially marine reptiles, are at risk of extinction. Some are threatened by habitat loss. For example, many beaches where turtles lay their eggs have been taken over and developed by people. Other marine reptiles have been over-hunted by humans. Marine turtles and their eggs are still eaten in some countries despite being protected species.

Some reptiles are preyed upon by non-native species introduced by humans. For example, marine iguanas on the Galápagos Islands are threatened by dogs and cats that people have brought to the islands. The iguanas are slow and tame and have no adaptations to these new predators.

Lesson Summary

- Reptiles are a class of ectothermic, tetrapod vertebrates. They have several adaptations for living on dry land, such as tough keratin scales and efficient lungs for breathing air. They also have a three-chambered heart and relatively well-developed brain.
- Most reptiles reproduce sexually and have internal fertilization. Their eggs are amniotic, so they can be laid on land instead of in water. Reptiles do not have a larval stage, and their hatchlings are relatively mature. Reptile parents provide little if any care to their young.
- There are more than 8,200 living species of reptiles, and they are placed in four orders: Crocodilia, which includes crocodiles and alligators; Sphenodontia, or tuataras; Squamata, which includes lizards and snakes; and Testudines, such as turtles and tortoises.
- The earliest amniotes appeared about 350 million years ago, and the earliest reptiles evolved from a sauropsid ancestor by about 315 million years ago. Dinosaurs evolved around 225 million years ago and dominated animal life on land until 65 million years ago, when they all went extinct. Other reptiles survived and evolved into the classes of reptiles that exist today.
- Reptiles can be found on every continent except Antarctica. They may live in terrestrial, freshwater, or marine habitats. Most reptiles are carnivores, and large reptiles are the top predators in their ecosystems. Many species of reptiles, especially marine reptiles, are at risk of extinction.

Lesson Review Questions

Recall

1. Describe reptile scales and the functions they serve.
2. What is a diaphragm? What does it do?
3. Describe two senses that reptiles may use to locate prey.
4. Outline the structure and function of an amniotic egg.
5. Identify amniotes called synapsids and sauropsids.
6. Give a brief overview of reptile evolution.

Apply Concepts

7. Pretend you are a reptile such as a lizard. Explain how you might stay warm on a cold day.

Think Critically

8. Compare and contrast crocodilians with other orders of reptiles.
9. Explain why reptiles were able to replace amphibians as the dominant land vertebrates.

Points to Consider

Birds evolved from a reptile ancestor but they are very different from reptiles today. Birds are also the most numerous tetrapod vertebrates.

- What are some traits that differ in birds and modern reptiles?
- What traits might explain why birds have been so successful?

5.5 Birds

Lesson Objectives

- Outline structure and function in birds.
- Describe how birds reproduce and care for their young.
- Identify several common orders of modern birds.
- Give an overview of the evolution of birds.
- Summarize the diversity of bird habitats and food sources.

Vocabulary

- bird
- courtship
- crop
- generalist
- gizzard
- incubation

Introduction

Birds are endothermic tetrapod vertebrates. They are bipedal, which means they walk on two legs. Birds also lay amniotic eggs, and the eggs have hard, calcium carbonate shells. Although birds are the most recent class of vertebrates to evolve, they are now the most numerous vertebrates on Earth. Why have birds been so successful? What traits allowed them to increase and diversify so rapidly?

Structure and Function in Birds

Birds can vary considerably in size, as you can see from the **Figure** 5.26. The world's smallest bird, the tiny bee hummingbird, is just 5 centimeter (2 inches) long, whereas the ostrich towers over people at a height of 2.7 meters (9 feet). All modern birds have wings, feathers, and beaks. They have a number of other unique traits as well, most of which are adaptations for flight. Flight is used by birds as a means of locomotion in order to find food and mates and to avoid predators. Although not all modern birds can fly, they all evolved from ancestors that could.

Wings and Feathers

Wings are an obvious adaptation for flight. They are actually modified front legs. Birds move their wings using muscles in the chest. These muscles are quite large, making up as much as 35 percent of a bird's body weight.

FIGURE 5.26
Range of Body Size in Birds. The bee hummingbird is the smallest bird. The ostrich is the largest.

Feathers help birds fly and also provide insulation and serve other purposes. Birds actually have two basic types of feathers: flight feathers and down feathers. Both are shown in **Figure** 5.27. Flight feathers are long, stiff, and waterproof. They provide lift and air resistance without adding weight. Down feathers are short and fluffy. They trap air next to a bird's skin for insulation.

FIGURE 5.27
Types of Bird Feathers. These two types of bird feathers have different uses. How is each feather's structure related to its function?

Organ Systems Adapted for Flight

Birds need a light-weight body in order to stay aloft. Even so, flying is hard work, and flight muscles need a constant supply of oxygen- and nutrient-rich blood. The organ systems of birds are adapted to meet these needs.

- Birds have light-weight bones that are filled with air. They also lack a jaw, which in many vertebrates is a dense, heavy bone with many teeth. Instead, birds have a light-weight keratin beak without teeth.
- Birds have air sacs that store inhaled air and push it into the lungs like bellows. This keeps the lungs constantly filled with oxygenated air. The lungs also contain millions of tiny passages that create a very large surface area for gas exchange with the blood (see **Figure** 5.28).
- Birds have a relatively large, four-chambered heart. The heart beats rapidly to keep oxygenated blood flowing to muscles and other tissues. Hummingbirds have the fastest heart rate at up to 1,200 times per minute. That's almost 20 times faster than the human resting heart rate!

- Birds have a sac-like structure called a **crop** to store and moisten food that is waiting to be digested. They also have an organ called a **gizzard** that contains swallowed stones. The stones make up for the lack of teeth by grinding food, which can then be digested more quickly. Both structures make it easier for the digestive system to produce a steady supply of nutrients from food.

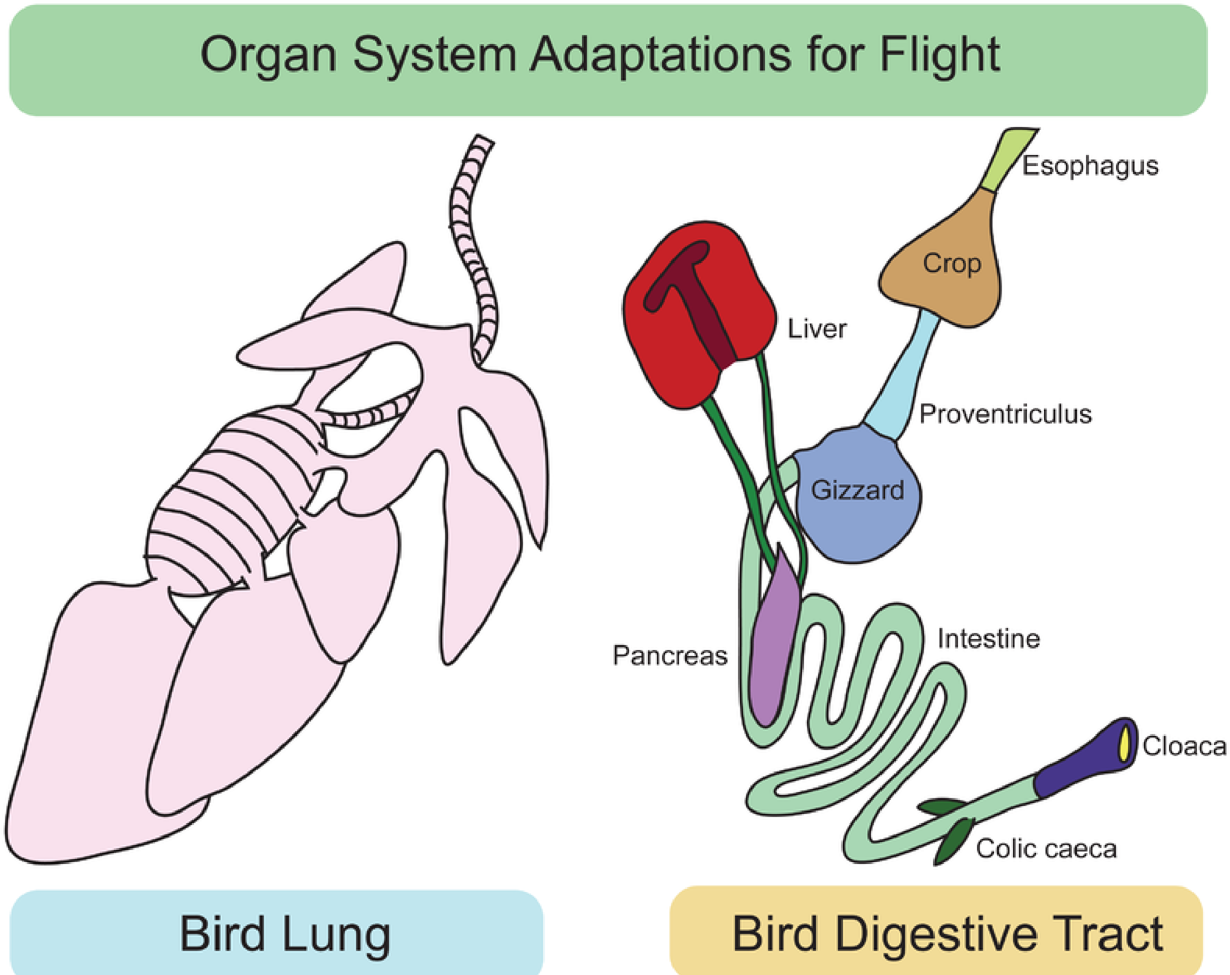


FIGURE 5.28
Organ System Adaptations for Flight. The intricate passageways in a bird's lung are adapted for efficient gas exchange. Find the crop and gizzard in the digestive tract diagram. What are their functions? Bird Lung (left), Bird Digestive Tract (right)

Nervous System and Sense Organs

Birds have a large brain relative to the size of their body. Not surprisingly, the part of the brain that controls flight is the most developed part. The large brain size of birds is also reflected by their high level of intelligence and complex behavior. In fact, birds such as crows and ravens may be more intelligent than many mammals. They are smart enough to use objects such as twigs for tools. They also demonstrate planning and cooperation. Most birds have a

poor sense of smell, but they make up for it with their excellent sense of sight. Predatory birds have especially good eyesight. Hawks, for example, have vision that is eight times sharper than human vision.

Bird Reproduction

Reproduction in birds may be quite complicated and lengthy. Birds reproduce sexually and have separate sexes and internal fertilization, so males and females must mate for fertilization to occur. Mating is generally preceded by courtship. In most species, parents also take care of their eggs and hatchlings.

Courtship and Mating

Courtship is behavior that is intended to attract a mate. It may involve singing specific courtship songs or putting on some type of visual display. For example, a bird may spread out and display its tail feathers or do a ritualized mating "dance." Typically, males perform the courtship behavior, and females choose a mate from among competing males.

During mating, a male bird presses his cloaca against his mate's cloaca and passes sperm from his cloaca to hers. After fertilization, eggs pass out of the female's body, exiting through the opening in the cloaca.

Nesting and Incubation

Eggs are usually laid in a nest. The nest may be little more than a small depression in the ground, or it may be very elaborate, like the weaver bird nest in **Figure** 5.29. Eggs that are laid on the ground may be camouflaged to look like their surroundings (also shown in **Figure** 5.29). Otherwise, eggs are usually white or pastel colors such as pale blue or pink.

FIGURE 5.29
Variation in Bird Nests. A weaver bird uses grasses to weave an elaborate nest (left). The eggs of a ground-nesting gull are camouflaged to blend in with the nesting materials (right).

After birds lay their eggs, they generally keep the eggs warm with their body heat while the embryos inside continue to develop. This is called **incubation,** or brooding. In most species, parents stay together for at least the length of the breeding season. In some species, they stay together for life. By staying together, the males as well as females can incubate the eggs and later care for the hatchlings. Birds are the only nonhuman vertebrates with this level of male parental involvement.

Hatchlings

Ground-nesting birds, such as ducks and chickens, have hatchlings that are able to run around and feed themselves almost as soon as they break through the eggshell. Being on the ground makes them vulnerable to predators, so they

need to be relatively mature when they hatch in order to escape. In contrast, birds that nest off the ground—in trees, bushes, or buildings—have hatchlings that are naked and helpless. The parents must protect and feed the immature offspring for weeks or even months. However, this gives the offspring more time to learn from the parents before they leave the nest and go out on their own.

Classification of Birds

There are about 10,000 living species of birds. Almost all of them can fly, but there are several exceptions.

Flightless Birds

Some birds have lost the ability to fly during the course of their evolution. Several flightless birds are shown in **Figure** 5.30. They include the ostrich, kiwi, rhea, cassowary, and moa. All of these birds have long legs and are adapted for running. The penguins shown in the figure are also flightless birds, but they have a very different body shape. That's because they are adapted for swimming rather than running.

FIGURE 5.30
Flightless Birds. Flightless birds that are adapted for running include the ostrich, kiwi, rhea, cassowary, and moa. Penguins are flightless birds adapted for swimming.

Flying Birds

Birds that are able to fly are divided into 29 orders that differ in their physical traits and behaviors. **Table** 5.3 describes seven of the most common orders. As shown in the table, the majority of flying birds are perching birds, like the honeyeater described in the last row of the table. The order of perching birds has more species than all the other bird orders combined. In fact, this order of birds is the largest single order of land vertebrates.

TABLE 5.3: Orders of Flying Birds

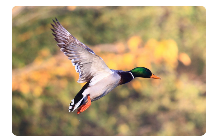
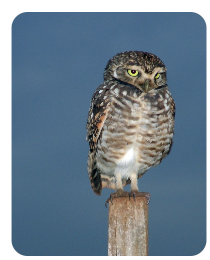
Order	Description	Example
Landfowl: turkeys, chickens, pheasants	They are large in size; they spend most of their time on the ground; they usually have a thick neck and short, rounded wings; their flight tends to be brief and close to the ground.	turkey 
Waterfowl: ducks, geese, swans	They are large in size; they spend most of their time on the water surface; they have webbed feet and are good swimmers; most are strong flyers.	ducks 
Shorebirds: puffins, gulls, plovers	They range from small to large; most live near the water, and some are sea birds; they have webbed feet and are good swimmers; most are strong flyers.	puffin 
Diurnal Raptors: hawks, falcons, eagles	They range from small to large; they are active during the day and sleep during the night; they have a sharp, hooked beak and strong legs with clawed feet; they hunt by sight and have excellent vision.	hawk 
Nocturnal Raptors: burrowing owls, barn owls, horned owls	They range from small to large; they are active during the night and sleep during the day; they have a sharp, hooked beak and strong legs with clawed feet; they have large, forward-facing eyes; they have excellent hearing and can hunt with their sense of hearing alone.	burrowing owl 

TABLE 5.3: (continued)

Order	Description	Example
Parrots: cockatoos, parrots, parakeets	They range from small to large; they are found in tropical regions; they have a strong, curved bill; they stand upright on strong legs with clawed feet; many are brightly colored; they are very intelligent.	cockatoo 
Perching Birds: honeyeaters, sparrows, crows	They are small in size; they perch above the ground in trees and on buildings and wires; they have four toes for grasping a perch; many are songbirds.	honeyeater 

Evolution of Birds

Birds are thought to have evolved from a group of bipedal dinosaurs called theropods. The ancestor of birds was probably similar to the theropod called *Deinonychus,* which is represented by the sketch in **Figure** 5.31. Fossils of *Deinonychus* were first identified in the 1960s. This was an extremely important discovery. It finally convinced most scientists that birds had descended from dinosaurs, which had been debated for almost a century.

FIGURE 5.31

Extinct Bird Relative: Deinonychus. Deinonychus shared many traits with birds. What similarities with birds to you see?

What was

Deinonychus is the genus name of an extinct dinosaur that is considered to be one of the closest non-bird relatives of modern birds. It lived about 110 million years ago in what is now North America. *Deinonychus* was a predatory carnivore with many bird-like features. For example, it had feathers and wings. It also had strong legs with clawed

feet, similar to modern raptors. Its respiratory, circulatory, and digestive systems were similar to those of birds as well. The location of fossilized eggs near *Deinonychus* fossils suggests that it may have brooded its eggs. This would mean that it was endothermic. (Can you explain why?) On the other hand, *Deinonychus* retained a number of reptile-like traits, such as jaws with teeth and hands with claws at the tips of its wings.

Evolution of Flight

Scientists have long speculated about the evolution of flight in birds. They wonder how and why birds evolved wings from a pair of front limbs. Several hypotheses have been suggested. Here are just two:

1. Wings evolved in a bird ancestor that leapt into the air to avoid predators or to capture prey. Therefore, wings are modified arms that helped the animal leap higher.
2. Wings evolved in a bird ancestor that lived in trees. Thus, wings are modified arms that helped the animal glide from branch to branch.

Scientists still don't know how or why wings and flight evolved, but they continue to search for answers. In addition to fossils, they are studying living vertebrates such as bats that also evolved adaptations for flight.

Ecology of Birds

Birds live and breed in most terrestrial habitats on all seven continents, from the Arctic to Antarctica. Because they are endothermic, birds can live in a wider range of climates than reptiles or amphibians, although the greatest diversity of birds occurs in tropical regions. Birds are important members of every ecosystem in which they live, occupying a wide range of ecological positions.

Bird Diets

Some birds are generalists. A **generalist** is an organism that can eat many different types of food. Other birds are highly specialized in their food needs and can eat just one type of food.

Raptors such as hawks and owls are carnivores. They hunt and eat mammals and other birds. Vultures are scavengers. They eat the remains of dead animals, such as roadkill. Aquatic birds generally eat fish or water plants. Perching birds may eat insects, fruit, honey, or nectar. Many fruit-eating birds play a key role in seed dispersal, and some nectar-feeding birds are important pollinators.

Bird beaks are generally adapted for the food they eat. For example, the sharp, hooked beak of a raptor is well suited for killing and tearing apart prey. The long beak of the hummingbird in **Figure** 5.32 co-evolved with the tube-shaped flowers from which it sips nectar.

Birds at Risk

Hundreds of species of birds have gone extinct as a result of human actions. A well-known example is the passenger pigeon. It was once the most common bird in North America, but over-hunting and habitat destruction led to its extinction in the 1800s. Habitat destruction and use of the pesticide DDT explain the recent extinction of the dusky seaside sparrow. This native Florida bird was declared extinct in 1990.

Today, some 1,200 species of birds are threatened with extinction by human actions. Humans need to take steps to protect this precious and important natural resource. What can you do to help?

FIGURE 5.32

Hummingbird Sipping Nectar. A hummingbird gets nectar from flowers and pollinates the flowers in return. What type of relationship exists between the bird and the flowering plant?

KQED: The Golden Eagle

Although not as famous as its bald cousin, Golden Eagles are much easier to find in Northern California - one of the largest breeding populations for Golden Eagles. The largest of the raptors, Golden Eagles weigh typically between 8 and 12 pounds, and their wing span is around 6 to 7 feet. These eagles dive towards earth to catch prey, and can reach speeds of up to 200 mph! Meet one of the largest birds of prey at http://www.kqed.org/quest/television/cool-critters-the-golden-eagle .

MEDIA

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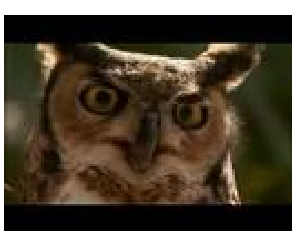
KQED: The Great Horned Owl

Owls are amazing creatures. They have many adaptations that allow them to thrive in their environments. Their claws are enormous and powerful, they have excellent hearing, and fantastic vision in low light. And the Great Horned Owl can fly almost silently due to "fringes" on their feathers that help to break up the sound of air passing over their wings. Learn more of the Great Horned Owl at http://science.kqed.org/quest/video/cool-critters-great-horned-owls/ .



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KQED: The Turkey Vulture

Ever wonder why a vulture's head is bald? Turkey Vultures are very interesting birds. The Turkey Vulture has no vocal organs –they can only grunt or hiss, although they usually stay silent. They do not build nests –they lay their eggs directly on the ground in caves, crevices, burrows, hollow logs, under fallen trees, or even in abandoned buildings. While these vultures have few natural predators, their main form of defense is vomiting. The foul smelling substance deters most creatures, and will also sting if the offending animal is close enough to get vomit on them. Learn more about Turkey Vultures at http://www.kqed.org/quest/television/cool-critters-turkey-vultures . Also see http://www.wildlife-museum.org/ for the Lindsay Wildlife Museum.

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Lesson Summary

- Birds are endothermic tetrapod vertebrates. They are bipedal and have wings and feathers. Their organ systems are adapted for flight. For example, they have light-weight air-filled bones and a large four-chambered heart. Birds also have relatively large brains and a high level of intelligence.
- Birds reproduce sexually and have internal fertilization. Mating is generally preceded by courtship. Their amniotic eggs have hard shells and are laid in a nest. The eggs are usually incubated until they hatch. Most species have a relatively long period of parental care.
- There are about 10,000 living species of birds, almost all of which can fly. Flying birds are divided into 29 orders. The most common orders include landfowl, waterfowl, shorebirds, diurnal and nocturnal raptors, parrots, and perching birds.
- Birds are thought to have evolved from theropod dinosaurs around 150 million years ago. Their ancestor may have been similar to the extinct theropod *Deinonychus,* whose fossils convinced most scientists that birds evolved from dinosaurs. Scientist still don't know how or why wings and flight evolved, but they continue to search for answers.
- Birds live and breed in most terrestrial habitats on all seven continents. They occupy a wide range of ecological positions. Raptors are carnivores; aquatic birds eat fish or water plants; and perching birds may eat insects, fruit, honey, or nectar. Some birds are pollinators that co-evolved with plants. Human actions have caused the extinction of hundreds of species of birds, and some 1,200 species are threatened with extinction today.

Lesson Review Questions

Recall

1. List two functions of feathers in birds.

2. Describe the bird crop and gizzard. What are their functions?

3. How do birds keep their lungs filled with oxygenated air?

4. Give an example of bird behavior that shows their relatively great intelligence.

5. What is courtship? What is its purpose?

Apply Concepts

6. Draw a sketch of a hypothetical bird that preys on small mammals. The bird must exhibit traits that suit it for its predatory role.

Think Critically

7. Relate two unique traits of birds to flight.

8. Contrast hatchling maturity in birds that are ground-nesting and those that nest off the ground. What is the adaptive significance of the differences?

9. Why did the hummingbird pictured in the **Hummingbird Sipping Nectar Figure** 5.32 evolve such a long, pointed beak?

Points to Consider

Birds share a number of important traits with mammals, including a four-chambered heart and endothermy. The next chapter describes mammals in detail.

- What are some examples of mammals?
- What other traits do you think mammals might have? What traits do you think set mammals apart from all other vertebrates, including birds?

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CHAPTER 6 Mammals and Animal Behavior

Chapter Outline

You might think that these young tigers are fighting, but they're really playing. Like most other young mammals, tigers like to play. Why do mammals play? Is playing just for fun, or does it serve some other purpose as well?

Playing is actually an important way of learning. By playing, these tigers are learning moves that will help them become successful predators as adults. Playing is just one of many ways that mammals and other animals learn how to behave. In this chapter, you will learn more about mammals such as tigers. You will also learn more about animal behavior and other ways that animals learn.

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6.1 Mammalian Traits

Lesson Objectives

- List characteristics of mammals.
- Describe structure and function in mammals.

Vocabulary

- alveoli (singular, alveolus)
- arboreal
- cerebrum
- lactation
- mammal
- mammary gland
- neocortex

Introduction

Mammals are a class of endothermic vertebrates. They have four limbs and produce amniotic eggs. Examples of mammals include bats, whales, mice, and humans. Clearly, mammals are a very diverse group. Nonetheless, they share many traits that set them apart from other vertebrates.

Characteristics of Mammals

Two characteristics are used to define the mammal class. They are mammary glands and body hair (or fur).

1. Female mammals have **mammary glands**. The glands produce milk after the birth of offspring. Milk is a nutritious fluid. It contains disease-fighting molecules as well as all the nutrients a baby mammal needs. Producing milk for an offspring is called **lactation**.
2. Mammals have hair or fur. It insulates the body to help conserve body heat. It can also be used for sensing and communicating. For example, cats use their whiskers to sense their surroundings. They also raise their fur to look larger and more threatening (see **Figure** 6.1).

Most mammals share several other traits. The traits in the following list are typical of, but not necessarily unique to, mammals.

- The skin of many mammals is covered with sweat glands. The glands produce sweat, the salty fluid that helps cool the body.

FIGURE 6.1
Cat Communicating a Warning. By raising its fur, this cat is "saying" that it's big and dangerous. This might discourage a predator from attacking.

- Mammalian lungs have millions of tiny air sacs called **alveoli**. They provide a very large surface area for gas exchange.
- The heart of a mammal consists of four chambers. This makes it more efficient and powerful for delivering oxygenated blood to tissues.
- The brain of a mammal is relatively large and has a covering called the **neocortex**. This structure plays an important role in many complex brain functions.
- The mammalian middle ear has three tiny bones that carry sound vibrations from the outer to inner ear. The bones give mammals exceptionally good hearing. In other vertebrates, the three bones are part of the jaw and not involved in hearing.
- Mammals have four different types of teeth. The teeth of other vertebrates, in contrast, are all alike.

Structure and Function in Mammals

Many structures and functions in mammals are related to endothermy. Mammals can generate and conserve heat when it's cold outside. They can also lose heat when they become over-heated. How do mammals control their body temperature in these ways?

How Mammals Stay Warm

Mammals generate heat mainly by keeping their metabolic rate high. The cells of mammals have many more mitochondria than the cells of other animals. The extra mitochondria generate enough energy to keep the rate of metabolism high. Mammals can also generate little bursts of heat by shivering. Shivering occurs when many muscles contract a little bit all at once. Each muscle that contracts produces a small amount of heat.

Conserving heat is also important, especially in small mammals. A small body has a relatively large surface area compared to its overall size. Because heat is lost from the surface of the body, small mammals lose a greater proportion of their body heat than large mammals. Mammals conserve body heat with their hair or fur. It traps a layer of warm air next to the skin. Most mammals can make their hair stand up from the skin, so it becomes an even

better insulator (see **Figure** 6.2). Mammals also have a layer of fat under the skin to help insulate the body. This fatty layer is not found in other vertebrates.

FIGURE 6.2
Goosebumps. Mammals raise their hair with tiny muscles in the skin. Even humans automatically contract these muscles when they are cold. They cause "goosebumps," as shown here.

How Mammals Stay Cool

One way mammals lose excess heat is by increasing blood flow to the skin. This warms the skin so heat can be given off to the environment. That's why you may get flushed, or red in the face, when you exercise on a hot day. You are likely to sweat as well. Sweating also reduces body heat. Sweat wets the skin, and when it evaporates, it cools the body. Evaporation uses energy, and the energy comes from body heat. Animals with fur, such as dogs, use panting instead of sweating to lose body heat (see **Figure** 6.3). Evaporation of water from the tongue and other moist surfaces of the mouth and throat uses heat and helps cool the body.

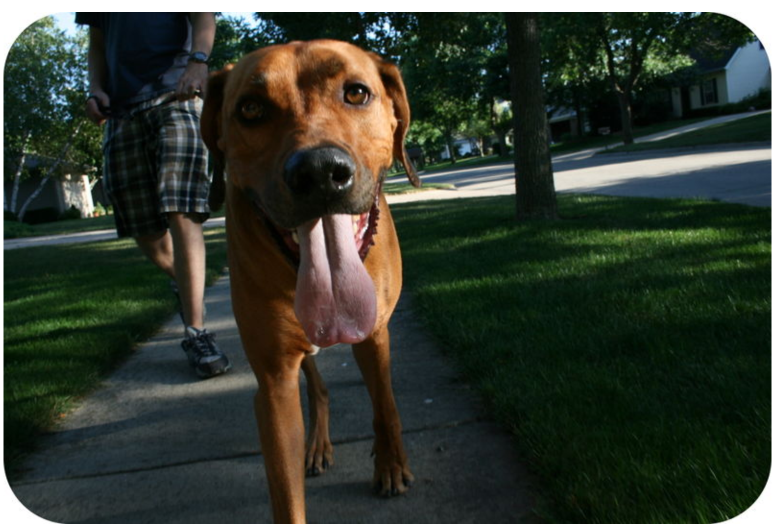

FIGURE 6.3
Panting Dog. This dog is overheated. It is losing excess body heat by panting.

Eating and Digesting Food

Maintaining a high metabolic rate takes a lot of energy. The energy must come from food. Therefore, mammals need a nutritious and plentiful diet. The diets of mammals are diverse. Except for leaf litter and wood, almost any kind of organic matter may be eaten by mammals. Some mammals are strictly herbivores or strictly carnivores. However, most mammals will eat other foods if necessary. Some mammals are omnivores. They routinely eat a variety of both plant and animal foods. Most mammals also feed on a variety of other species. The few exceptions include koalas, which feed only on eucalyptus plants, and giant pandas, which feed only on bamboo. Types of mammalian diets and examples of mammals that eat them are given in **Table** 6.1. How would you classify your own diet?

TABLE 6.1: Mammalian Diets

Type of Diet	Foods Eaten	Examples of Mammals with this Type of Diet
herbivorous diet: plants	leaves, grasses, shoots, stems, roots, tubers, seeds, nuts, fruits, bark, conifer needles, flowers	rabbit, mouse, sea cow, horse, goat, elephant, zebra, giraffe, deer, elk, hippopotamus, kangaroo, monkey 
carnivorous diet: animals	other mammals, birds, reptiles, amphibians, fish, mollusks, worms, insects	aardvark, anteater, whale, hyena, dog, jackal, dolphin, wolf, weasel, seal, walrus, cat, otter, mole 
omnivorous diet: plants and animals	any of the foods eaten in herbivorous and carnivorous diets	bear, badger, mongoose, fox, raccoon, human, rat, chimpanzee, pig 

Different diets require different types of digestive systems. Mammals that eat a carnivorous diet generally have a relatively simple digestive system. Their food consists mainly of proteins and fats that are easily and quickly digested. Herbivorous mammals, on the other hand, tend to have a more complicated digestive system. Complex plant carbohydrates such as cellulose are more difficult to digest. Some herbivores have more than one stomach. The stomachs store and slowly digest plant foods.

Mammalian teeth are also important for digestion. The four types of teeth are specialized for different feeding functions, as shown in **Figure** 6.4. Together, the four types of teeth can cut, tear, and grind food. This makes food easier and quicker to digest.

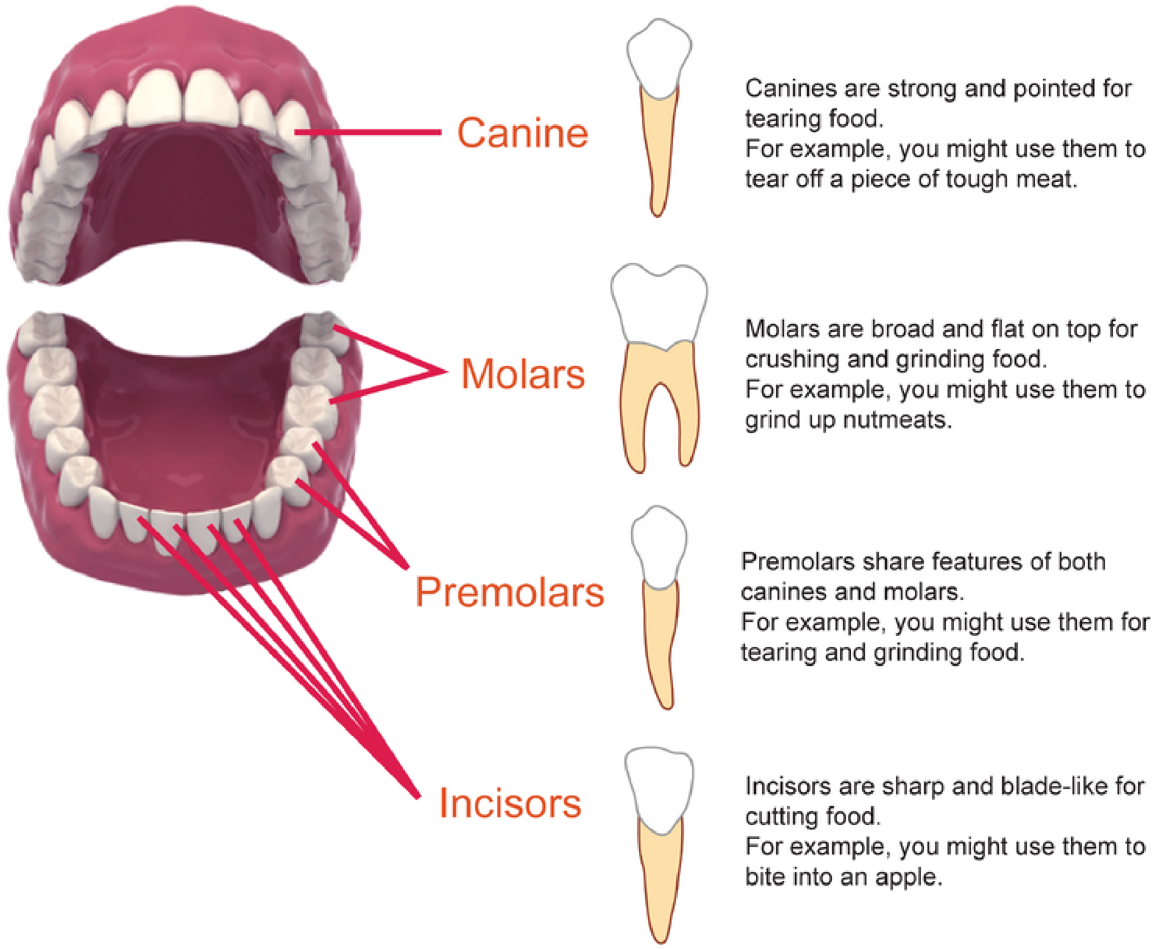

FIGURE 6.4
Mammalian Teeth (Human). With their different types of teeth, mammals can eat a wide range of foods.

Lungs and Heart of Mammals

Keeping the rate of metabolism high takes a constant and plentiful supply of oxygen. That's because cellular respiration, which produces energy, requires oxygen. The lungs and heart of mammals are adapted to meet their oxygen needs.

The lungs of mammals are unique in having alveoli. These are tiny, sac-like structures. Each alveolus is surrounded by a network of very small blood vessels (see **Figure** 6.5). Because there are millions of alveoli in each lung, they greatly increase the surface area for gas exchange between the lungs and bloodstream. Human lungs, for example, contain about 300 million alveoli. They give the lungs a total surface area for gas exchange of up to 90 square meters (968 square feet). That's about as much surface area as one side of a volleyball court!

Mammals breathe with the help of a diaphragm. This is the large muscle that extends across the bottom of the chest below the lungs. When the diaphragm contracts, it increases the volume of the chest. This decreases pressure on the lungs and allows air to flow in. When the diaphragm relaxes, it decreases the volume of the chest. This increases pressure on the lungs and forces air out.

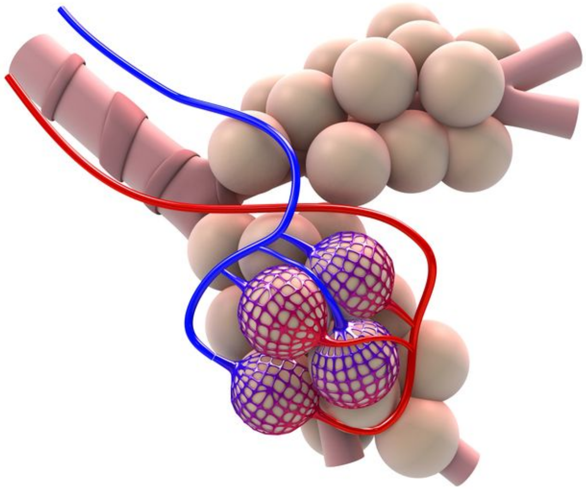

FIGURE 6.5
Alveoli of Mammalian Lungs. Clusters of alveoli resemble tiny bunches of grapes. They are surrounded by many blood vessels for gas exchange.

The four-chambered mammalian heart can pump blood in two different directions. The right side of the heart pumps blood to the lungs to pick up oxygen. The left side of the heart pumps blood containing oxygen to the rest of the body. Because of the dual pumping action of the heart, all of the blood going to body cells is rich in oxygen.

The Mammalian Brain

Of all vertebrates, mammals have the biggest and most complex brain for their body size (see **Figure** 6.6). The front part of the brain, called the **cerebrum**, is especially large in mammals. This part of the brain controls functions such as memory and learning.

The brains of all mammals have a unique layer of nerve cells covering the cerebrum. This layer is called the neocortex (the pink region of the brains in **Figure** 6.6). The neocortex plays an important role in many complex brain functions. In some mammals, such as rats, the neocortex is relatively smooth. In other mammals, especially humans, the neocortex has many folds. The folds increase the surface area of the neocortex. The larger this area is, the greater the mental abilities of an animal.

Intelligence of Mammals

Mammals are very intelligent. Of all vertebrates, they are the animals that are most capable of learning. Mammalian offspring are fed and taken care of by their parents for a relatively long time. This gives them plenty of time to learn from their parents. By learning, they can benefit from the experiences of their elders. The ability to learn is the main reason that the large mammalian brain evolved. It's also the primary reason for the success of mammals.

Social Living in Mammals

Many mammals live in social groups. Social living evolved because it is adaptive. Consider these two examples:

1. Herbivores such as zebras and elephants live in herds. Adults in the herd surround and protect the young, who are most vulnerable to predators.

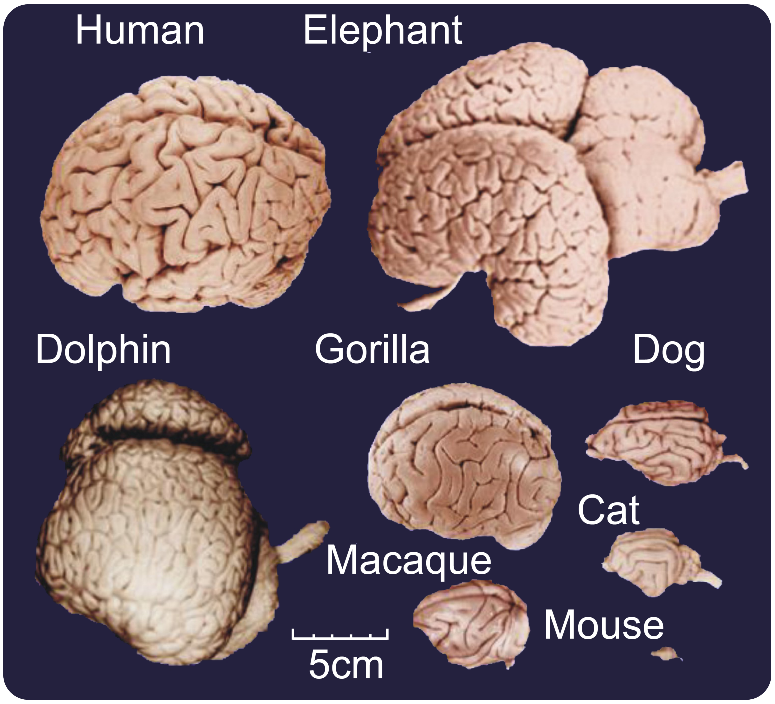

FIGURE 6.6
Vertebrate Brains. Vertebrate brains come in a range of sizes. Even the brains of mammals show a lot of variation in size. The area of the neocortex is greatest in humans.

2. Lions live in social groups called prides. Adult females in the pride hunt cooperatively, which is more efficient than hunting alone. Then they share the food with the rest of the pride. For their part, adult males defend the pride's territory from other predators.

Locomotion in Mammals

Mammals are noted for the many ways they can move about. Generally, their limbs are very mobile. Often, they can be rotated. Many mammals are also known for their speed. The fastest land animal is a predatory mammal. Can you guess what it is? Racing at speeds of up to 112 kilometers (70 miles) per hour, the cheetah wins hands down. In addition, the limbs of mammals let them hold their body up above the ground. That's because the limbs are attached beneath the body, rather than at the sides as in reptiles (see **Figure** 6.7).

Mammals may have limbs that are specialized for a particular way of moving. They may be specialized for running, jumping, climbing, flying, or swimming. Mammals with these different modes of locomotion are pictured in **Figure** 6.8.

The deer in the **Figure** 6.8 is specialized for running. Why? It has long legs and hard hooves. Can you see why the other animals in the figure are specialized for their particular habitats? Notice how **arboreal**, or tree-living animals, have a variety of different specializations for moving in trees. For example, they may have:

- A prehensile, or grasping, tail. This is used for climbing and hanging from branches.
- Very long arms for swinging from branch to branch. This way of moving is called brachiation.
- Sticky pads on their fingers. The pads help them cling to tree trunks and branches.

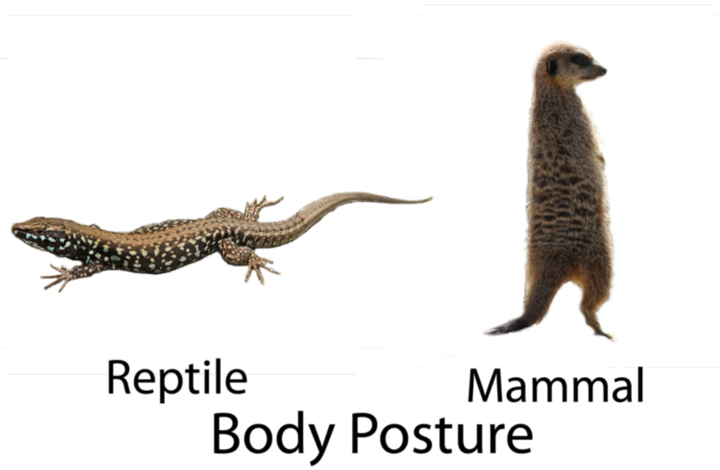

FIGURE 6.7
Limb Positions in Reptiles and Mammals. The sprawling limbs of a reptile keep it low to the ground. A mammal has a more upright stance.

Lesson Summary

- Mammals are a class of endothermic vertebrates. They have four limbs and produce amniotic eggs. The mammal class is defined by the presence of mammary glands and hair (or fur). Other traits of mammals include sweat glands in their skin, alveoli in their lungs, a four-chambered heart, and a brain covering called the neocortex.
- Mammals have several ways of generating and conserving heat, such as a high metabolic rate and hair to trap heat. They also have several ways to stay cool, including sweating or panting. Mammals may be herbivores, carnivores, or omnivores. They have four types of teeth, so they can eat a wide range of foods. Traits of the heart and lungs keep the cells of mammals well supplied with oxygen and nutrients.
- Mammals have a relatively large brain and a high level of intelligence. They also have many ways of moving about and may move very quickly.

Lesson Review Questions

Recall

1. List five traits that are shared by all mammals, including the two traits that are used to define the mammal class.

2. Describe how mammals stay warm.

3. What is the function of sweating?

4. Identify mammals that are herbivores, carnivores, and omnivores.

5. What are alveoli? What is their function?

Apply Concepts

6. A certain mammal has very long forelimbs. What does that suggest about where the animal lives and how it moves?

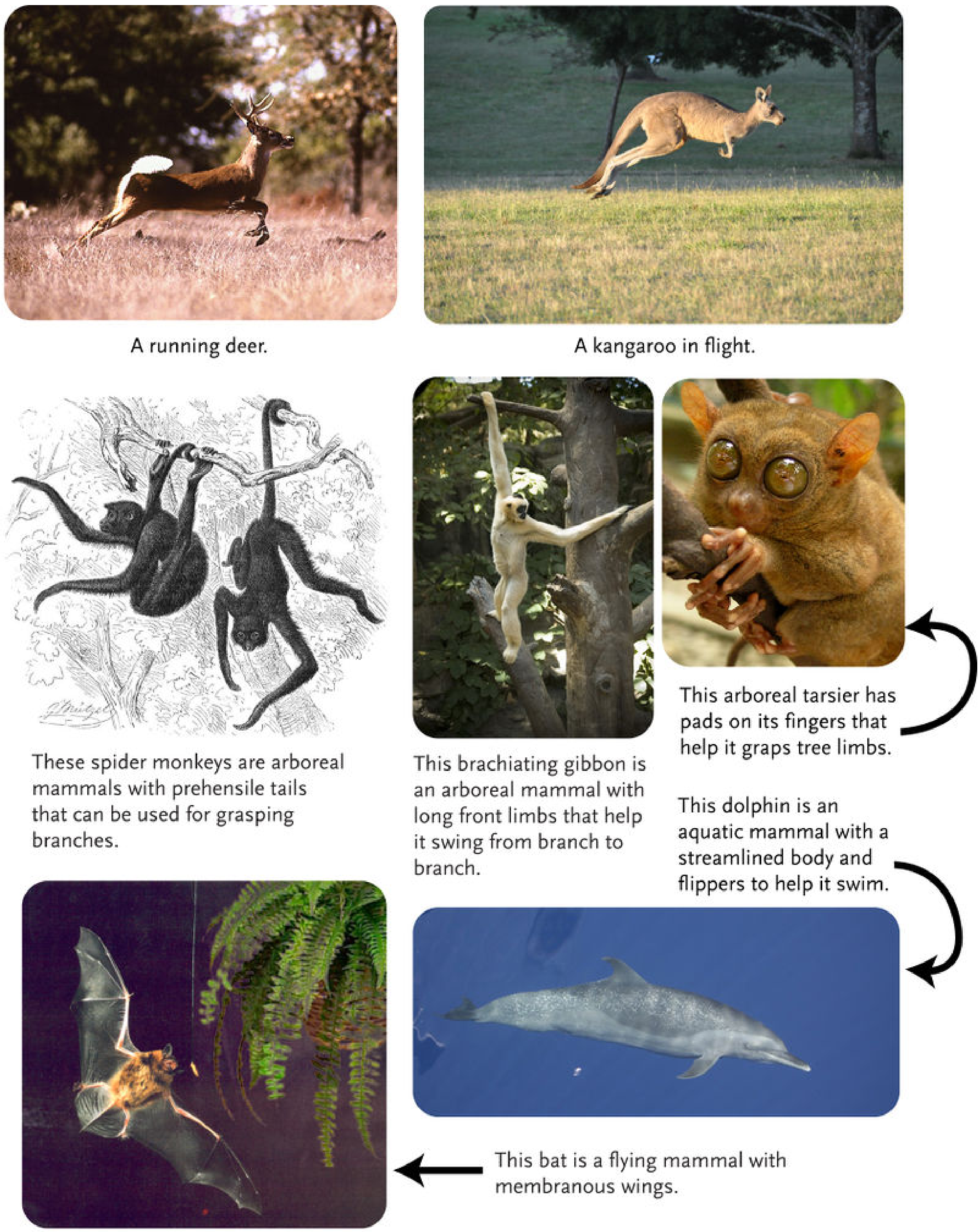

FIGURE 6.8
Mammalian Locomotion. Mammals have many different modes of locomotion.

Think Critically

7. Explain how mammalian teeth differ from the teeth of other vertebrates. How are mammalian teeth related to endothermy?

8. Compare and contrast the mammalian brain with the brains of other vertebrates. How is the brain of mammals related to their ability to learn?

Points to Consider

Most mammals are born as live young, as opposed to hatching from eggs. Giving birth to live young has certain advantages over egg laying.

- What do you think the advantages of live births might be? How might this form of reproduction help ensure that the offspring survive?
- Do you think that giving birth to live young, as opposed to laying eggs, might have disadvantages? What might the disadvantages be?

6.2 Reproduction in Mammals

Lesson Objectives

- Describe female reproductive structures of therian mammals.
- Outline reproduction in placental mammals.
- Explain how marsupials reproduce.
- Describe monotreme reproduction.

Vocabulary

- marsupial
- monotreme
- placenta
- placental mammal
- therian mammal
- uterus (plural, uteri)
- vagina

Introduction

Most mammals are viviparous. Their young are born live. They are born either as relatively large, well-developed fetuses or as tiny, immature embryos. Mammals that are viviparous are called **therian mammals**. Only a few mammals lay eggs instead of giving birth to an infant or embryo.

Therian Mammals

Like other female vertebrates, all female mammals have ovaries. These are the organs that produce eggs (see **Figure** 6.9). Therian mammals also have two additional female reproductive structures that are not found in other vertebrates. They are the uterus and vagina.

- The **uterus** (plural, uteri) is a pouch-like, muscular organ. The embryo or fetus develops inside the uterus. Muscular contractions of the uterus push the offspring out during birth.
- The **vagina** is a tubular passageway through which the embryo or fetus leaves the mother's body during birth. The vagina is also where the male deposits sperm during mating.

Therian mammals are divided into two groups: placental mammals and marsupial mammals. Each group has a somewhat different reproductive strategy.

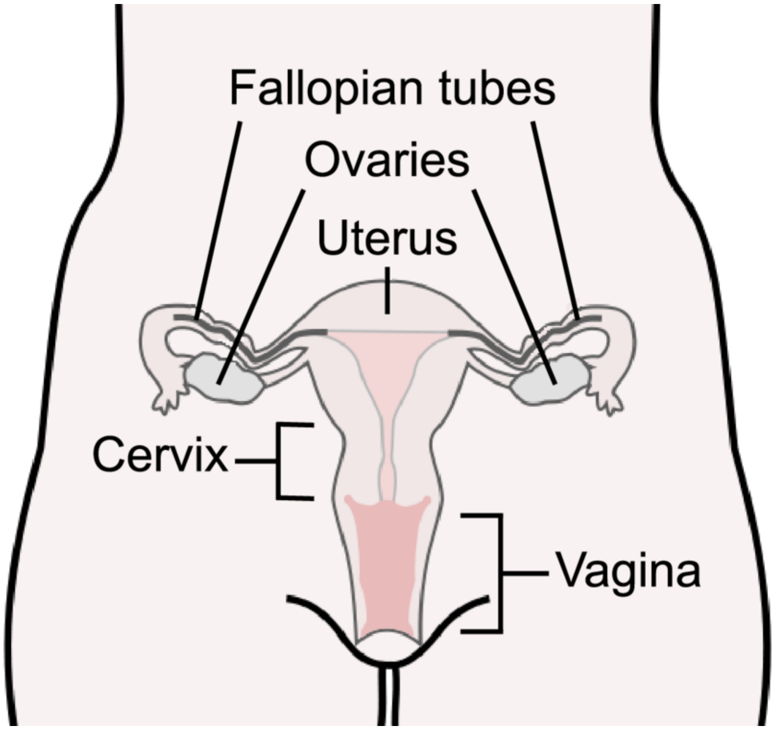

FIGURE 6.9
Female Reproductive System of a Therian Mammal (Human). The female reproductive system of all therian mammals is similar to that of humans.

Placental Mammals

Placental mammals are therian mammals in which a placenta develops during pregnancy. The placenta sustains the fetus while it grows inside the mother's uterus. Placental mammals give birth to relatively large and mature infants. Most mammals are placental mammals.

The Placenta

The **placenta** is a spongy structure. It consists of membranes and blood vessels from both mother and embryo (see **Figure** 6.10). The placenta passes oxygen, nutrients, and other useful substances from the mother to the fetus. It also passes carbon dioxide and other wastes from the fetus to the mother. The placenta lets blood from the fetus and mother exchange substances without actually mixing. Thus, it protects the fetus from being attacked by the mother's immune system as a "foreign parasite."

Pros and Cons of Placental Reproduction

The placenta permits a long period of fetal growth in the uterus. As a result, the fetus can become large and mature before birth. This increases its chances of surviving.

On the other hand, supporting a growing fetus is very draining and risky for the mother. The mother has to eat more food to nourish the fetus. She also becomes heavier and less mobile as the fetus gets larger. As a result, she may be less able to escape from predators. Because the fetus is inside her, she can't abandon it to save her own life if she is pursued or if food is scarce. Giving birth to a large infant is also risky. It may even result in the mother's death.

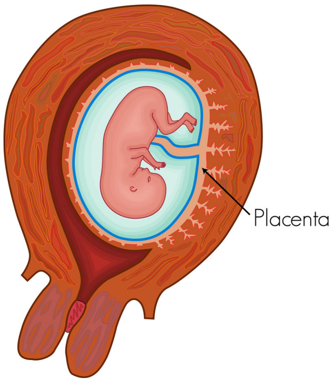

FIGURE 6.10
Placenta of a Placental Mammal (Human). The placenta allows the exchange of gases, nutrients, and other substances between the fetus and mother.

Marsupials

Marsupials have a different way of reproducing that reduces the mother's risks. A **marsupial** is a therian mammal in which the embryo is born at an early, immature stage. The embryo completes its development outside the mother's body in a pouch on her belly. Only a minority of therian mammals are marsupials. They live mainly in Australia. Examples of marsupials are pictured in **Figure** 6.11.

FIGURE 6.11
Marsupials. Marsupials include the kangaroo, koala, and opossum.

The Marsupial Embryo

The marsupial embryo is nourished inside the uterus with food from a yolk sac instead of through a placenta. The yolk sac stores enough food for the short period of time the embryo remains in the uterus. After the embryo is born, it moves into the mother's pouch, where it clings to a nipple. It remains inside the pouch for several months while it continues to grow and develop. Even after the offspring is big enough to leave the pouch, it may often return to the pouch for warmth and nourishment (**Figure** 6.12). Eventually, the offspring is mature enough to remain outside the pouch on its own.

Pros and Cons of Marsupial Reproduction

In marsupials, the short period of development within the mother's uterus reduces the risk of her immune system attacking the embryo. In addition, the marsupial mother doesn't have to eat extra food or carry a large fetus inside her. The risks of giving birth to a large fetus are also avoided. Another pro is that the mother can expel the embryo

FIGURE 6.12
The marsupial embryo finishes development in the mother's pouch. Here, a joey is shown in the mother's pouch.

from her pouch if she is pursued by a predator or if food is scarce. On the other hand, a newborn marsupial is tiny and fragile. Therefore, it may be less likely to survive than a newborn placental mammal.

KQED: The North American Marsupial: The Opossum

Most people think of Opossums as scary creatures. Is this because they look kind of funny, walk kind of funny, have beady eyes and sharp teeth, and can emit a very foul odor? Maybe. But what is so different about opossums is that they are the only marsupial in North America.

But opossums can be beneficial to humans. They use their sharp teeth to crush bone –which means that they are good getting rid of unwanted rodents in your neighborhood. They have excellent immune systems and they emit that terrible odor for protection. Learn more about opossums at http://www.kqed.org/quest/blog/2009/03/31/producers-notes-for-cool-critters-opossums/ .

MEDIA
Click image to the left or use the URL below.
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Monotremes

Only five living species of mammals are not therian mammals. They are called monotremes. **Monotremes** are mammals that reproduce by laying eggs. The only living monotreme species are the platypus and echidnas (see **Figure** 6.13 and **Figure** 6.14). They are found solely in Australia and New Guinea (an island not far from Australia).

FIGURE 6.13
Platypus. The platypus is a monotreme, a mammal that reproduces by laying eggs.

FIGURE 6.14
Echidna. Like the platypus, the echnida is a monotreme. The only living monotreme species inhabit Australia and New Guinea.

Eggs and Lactation in Monotremes

Female monotremes lack a uterus and vagina. Instead, they have a cloaca with one opening, like the cloacas of reptiles and birds. The opening is used to excrete wastes as well as lay eggs.

Monotreme eggs have a leathery shell, like the eggs of reptiles. The eggs are retained inside the mother's body for at least a couple of weeks. During that time, the mother provides the eggs with nutrients. Platypus females lay their eggs in a burrow. Echidna females have a pouch in which they store their eggs. Female monotremes have mammary glands but lack nipples. Instead, they "sweat" milk from a patch on their belly.

Pros and Cons of Monotreme Reproduction

The mother's risks are less in monotremes than in therian mammals. The mother doesn't need to eat more or put herself at risk by carrying and delivering a fetus or an embryo. On the other hand, externally laid eggs are more difficult to protect than an embryo in a pouch or a fetus in a uterus. Therefore, monotreme offspring may be less likely to survive than the offspring of therian mammals.

Lesson Summary

- Therian mammals are viviparous. They give birth to an embryo or infant rather than laying eggs. The female reproductive system of a therian mammal includes a uterus and a vagina. There are two groups of therian mammals: placental mammals and marsupials.
- Placental mammals give birth to a relatively large and mature fetus. This is possible because they have a placenta to nourish the fetus and protect it from the mother's immune system. This allows for a long period of growth and development before birth. Because the offspring is relatively large and mature at birth, it has a good chance of surviving. However, carrying and giving birth to a large fetus is risky for the mother. It also requires her to eat more food.
- Marsupials give birth to a tiny, immature embryo. The embryo then continues to grow and develop in a pouch on the mother's belly. This is less risky for the mother. However, the embryo is fragile, so it may be less likely to survive than the fetus of a placental mammal.
- Monotremes reproduce by laying eggs. They have a cloaca instead of a uterus and vagina. The eggs pass through the opening of the cloaca. This form of reproduction is the least risky for the mother. However, eggs are harder to protect than is an embryo or a fetus in a pouch or uterus. Therefore, monotreme offspring may have a lower chance of surviving than the offspring of therian mammals.

Lesson Review Questions

Recall

1. What are the functions of the uterus and vagina in therian mammals?

2. What is the placenta? What is its role?

3. Where does a marsupial embryo develop? How is it nourished?

4. Describe eggs and egg laying in monotremes.

5. How does lactation differ in monotremes and therian mammals?

Apply Concepts

6. Create a chart that you could use to explain to a younger student the different ways that mammals reproduce.

Think Critically

7. Compare and contrast the advantages and disadvantages of the three forms of reproduction in mammals.

8. Placental mammals greatly outnumber the other two groups of mammals. Infer why placental mammals have been so successful.

Points to Consider

Monotremes are less similar to therian mammals than the two groups of therian mammals are to each other.

- How might the different groups of mammals have evolved?

- Which group of mammals do you think evolved first?

6.3 Evolution and Classification of Mammals

Lesson Objectives

- Describe the therapsid ancestors of mammals.
- Outline the evolution of monotreme, marsupial, and placental mammals.
- Summarize the evolution of modern mammals.
- Contrast traditional and phylogenetic classifications of mammals.

Vocabulary

- therapsid

Introduction

Which mammalian trait evolved first? What was the first mammal like? When did the earliest mammal live? Detailed answers to these questions are still in dispute. However, scientists generally agree on the major events in the evolution of mammals. These are summarized in **Table** 6.2. Refer back to the table as you read about the events in this lesson. *mya = millions of years ago

TABLE 6.2: Major Events in Mammalian Evolution

Era	Period	Epoch	Major Events	Start (mya)*
Cenozoic	Neogene	Holocene	Rise of human civilization; spread and dominance of modern humans	0.01
-	-	Pleistocene	Spread and then extinction of many large mammals; appearance of modern humans	1.8
-	-	Pliocene	Appearance of many existing genera of mammals, including the genus *Homo*	5.3

TABLE 6.2: (continued)

Era	Period	Epoch	Major Events	Start (mya)*
-	-	Miocene	Appearance of remaining modern mammal families; diversification of horses and mastodons; first apes	23.0
-	Paleogene	Oligocene	Rapid evolution and diversification of placental mammals	33.9
-	-	Eocene	Appearance of several modern mammal families; diversification of primitive whales	55.8
-	-	Paleocene	Appearance of the first large mammals	65.5
Mesozoic	Cretaceous	-	Emergence of monotreme, marsupial, and placental mammals; possible first appearance of four clades (superorders) of placental mammals (Afrotheria, Xenarthra, Laurasiatheria, Supraprimates)	145.5
-	Jurassic	-	Spread of mammals, which remain small in size	199.6
-	Triassic	-	Evolution of cynodonts to become smaller and more mammal-like; appearance of the first mammals	251.0
Paleozoic	Permian	-	Evolution and spread of synapsids (pelycosaurs and therapsids)	299.0
-	Carboniferous	-	Appearance of amniotes, the first fully terrestrial vertebrates	359.0

Mammalian Ancestors

Ancestors of mammals evolved close to 300 million years ago. They were amniotes called synapsids. **Figure** 6.15 shows how modern mammals evolved from synapsids. The stages of evolution from synapsids to mammals are described below.

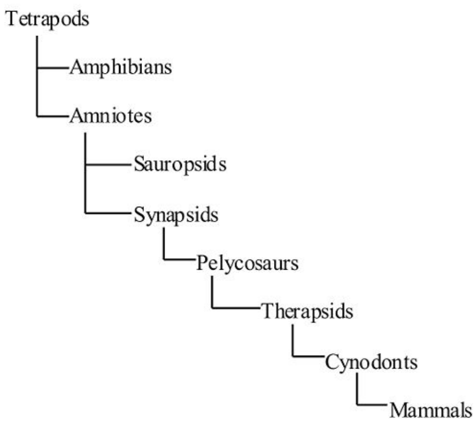


FIGURE 6.15
Phylogeny of Mammalian Evolution. This diagram represents the evolution of mammals.

Pelycosaurs

Synapsids called pelycosaurs became the most common land vertebrates during the first half of the Permian Period. A pelycosaur genus called *Dimetrodon* is shown in **Figure** 6.16. *Dimetrodon* had sprawling legs and walked like a lizard. It also had a fairly small brain. However, it had started to develop some of the traits of mammals. For example, it had teeth of different types.

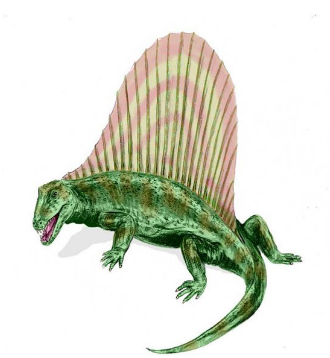


FIGURE 6.16
Pelycosaur Synapsid: Dimetrodon. Dimetrodon was a pelycosaur. It lived about 275 million years ago.

Therapsids

Some pelycosaurs gave rise to a group of animals called **therapsids**. The earliest therapsids lived about 260 million years ago. At first, the therapsids looked a lot like *Dimetrodon*. But after a while, they could easily be mistaken

for mammals. They evolved a number of mammalian traits, such as legs positioned under the body instead of along the sides. Therapsids became the most common and diverse land vertebrates during the second half of the Permian Period.

The Permian Period ended about 250 million years ago with a mass extinction. Most therapsids went extinct. Their niches were taken over by sauropsids. These were the amniotes that evolved into dinosaurs, reptiles, and birds. Not all therapsids went extinct, however. The few that remained no longer had to compete with many other therapsids. Some of them eventually evolved into mammals.

Cynodonts

The surviving therapsids were small animals. Some of the most successful were the cynodonts (see **Figure** 6.17). They flourished worldwide during the first half of the Triassic Period. Some of them ate insects and were nocturnal, or active at night. Being nocturnal may have helped save them from extinction. Why? A nocturnal niche was one of the few niches that dinosaurs did not take over in the Triassic Period.

Cynodonts became more mammal-like as they continued to evolve. Some of their mammalian traits may have been adaptations to their nocturnal niche. For example:

- The ability to regulate body temperature might have been selected for because it would allow nocturnal animals to remain active in the cool of the night.
- A good sense of hearing might have been selected for because it would be more useful than good vision when hunting in the dark.

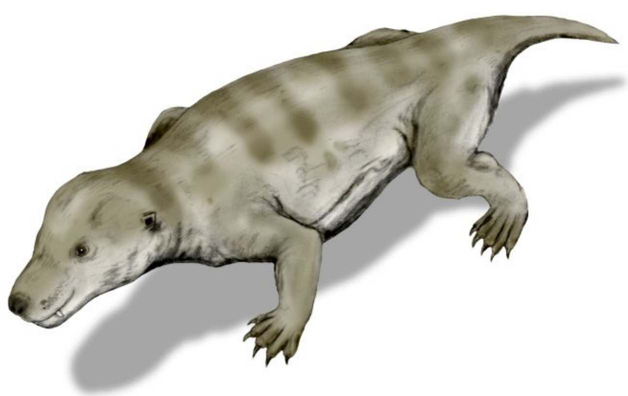


FIGURE 6.17
Probable Mammalian Ancestor: Cynodont. Cynodonts were mammal-like therapsids. They may have been ancestral to mammals. They were about the size of a rat.

By the end of the Triassic Period, cynodonts had become even smaller in size. They also had evolved many mammalian traits. For example, they had

- Four different types of teeth.
- A relatively large brain.
- Three tiny bones in the middle ear.
- A diaphragm for breathing.
- Endothermy.
- Lactation.
- Hair.

Cynodonts probably gave rise to mammals about 200 million years ago. However, they are not considered to be mammals themselves. In fact, competition with early mammals may have led to their extinction. They went extinct sometime during the Jurassic or Cretaceous Period.

Evolution of Early Mammals

The earliest mammals evolved from cynodonts. But the evolution of mammals didn't end there. Mammals continued to evolve. Monotreme mammals probably split off from other mammals first. They were followed by marsupials. Placental mammals probably evolved last.

Evolution of Monotremes

The first monotremes may have evolved about 150 million years ago. Early monotreme fossils have been found in Australia. An example is a genus called *Steropodon*, shown in **Figure** 6.18. It may have been the ancestor of the platypus. Early monotremes retained some of the traits of their therapsid ancestors. For example, they laid eggs and had a cloaca. These traits are still found in modern monotremes.

FIGURE 6.18
Probable Monotreme Ancestor: Steropodon. Like the platypus, Steropodon probably had a bill.

Evolution of Marsupials

The first marsupials may have evolved about 130 million years ago. One of the earliest was the extinct genus *Sinodelphys*. A fossil of this mammal has been identified. It is a remarkable fossil find. It represents a nearly complete animal. Even tufts of hair and imprints of soft tissues were preserved. For additional information, see *Highway of Life* at http://www.lihatvideo.com/highway-of-life-part-2-of-2/FtJC3C6hxzU . *Sinodelphys* was about 15 centimeters (6 inches) long. Its limb structure suggests that it was a climbing animal. It could escape from predators by climbing into trees. It probably lived on a diet of insects and worms.

Evolution of Placental Mammals

The earliest placental mammals may have evolved about 110 million years ago. The ancestor of placental mammals may be the extinct genus *Eomaia*. Fossils of *Eomaia* have been found in what is now China. It was only about 10

centimeters (4 inches) long. It was a tree climber and probably ate insects and worms. *Eomaia* had several traits of placental mammals. **Figure** 6.19 shows an *Eomaia* fossil.

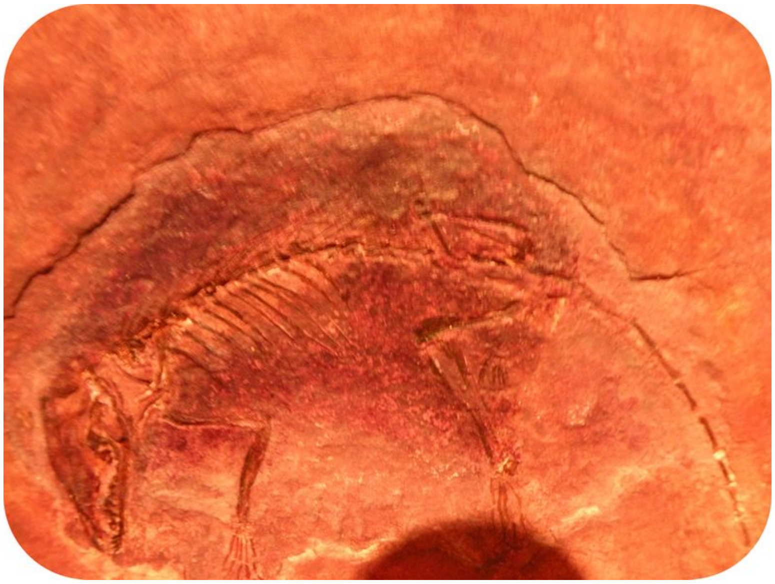


FIGURE 6.19
Probable Ancestor of Placental Mammals: Eomaia. Eomaia lived over 100 million years ago.

The placental mammal descendants of *Eomaia* were generally more successful than marsupials and monotremes. On most continents, placental mammals became the dominant mammals, while marsupials and monotremes died out. Marsupials remained the most common and diverse mammals in Australia. The reason for their success there is not yet resolved.

Evolution of Modern Mammals

The Cretaceous Period ended with another mass extinction. This occurred about 65 million years ago. All of the dinosaurs went extinct at that time. Did the extinction of the dinosaurs allow mammals to take over?

Traditional View

Scientists have long assumed that the extinction of the dinosaurs opened up many niches for mammals to exploit. Presumably, this led to an explosion of new species of mammals early in Cenozoic Era. Few mammalian fossils from the early Cenozoic have been found to support this theory. Even so, it was still widely accepted until recently.

View from the Mammalian Supertree

In 2007, an international team of scientists compared the DNA of almost all known species of living mammals. They used the data to create a supertree of mammalian evolution. The supertree shows that placental mammals started to diversify as early as 95 million years ago.

What explains the diversification of mammals long before the dinosaurs went extinct? What else was happening at that time? One change was a drop in Earth's temperature. This may have favored endothermic mammals over ectothermic dinosaurs. Flowering plants were also spreading at that time. They may have provided new and plentiful foods for small mammals or their insect prey.

The supertree also shows that another major diversification of mammals occurred about 50 million years ago. Again, worldwide climate change may have been one reason. This time Earth's temperature rose. The warmer temperature led to a greater diversity of plants. This would have meant more food for mammals or their prey.

Classification of Placental Mammals

Traditional classifications of mammals are based on similarities in structure and function. Increasingly, mammals are being classified on the basis of molecular similarities.

Traditional Classification

The most widely accepted traditional classification of mammals divides living placental mammals into 17 orders. These orders are shown in **Table** 6.3. This classification of mammals was widely accepted for more than 50 years. Placental mammals are still commonly placed in these orders. However, this classification is not very useful for studies of mammalian evolution. That's because it groups together some mammals that do not seem to be closely related by descent from a recent common ancestor.

TABLE 6.3: Orders of Placental Mammals (Traditional Classification)

Order	Example	Sample Trait
Insectivora	mole 	small sharp teeth
Edentata	anteater 	few or no teeth
Pholidota	pangolin 	large plate-like scales
Chiroptera	bat 	digits support membranous wings

TABLE 6.3: (continued)

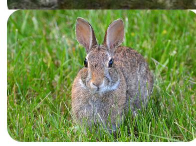
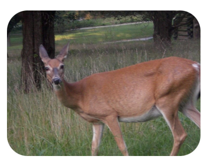
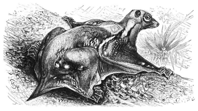
Order	Example	Sample Trait
Carnivora	coyote 	long pointed canine teeth
Rodentia	mouse 	incisor teeth grow continuously
Lagomorpha	rabbit 	chisel-like incisor teeth
Perissodactyla	horse 	odd-toed hooves
Artiodactyla	deer 	even-toed hooves
Cetacea	whale 	paddle-like forelimbs
Primates	monkey 	five digits on hands and feet

TABLE 6.3: (continued)

Order	Example	Sample Trait
Proboscidea	elephant 	tusks
Hyracoidea	hyrax 	rubbery pads on feet
Dermoptera	colugo 	membrane of skin between legs for gliding
Pinnipedia	seal 	feet with fins
Sirenia	manatee 	paddle-like tail
Tubulidentata	aardvark 	teeth without enamel

Phylogenetic Classification

The mammalian supertree classifies placental mammals phylogenetically. It groups together mammals that are closely related because they share a recent common ancestor. These groups are not necessarily the same as the traditional groups based on structure and function.

The supertree classification places placental mammals in four superorders. The four superorders and some of the mammals in them are:

- Afrotheria—aardvarks, elephants, manatees.
- Xenarthra—anteaters, sloths, armadillos.
- Laurasiatheria—bats, whales, hoofed mammals, carnivores.
- Supraprimates—primates, rabbits, rodents.

All four superorders appear to have become distinct from one another between 85 and 105 million years ago. The exact relationships among the superorders are still not clear. Revisions in this classification of mammals may occur as new data become available.

Lesson Summary

- Amniotes called synapsids were the ancestors of mammals. Synapsids named pelycosaurs had some of the traits of mammals by 275 million years ago. Some of them evolved into therapsids, which became widespread during the Permian Period. The few therapsids that survived the Triassic takeover were small, arboreal insect eaters. They were also nocturnal. Being active at night may explain why they survived and evolved still more mammalian traits.
- Monotremes evolved about 150 million years ago. Like modern monotremes, they had a cloaca and laid eggs. Marsupials evolved about 130 million years ago. They were very small and ate insects and worms. Placental mammals evolved about 110 million years ago. They were also small and climbed trees. Placental mammals became the dominant land mammals. Most marsupials and monotremes died out except in Australia.
- Mammals used to be classified on the basis of similarities in structure and function into 17 different orders. Recently, DNA analyses have shown that the traditional orders include mammals that are not closely related. Phylogenetic classification, based on DNA data, groups placental mammals in four superorders. The superorders appear to have become distinct from each other 85–105 million years ago.

Lesson Review Questions

Recall

1. What were the synapsids? When were they most widespread?

2. Identify the therapsids. How were they related to mammals?

3. Describe cynodonts. What is their place in the evolution of mammals?

4. Outline the evolution of monotreme, marsupial, and placental mammals.

5. What is the mammalian supertree?

Apply Concepts

6. Assume that a new species of placental mammal has been discovered. Scientists have examined it closely and studied its DNA. It has wings similar to a bat that it uses for gliding. Its DNA is most similar to the DNA of rodents such as mice. How would you classify the new mammal? Explain your answer.

Think Critically

7. Explain why the extinction of most therapsids at the end of the Permian Period may have allowed mammals to evolve.

8. Relate the extinction of dinosaurs to the diversification of modern mammals.

9. Compare and contrast traditional and phylogenetic classifications of placental mammals. Explain which type of classification is more useful for understanding how mammals evolved.

Points to Consider

Some mammalian traits, such as different types of teeth, evolved in ancestors of mammals. Other traits, such as placental reproduction, evolved after the first mammals appeared. Mammals also evolved many behavioral traits.

- How do mammals behave? What behaviors do you think characterize mammals?
- How do you think these behaviors evolved?

6.4 Overview of Animal Behavior

Lesson Objectives

- Describe how and why ethologists study animal behavior.
- Explain how animal behaviors evolve.
- Define innate behavior.
- State ways that animals learn.
- Identify types of animal behavior.

Vocabulary

- aggression
- animal behavior
- circadian rhythm
- cooperation
- ethology
- innate behavior
- instinct
- learning
- nature-nurture debate
- reflex
- social animal
- society
- stimulus

Introduction

Did you ever see a dog sit on command? Have you ever watched a cat trying to catch a mouse? These are just two examples of the many behaviors of animals. **Animal behavior** includes all the ways that animals interact with each other and the environment. Examples of common animal behaviors are pictured in **Figure** 6.20.

Studying Animal Behavior

The branch of biology that studies animal behavior is called **ethology**. Ethologists usually study how animals behave in their natural environment, rather than in a lab. They generally try to answer four basic questions about the behaviors they observe:

FIGURE 6.20

Examples of Animal Behavior. Can you think of other examples of animal behavior besides the three shown here?

1. What causes the behavior? What is the **stimulus**, or trigger, for the behavior? What structures and functions of the animal are involved in the behavior?
2. How does the behavior develop? Is it present early in life? Or does it appear only as the animal matures? Are certain experiences needed for the behavior to develop?
3. Why did the behavior evolve? How does the behavior affect the fitness of the animal performing it? How does it affect the survival of the species?
4. How did the behavior evolve? How does it compare with similar behaviors in related species? In what ancestor did the behavior first appear?

As you read about animal behavior in the rest of this lesson, think about these four questions. Try to answer the questions for different types of animal behavior.

Evolution of Animal Behavior

To the extent that behaviors are controlled by genes, they may evolve through natural selection. If behaviors increase fitness, they are likely to become more common over time. If they decrease fitness, they are likely to become less common.

Nature vs. Nurture

Some behaviors seem to be controlled solely by genes. Others appear to be due to experiences in a given environment. Whether behaviors are controlled mainly by genes or by the environment is often a matter of debate. This is called the **nature-nurture debate**. Nature refers to the genes an animal inherits. Nurture refers to the environment that the animal experiences.

In reality, most animal behaviors are not controlled by nature or nurture. Instead, they are influenced by both nature and nurture. In dogs, for example, the tendency to behave toward other dogs in a certain way is probably controlled by genes. However, the normal behaviors can't develop in an environment that lacks other dogs. A puppy raised in isolation from other dogs may never develop the normal behaviors. It may always fear other dogs or act aggressively toward them.

How Behaviors Evolve

It's easy to see how many common types of behavior evolve. That's because they obviously increase the fitness of the animal performing them. For example, when wolves hunt together in a pack, they are more likely to catch prey (see **Figure** 6.21). Therefore, hunting with others increases a wolf's fitness. The wolf is more likely to survive and pass its genes to the next generation by behaving this way.

FIGURE 6.21
Wolves Hunting Cooperatively. Wolves hunt together in packs. This is adaptive because it increases their chances of killing prey and obtaining food.

The evolution of certain other types of behavior is not as easy to explain. An example is a squirrel chattering loudly to warn other squirrels that a predator is near. This is likely to help the other squirrels avoid the predator. Therefore, it could increase their fitness. But what about the squirrel raises the alarm? This squirrel is more likely to be noticed by the predator. Therefore, the behavior may actually lower this squirrel's fitness. How could such a behavior evolve through natural selection?

One possible answer is that helping others often means helping close relatives. Close relatives share many of the same genes that they inherited from their common ancestor. As a result, helping a close relative may actually increase the chances that copies of one's own genes will be passed to the next generation. In this way, a behavior that puts oneself at risk could actually increase through natural selection. This form of natural selection is called kin selection.

Innate Behavior

Behaviors that are closely controlled by genes with little or no environmental influence are called **innate behaviors**. These are behaviors that occur naturally in all members of a species whenever they are exposed to a certain stimulus. Innate behaviors do not have to be learned or practiced. They are also called instinctive behaviors. An **instinct** is the ability of an animal to perform a behavior the first time it is exposed to the proper stimulus. For example, a dog will drool the first time—and every time—it is exposed to food.

Significance of Innate Behavior

Innate behaviors are rigid and predictable. All members of the species perform the behaviors in the same way. Innate behaviors usually involve basic life functions, such as finding food or caring for offspring. Several examples are shown in **Figure** 6.22. If an animal were to perform such important behaviors incorrectly, it would be less likely to survive or reproduce.

FIGURE 6.22

Examples of Innate Behavior. These innate behaviors are necessary for survival or reproduction. Can you explain why each behavior is important?

Intelligence and Innate Behavior

Innate behaviors occur in all animals. However, they are less common in species with higher levels of intelligence. Humans are the most intelligent species, and they have very few innate behaviors. The only innate behaviors in humans are reflexes. A **reflex** is a response that always occurs when a certain stimulus is present. For example, a human infant will grasp an object, such as a finger, that is placed in its palm. The infant has no control over this reaction because it is innate. Other than reflexes such as this, human behaviors are learned–or at least influenced by experience—rather than being innate.

Learned Behavior

Learning is a change in behavior that occurs as a result of experience. Compared with innate behaviors, learned behaviors are more flexible. They can be modified to suit changing conditions. This may make them more adaptive than innate behaviors. For example, drivers may have to modify how they drive (a learned behavior) when roads are wet or icy. Otherwise, they may lose control of their vehicle.

Animals may learn behaviors in a variety of ways. Some ways are quite simple. Others are more complex. Several types of learning are described in **Figure** 6.23.

Insight learning, which is based on past experience and reasoning, is a hallmark of the human animal. Humans have used insight learning to solve problems ranging from starting a fire to traveling to the moon.

FIGURE 6.23
Types of Learning. Five different ways that animals may learn behaviors are shown here. What have you learned in each of these ways?

Types of Animal Behavior

Different types of behavior evolved in animals because the behaviors helped them survive or reproduce. Several different types of animal behavior are described below.

Social Behavior and Cooperation

In many species, animals live together in a close-knit group with other members of their species. Such a group is referred to as a **society**. Animals that live in a society are known as **social animals**. They live and work together for the good of the group. This called cooperation. Generally, each member of the group has a specific role that it plays in the society. **Cooperation** allows the group to do many things that a lone animal could never do. Look at the ants

in **Figure** 6.24. By working together, they are able to carry a large insect back to the nest to feed other members of their society.

FIGURE 6.24
Cooperation in a Social Insect. These ants are cooperating in a task that a single ant would be too small to do alone.

Communication

For individuals to cooperate, they need to communicate. Animals can communicate with sounds, chemicals, or visual cues. For example, to communicate with sounds, birds sing and frogs croak. Both may be communicating that they are good mates. Ants communicate with chemicals called pheromones. For example, they use the chemicals to mark trails to food sources so other ants can find them. Male dogs use pheromones in urine to mark their territory. They are "telling" other dogs to stay out of their yard. You can see several examples of visual communication in **Figure** 6.25.

Cyclic Behaviors

Many animal behaviors occur in a regular cycle. Two types of cyclic behaviors are circadian rhythms and migration.

- **Circadian rhythms** are regular changes in biology or behavior that occur in a 24-hour cycle. In humans, for example, blood pressure and body temperature change in a regular way throughout each 24-hour day.

- Migration refers to seasonal movements of animals from one area to another. Migrants typically travel long distances. Usually, the migrants move to another area in order to find food or mates. Many birds, fish, and insects migrate. Mammals such as whales and caribou migrate as well. **Figure** 6.26 shows the migration route of a bird called a godwit.

KQED: Flyways: The Migratory Routes of Birds

For thousands of years and countless generations, migratory birds have flown the same long-distance paths between their breeding and feeding grounds. Understanding the routes these birds take, called *flyways,* helps conservation

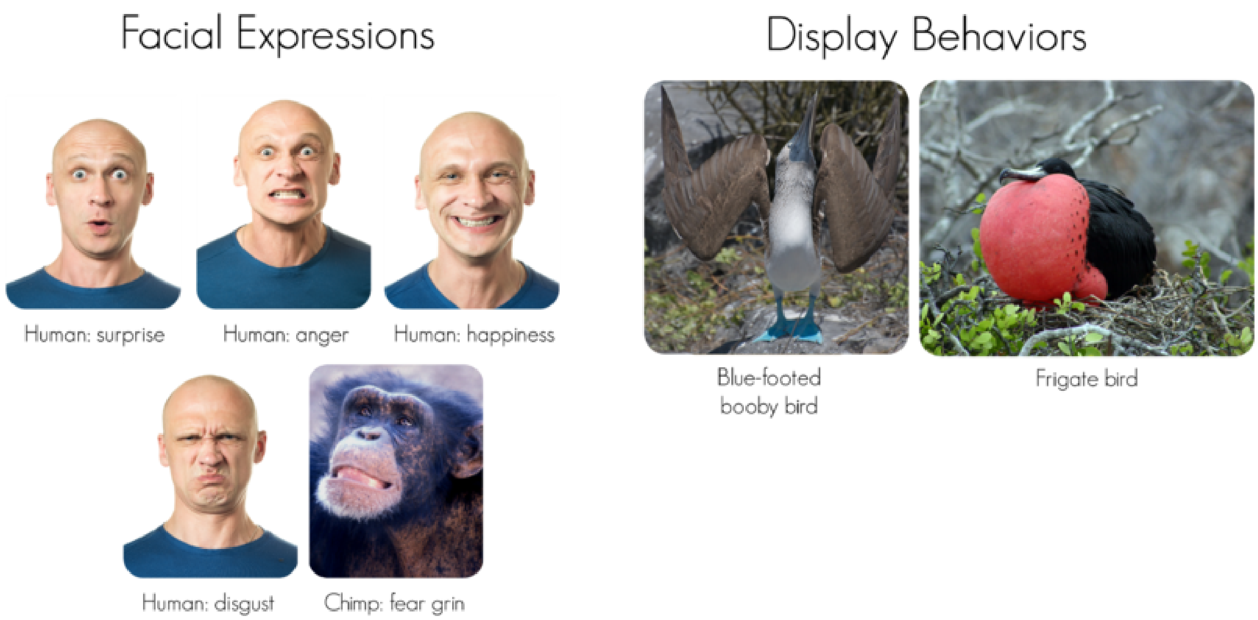


FIGURE 6.25
Visual Communication in Animals. Many animals use visual cues to communicate.

FIGURE 6.26
Godwit Migration Route. Godwits make this incredibly long journey twice a year. In the fall, they migrate from the Arctic to Antarctica. They make the return flight in the spring.

efforts and gives scientists better knowledge of global changes, both natural and man-made. See http://www.kqed.org/quest/television/the-great-migration for additional information.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/469

Aggression

Aggression is behavior that is intended to cause harm or pain. It may involve physical violence against other individuals. For example, two male gorillas may fight and use their canine teeth to inflict deep wounds. Expressing aggression this way may lead to serious injury and even death.

In many species, display behaviors—rather than actual physical attacks—are used to show aggression. This helps prevent injury and death. Male gorillas, for example, are more likely to put on a display of aggression than to attack another male. In fact, gorillas have a whole series of display behaviors that they use to show aggression. They beat on their chest, dash back and forth, and pound the ground with their hands.

Competition

Aggressive behavior often occurs when individuals compete for the same resources. Animals may compete for territory, water, food, or mates. There are two basic types of competition: intraspecific and interspecific.

- Intraspecific competition occurs between members of the same species. For example, two male deer may compete for mates by clashing their antlers together.
- Interspecific competition occurs between members of different species. For example, one species of ant may attack and take over the colony of another ant species.

Mating and Courtship

Mating refers to the union of a male and female of the same species for reproduction. The relationship between mates varies by species. Adults may have many mates, or they may mate with just one individual. Mates may stay together only while mating. Or they may stay together for an entire breeding season or even for life.

Females are likely to be more selective than males in choosing mates. In many species, males put on courtship displays to encourage females to choose them as mates. For example, to attract a mate, a male bowerbird builds an elaborate nest decorated with hundreds of small blue objects (see **Figure** 6.27). Other examples were described above and in previous lessons.

Parental Care

In most species of fish, amphibians, and reptiles, parents provide no care to their offspring. In birds and mammals, on the other hand, parental care is common. Most often, the mother provides the care. However, in some species, both parents or just the father may be involved.

Parental care is generally longest and most involved in mammals. Besides feeding and protecting their offspring, parents may teach their offspring skills they will need to survive on their own. For example, meerkat adults teach

FIGURE 6.27
Bowerbird Decorating His Nest. A male bowerbird spends many hours collecting bits of blue glass and other small blue objects to decorate his nest. A female bowerbird inspects the nests of many males before choosing as a mate the male with the best nest.

their pups how to eat scorpions. They show the pups how to safely handle the poisonous insects and how to remove the stingers.

Lesson Summary

- The branch of biology that studies animal behavior is called ethology. Ethologists usually study how animals behave in their natural environment. They try to determine the cause of behaviors, how behaviors develop, and how and why behaviors evolve.
- Most animal behaviors are controlled by both genes and experiences in a given environment. To the extent that behaviors are controlled by genes, they may evolve. Behaviors that improve fitness increase through natural selection.
- Innate behaviors are instinctive. They are controlled by genes and always occur in the same way. They do not have to be learned or practiced. Innate behaviors generally involve basic life functions, so it's important that they be performed correctly.
- Learning is a change in behavior that occurs as a result of experience. Learned behaviors are adaptive because they are flexible. They can change if the environment changes. Behaviors can be learned in several different ways, including through play.
- Types of animal behavior include social behaviors such as cooperation, communication such as facial expressions, and cyclic behaviors such as migration. Competition may lead to aggressive behaviors or displays of aggression. Behaviors relating to reproduction include mating, courtship, and parenting behaviors.

Lesson Review Questions

Recall

1. Define animal behavior.

2. What is the nature-nurture debate?

3. What are innate behaviors? Give an example.

4. What is the relationship between intelligence and learning?

5. Name three types of learning in animals.

6. Describe an example of courtship behavior in animals.

Apply Concepts

7. Assume you are an ethologist. Apply lesson concepts to develop a hypothesis about a particular animal behavior. As an ethologist, how would you study the behavior in order to test your hypothesis?

8. Create a bulletin board or brief video to demonstrate the role of facial expressions in human communication.

Think Critically

9. Infer how and why cooperative hunting in female lions evolved.

10. Compare and contrast instinct and learning.

11. Explain why communication is needed for social living.

Points to Consider

In this lesson, you learned some of the ways that humans differ from other mammals. For example, humans have a larger and more complex brain than other mammals. That's why they are also the most intelligent mammals. The next chapter introduces the biology of the human animal.

- Besides their big brain and intelligence, how else might humans differ from other mammals?
- What organs and organ systems do you think make up the human body?

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