Fruit

Because plants cannot move, they must have a method of dispersing their seeds to new locations. Most fruits are involved in the dispersal of plants.

Some fruits—for example, apples, watermelon, tomatoes, and raspberries—contain large amounts of nutritious materials. The nutrients are not for the plant's use but, rather, attract animals that eat the seeds along with the fruit. The seeds pass through the animals' digestive tract unharmed, dispersing the plant's offspring. Other fruits—such as cottonwoods, milkweeds, and dandelions—release fluffy seeds, which are carried by the wind. Many trees—such as maples and ashes—produce fruits with wings, which aid their dispersal by wind. The fruits of some plants have hooks or sticky surfaces, which become attached to the fur or feathers of passing animals. Figure 22.21 shows several kinds of fruits.

Angiosperm Diversity

Flowering plants are the most diverse group of plants, with about 260,000 species. Botanists classify angiosperms into two groups: *dicots* or *monocots*. The names *dicot* and *monocot* refer to structures in the seeds of these plants called cotyledons. **Cotyledons,** also known as seed leaves, are embryonic leaves that have food stored in them. They are the first leaves that emerge when a seed germinates. A **monocot** has one cotyledon, and a **dicot** has two cotyledons (figure 22.22). A peanut is a dicot, as are lima beans and apples. Grasses, lilies, palms, and orchids are monocots. Figure 22.23 lists the differences between monocots and dicots.

Even with this separation into monocots and dicots, the diversity is staggering. Although some monocots are woody species, such as yuccas and palms, most monocots are herbaceous.

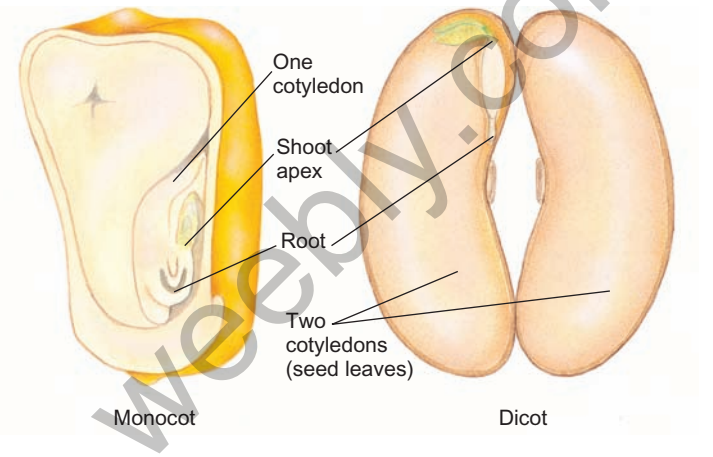
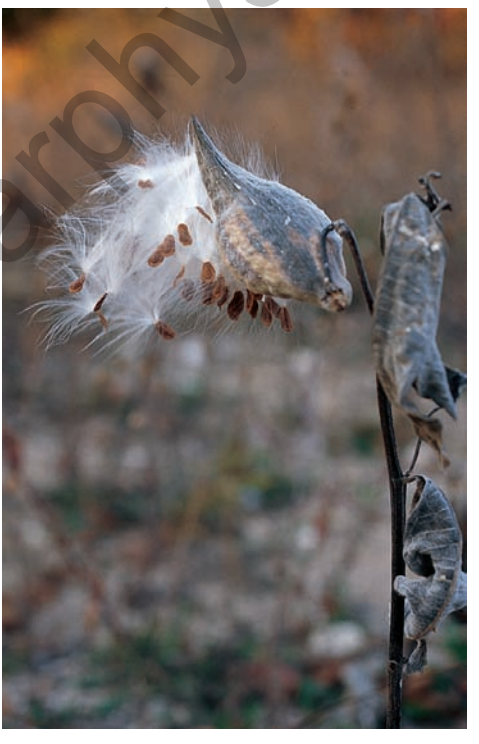


FIGURE 22.22 Embryos in Monocots and Dicots
The embryos of plants have embryonic leaves, called seed leaves or cotyledons, attached to the embryonic stem. The monocots have one cotyledon and the dicots have two.

Burdock



Milkweed

Raspberry

FIGURE 22.21 Types of Fruits
From a plant's point of view, fruits are useful as methods of dispersal. Each of these kinds of fruits uses a different method of dispersal. Burdock has hooks, which stick to passing animals. Milkweed fruits open to release seeds, which are carried by the wind. Raspberries are eaten by birds or other animals. The raspberry seeds pass through the gut and are distributed in the feces.

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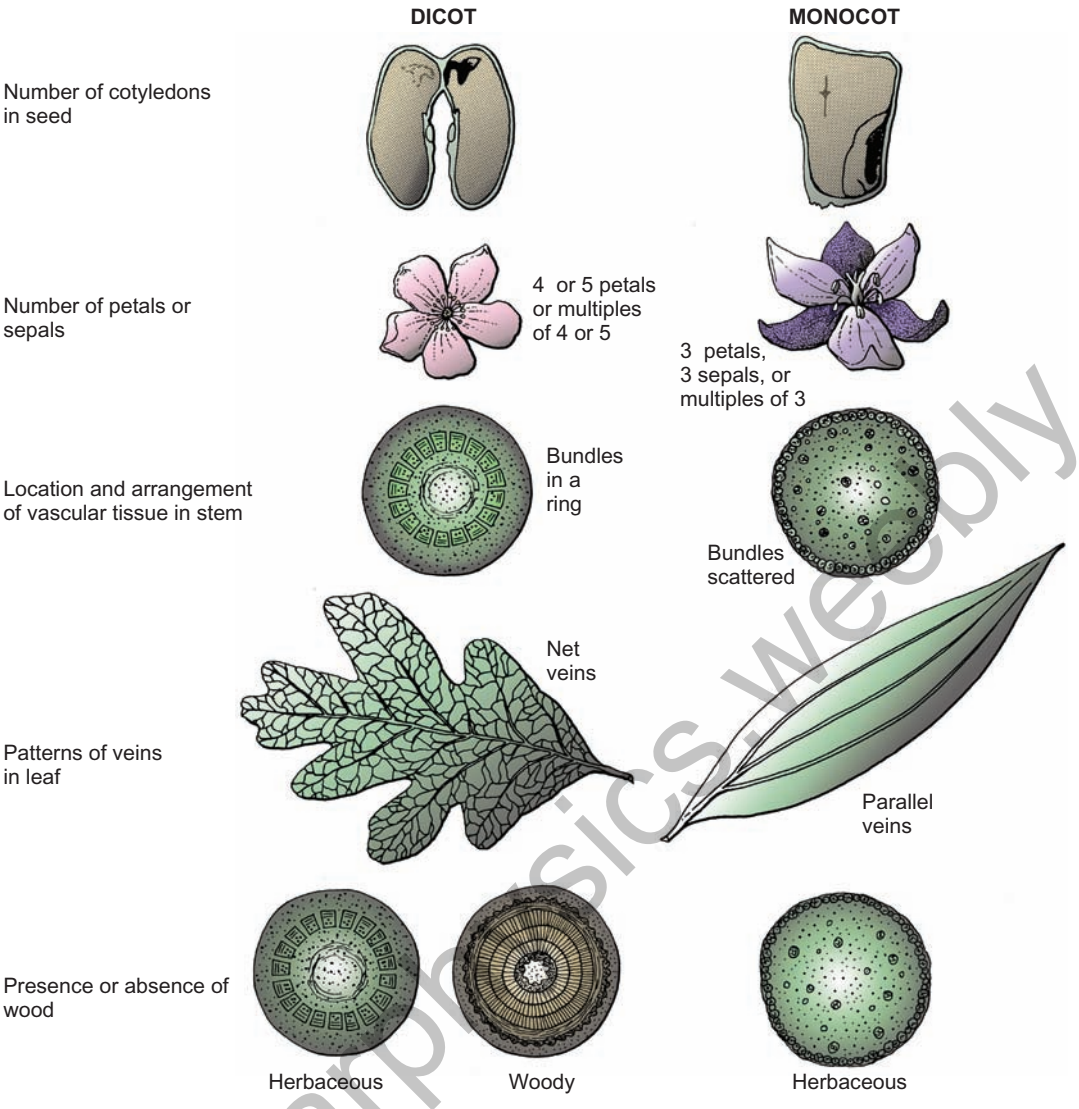

FIGURE 22.23 A Comparison of Structures in Dicots and Monocots
Botanists classify angiosperms into the monocots and the dicots. Several general characteristics help differentiate these two groups.

Many of these plants grow from underground structures, in which they store food. Many important food plants are monocots, including wheat, rice, corn, yams, onions, and bananas.

Common herbaceous dicots, such as mints, carrots, cabbages, mustards, tomatoes, potatoes, and peppers, are important food plants. About half of the dicots are woody trees and shrubs, such as aspen trees and sagebrush. These plants add layers of new xylem and phloem each year, as the stem and root of the plant get larger in diameter. The phloem is in the outermost part of the stem called the bark. Dicot trees and shrubs generally produce broad, flat leaves. In colder parts of the world, most woody dicots lose all their leaves during the fall. Such trees are said to be **deciduous** (figure 22.24). However, there are exceptions. Some are **nondeciduous,** keeping their leaves and staying green throughout the winter—for example, American holly (*Ilex opaca*). In tropical and semitropical regions, many of these trees shed leaves one at a time, so they retain their leaves throughout the year. In areas that have pronounced changes in rainfall, many trees and shrubs lose their leaves during the dry part of the year.

22.8 CONCEPT REVIEW

15. How is a seed different from pollen, and how do both of these differ from a spore?
16. Describe how wind and insect pollinated flowers differ.
17. Describe the major kinds of gymnosperms.
18. Describe how monocots and dicots differ.
19. Describe two ways the life cycle of flowering plants differs from that of cone-bearing plants.
20. List the parts of the flower.

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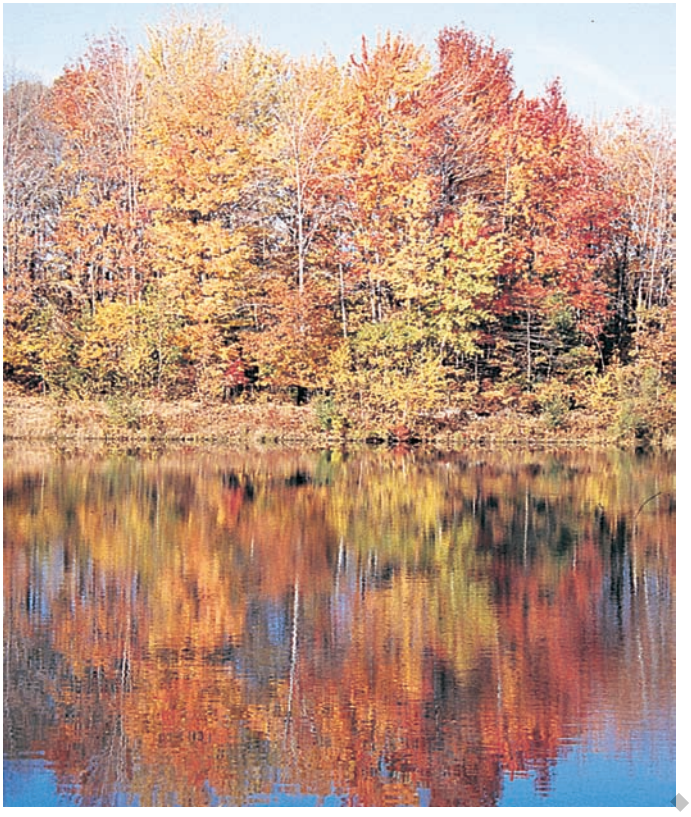

FIGURE 22.24 Deciduous Trees and Fall Colors
The cells of leaves contain a variety of pigments. In the fall, a layer of waterproof tissue forms at the base of each leaf, cutting off the flow of water and other nutrients. The cells of the leaf die and their chlorophyll disintegrates. The color change seen in leaves in the fall in certain parts of the world is the result of the breakdown of the green chlorophyll. Other pigments (red, yellow, orange, brown) are present but are masked by the green chlorophyll pigments. When the chlorophyll disintegrates, the reds, oranges, yellows, and browns are revealed. It appears that red pigments are synthesized in the fall but most of the other pigments are present throughout the year.

FIGURE 22.25 A Cross Section of Woody Stem
Woody stems are composed of xylem in the middle and a covering of bark on the outside. The phloem is located in the bark. Between the xylem and phloem is the vascular cambium. The cells of the vascular cambium divide and add to the diameter of the stem by adding xylem and phloem.

22.9 The Growth of Woody Plants

All gymnosperms and a large proportion of the dicots are woody plants. Although these two groups of plants have different evolutionary histories, they share the ability to grow continuously for many years. The trees get taller and larger in diameter each year. Both the stems and the roots grow from their tips and add to their length. In addition, they increase in diameter by adding new xylem and phloem to the outside of the stem.

As a tree becomes larger, the strengthening tissue in the stem becomes more and more important. A layer of cells in the stem, called the **vascular cambium,** is responsible for this increase in diameter. The vascular cambium is between the xylem and the phloem. Xylem tissue is the innermost part of the tree trunk or limb, and phloem is outside. The bark of the tree, containing the phloem, is important in protecting the underlying tissues. Cambium cells go through a mitotic cell division, and two cells form. One cell remains cambium tissue, and the other specializes to form vascular tissue. If the cell is on the inside of the cambium ring, it becomes xylem; if it is on the outside of the cambium ring, it becomes phloem. As cambium cells divide again and again, one cell always remains cambium, and the other becomes vascular tissue. Thus, the tree constantly increases in diameter (figure 22.25) (How Science Works 22.1).

The accumulation of the xylem in the trunk of gymnosperms and woody angiosperms is called **wood.** Wood is one of the most valuable biological resources of the world. We get lumber, paper products, turpentine, and many other valuable materials from the wood of gymnosperms and angiosperms. In many areas of the world, firewood is the primary fuel for cooking and heating homes.

As you can see from this discussion, both angiosperms and gymnosperms have members that are woody. Therefore the term *woody* cuts across taxonomic lines.

22.9 CONCEPT REVIEW

21. What is the significance of the vascular cambium tissue in woody perennials?
22. Wood is composed of what kind of cell?

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HOW SCIENCE WORKS 22.1

Using Information from Tree Rings

Trees that live in seasonal climates produce a ring of new growth each year. These annual rings are visible in the cut stem because in the spring, when trees start to produce new growth, the xylem cells produced are large. The cells produced later in the year are smaller. The abrupt change between the small cells produced in the fall and the large cells produced the following spring is easy to see.

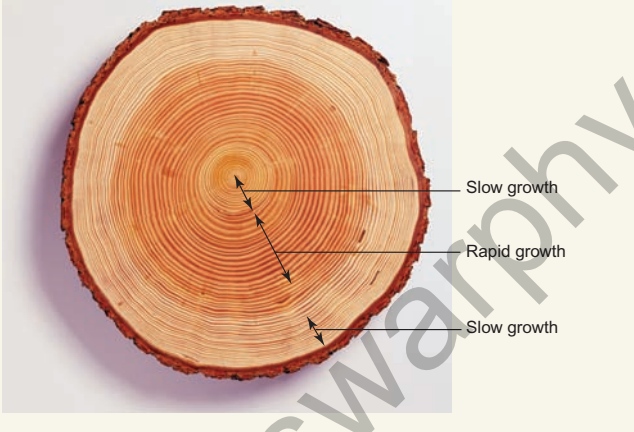
In the accompanying photograph of a cross section of a Douglas fir tree, we can gather several bits of information:

1. We can count the rings and determine that the tree was about 50 years old when it was harvested.
2. By noticing how close together the annual rings are in the center of the stem, we can see that in the early years of its life, it grew relatively slowly.
3. By examining the width of the annual rings in the darker brown area and counting the rings, we can determine that the tree grew rapidly for about 20 years in the middle of its life.
4. Growth then slowed considerably in the later part of the tree's life as evidenced by the narrow annual rings in the outer portion of the stem.

Scientists can use this information for a variety of purposes. Foresters can bore into a tree and obtain a sample of the tree rings to assess how well the tree is growing. Healthy, rapidly growing trees will show wide annual rings, while poorly growing trees will show narrow annual rings. Based on this information they can make decisions about when to harvest trees to get the greatest production from a forest.

Scientists interested in how climate may have changed in the past can look at tree rings and determine if there were periods of drought or other factors that may have altered a tree's growth pattern. Since some trees live for thousands of years, it is possible to use tree rings to get an idea of climate alterations that occurred before recorded history.

Because the trees used in wooden structures were killed when they were harvested, archaeologists can use tree rings to determine the age of artifacts and ancient structures. The tree ring patterns in wooden structures and implements can be examined for patterns of growth that can be correlated with known events. Thus, it is possible to place precise dates on certain archaeological structures. It is even possible of examine growth patterns in petrified wood (see photo).



Tree rings give information about rates of growth.

Ancient tree rings in a petrified tree stump.

22.10 Plant Responses to Their Environment

Our casual impression of plants is that they are unchanging objects. However, on closer examination we recognize that plants change over time. They grow, produce flowers and fruits at certain times of the year, and grow toward a source of light. Furthermore, they respond to organisms that harm them and may even mount an attack against competitors.

Tropisms

A **tropism** is a growth movement toward or away from a stimulus. For example, plants orient themselves toward light. This is known as *phototropism*. The value of this response is obvious, because plants need light to survive. The mechanism that allows this response involves a hormone known as auxin. The growing tip of the stem produces auxin, which is transported down the stem. Auxin stimulates cells to divide, grow, and elongate. If the growing tip of a plant receives more light on one side, the shaded side produces more auxin than does the lighted side. The larger amount of auxin on the shaded side causes greater growth in that area, and the tip of the stem bends toward the light. When all the sides of the stem are equally illuminated, the stem grows equally on all sides and grows straight. House plants near a window must be turned regularly, or they will grow more on one side than the other (figure 22.26).

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FIGURE 22.26 Phototropism
These tomato plants were growing in a window and have oriented themselves to the light coming through the window.

Many kinds of climbing vines are able to wrap stringlike *tendrils* around sturdy objects in a matter of minutes. This kind of growth response is called *thigmotropism*. As the tendrils grow, they slowly wave about. When they encounter an object, their tropic response is to wrap around it and anchor the vine. Once attached, the tendrils change into hard structures that bind the vine to its attachment. Sweet peas, grapevines, and ivy attach in this manner (figure 22.27). Ivy can cause great damage to buildings as it grows, and its tendrils loosen siding and serve as a haven for the growth of other destructive organisms.

Plants also have growth responses to gravity and the presence of water. Stems grow up; roots grow down and toward water in the soil.

Seasonal Responses

Plants live in a seasonal world, and they respond accordingly. Plants that live in temperate regions experience changes in temperature and the amount of sunlight. The days are longest in the summer and shortest in the winter. Plants are able to measure day length and manufacture hormones that cause changes in the growth and development of specific parts of the plant. Some plants produce flowers only when the days are getting longer, some only when the days are getting shorter, and some only after the days have reached a specific length. In deciduous trees, the shortening day length in the fall triggers a response that causes the tree to produce a wall of waterproof tissue between the leaves and the stem. Because the leaves no longer receive water, they die and fall to the ground.

Other plants store food materials in underground structures such as bulbs and tubers during the active growing period in the summer. In the fall the above-ground part of the plant dies back, but the underground portion remains alive in a dormant state. In the spring, as the soil warms, these storage structures send up new growth.

FIGURE 22.27 Thigmotropism—Clinging Stems
Some stems are modified to wrap themselves around objects and give support. The tendrils of this grapevine are a good example.

Many parts of the world experience seasonal rainfall. Rain is abundant for several months and totally absent during others. Plants' responses to these conditions are similar to those of plants that respond to seasonal changes in temperature. During the dry season, the leaves fall from trees and many smaller plants become dormant. When it rains, the plants respond by growing, flowering, and fruiting.

Responses to Injury

Plants are attacked by a variety of disease-causing organisms and by plant-eating herbivores. Plants respond to disease in much the same way as animals do. When infected with a disease organism, they have an innate ability to fight the infection. Plants also repair wounds by growing a form of scar tissue over the wounded area.

Attack by herbivores is handled in a different way. Many plants produce toxic materials, which interfere with the metabolism of animals that eat plants. When the leaves of plants are eaten by animals, the new leaves produced to replace those lost often contain higher amounts of toxic materials than the original leaves.

Plants may even have the ability to communicate with one another. An experiment carried out in a greenhouse produced some interesting results. Some of the plants had their leaves mechanically "eaten" by an experimenter, whereas nearby plants were not harmed. Not only did the cut plants produce new leaves with more toxins, but the new growth on neighboring, nonmutilated plants had increased toxin levels as well. This raises the possibility that plants communicate in some way, perhaps by the release of molecules that cause changes in the receiving plant.

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22.10 CONCEPT REVIEW

23. Describe phototropism and thigmotropism.
24. Describe two examples of how plants respond to environmental changes.
25. Why might a plant gain an advantage by producing toxic substances in its tissues?

22.11 The Coevolution of Plants and Animals

The first terrestrial organisms were plants. Shortly after the plants became established on land, animals, such as insects and amphibians, arrived. Thus, terrestrial plants and animals have a long history of interaction, which has had an influence on the evolution of each group. There are many examples of their coevolution.

Most flowering plants are pollinated by insects or other animals. Insect-pollinated plants produce flowers that are showy, have nectar, and produce odors. Many flowers that are pollinated by birds are red and produce much nectar. Some flowers bloom only at night and are pollinated by moths or bats.

Grasses and grazers have coevolved. Grasses have silica in their cell walls. This is a very hard material, and it tends to wear down the teeth of grazers. Most grazing animals have very long teeth, which can accommodate a lifetime of wear. Grasses also differ from most other plants in that their leaves and stems grow from the base of the plant rather than from the tip. Thus, they can withstand regularly having the tips of their leaves chewed off.

Many kinds of flowering plants produce large, nutritious fruits, which animals use for food, in the process distributing the seeds. There are even seeds that will not germinate unless they have passed through the gut of an animal. Birds eat small fruits and their seeds, which are dispersed when the birds defecate. In tropical forests, many trees have very large fruits, which are eaten by monkeys. They eat the fleshy part of the fruit and drop the seeds.

Browsers are animals that eat the leaves and small twigs of woody plants. Many kinds of woody plants have thorns, making this task more difficult, but browsers have techniques or structures that allow them to put up with the prickly deterrents.

Plants produce a variety of chemicals. Some of these chemicals are toxic or irritating and deter certain animals from eating portions of the plant. Others chemicals produce odors that help animals locate flowers or fruits. These attractive odors aid the plant by assuring that pollination and seed dispersal will take place. Humans use many of these plants and the chemicals they produce as spices and flavorings (Outlooks 22.2).

22.11 CONCEPT REVIEW

26. Describe how the coevolution of grasses and grazing animals affected both kinds of organisms.
27. In what ways do some flowering plants encourage insects to visit them?

OUTLOOKS 22.2

Spices and Flavorings

Think about all the plant materials we use to season our foods. Black pepper comes from the hard, dried berries of a tropical plant, *Piper nigrum*. Cayenne pepper is made from the ground-up fruits of *Capsicum annuum*, and the hot, spicy chemical in the fruit and seeds is known as capsaicin. The seeds of the dill plant, *Anethum graveolens*, are used to flavor pickles and many other foods. The dried or fresh leaves of many herbs such as thyme, rosemary, chives, and parsley, are also used as flavorings. Many kitchen cabinets also contain cinnamon from the bark of a tree found in India; cloves, which are the dried flower buds of a tropical tree; ginger from the root of a tropical plant of Africa and China; nutmeg from the seed of a tropical tree of Asia; and saffron from the dried, fragrant stigmas of the crocus flower (*Crocus sativus*) from Spain. Saffron's small size and difficulty in harvesting the stigmas make it the most expensive spice on Earth.

Centuries ago, spices such as these were so highly prized that fortunes were made in the spice trade. Beginning in the early 1600s, ships from Europe regularly visited the tropical regions of Asia and Africa, returning with cargoes of spices and other rare commodities that could be sold at great profit. Consequently, India has been greatly influenced by Britain, Indonesia has been greatly influenced by the Netherlands, and the development of various portions of Africa has been influenced by Britain and France.

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Summary

The plant kingdom is composed of eukaryotic, multicellular organisms that can manufacture their own food through photosynthesis. All plants have alternation of generations with a haploid, gametophyte generation and a diploid, sporophyte generation. The gametophyte produces sex cells (eggs and sperm) by mitosis and the sporophyte produces haploid spores by meiosis. There is a general trend in the evolution of plants for less dependence on a moist environment and an increase in the importance of the sporophyte generation. The nonvascular plants (mosses and related organisms) lack vascular tissue, have the gametophyte generation as the dominant generation, and have swimming sperm. The seedless vascular plants (ferns and related organisms) have vascular tissue, a dominant sporophyte generation, and swimming sperm. Seed-producing vascular plants (cone-bearing and flowering plants) have vascular tissue, a dominant sporophyte generation, the development of pollen, and seeds.

Vascular tissue consists of xylem, which carries water and inorganic nutrients from the roots to the leaves; and phloem, which carries organic molecules from the leaves to places where they are needed. The presence of vascular tissue is associated with the specialization of body parts into roots, stems, and leaves. Roots anchor the plant and absorb water and nutrients from the soil. Leaves are generally thin, flat structures specialized for photosynthesis. Stems connect the roots to the leaves and position the leaves to receive sunlight.

Pollen is the male gametophyte plant and is either carried by wind or animals from one plant to another. Wind-pollinated plants produce huge amounts of pollen. Some flowering plants are pollinated by animals and produce showy flowers and nectar to attract animals.

Plants respond to their environment in complex and interesting ways. They respond to the position of the sun, day length, contact with other objects, and injury.

Key Terms

Use the interactive flash cards on the ***Concepts in Biology,*** *14/e website to help you learn the meaning of these terms.*

angiosperms 491
antheridium 482
archegonium 482
cones 491
cotyledons 495
deciduous 496
dicot 495
flower 493
fruit 493
gametophyte generation 481
gymnosperms 491
imperfect flower 493
leaf 486
monocot 495
nondeciduous 496
perfect flower 493
petals 493
phloem 483
pistil 493
pollen 491
pollination 491
root 483
root hairs 485
seed 490
sepals 493
sporophyte generation 480
stamens 493
stem 483
tropism 498
vascular cambium 497
vascular tissue 481
wood 497
xylem 483

Basic Review

1. The sporophyte generation
   a. is diploid.
   b. produces spores.
   c. is the dominant stage in angiosperms.
   d. All of the above are correct.
2. Gymnosperms produce fruits. (T/F)
3. All of the following are vascular plants except
   a. ferns.
   b. mosses.
   c. horsetails.
   d. gymnosperms.
4. There are two kinds of vascular tissue: xylem and _____.
5. The central part of a woody stem consists of
   a. xylem.
   b. phloem.
   c. silica.
   d. bark.
6. Nearly all gymnosperms are woody perennials. (T/F)
7. Plants are able to sense changes in their environment. (T/F)
8. From a plant's point of view, a fruit
   a. is used to feed seeds.
   b. is used to disperse seeds.
   c. requires little energy to produce.
   d. All of the above are correct.
9. The pollination of plants by insects is an example of _____.
10. Which one of the following plant groups has the largest number of species?
    a. conifers
    b. ferns
    c. angiosperms
    d. mosses

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11. Which of the following does not have swimming sperm?
    a. moss
    b. fern
    c. gymnosperm
    d. horsetail
12. Phototropism is a response to _____.
13. Phloem
    a. cells are hollow.
    b. is found in the center of a tree.
    c. has companion cells.
    d. is found in mosses.
14. Fossils of mosses that are trees have been found. (T/F)
15. All plants have a gametophyte generation. (T/F)

Answers
1. d 2. F 3. b 4. phloem 5. a 6. T 7. T 8. b 9. coevolution 10. c 11. c 12. light 13. c 14. F 15. T

Thinking Critically

Potato Facts
Some people say the ordinary "Irish" potato is poisonous when the skin is green, and they are at least partly correct. A potato develops a green skin if the potato tuber grows so close to the surface of the soil that it is exposed to light. An alkaloid called *solanine* develops under this condition and may be present in toxic amounts. Eating such a potato raw can be dangerous. However, cooking breaks down the solanine molecules and makes the potato as edible and tasty as any other. The so-called Irish potato is of interest historically. Its country of origin is only part of the story. Check your local library to find out about this potato and its relatives. Are all related organisms edible? Where did this group of plants develop? Why is it called the Irish potato?

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CHAPTER 23

The Animal Kingdom

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Peregrine Falcon Back from the Brink of Extinction

Urban birds are part of the story.

The peregrine falcon (*Falco peregrinus*) is a crow-sized bird with a worldwide distribution. It is a predator on smaller birds such as pigeons, doves, shorebirds, and ducks. Its method of hunting is adapted to open spaces where it can spot prey and pursue it. Typically a peregrine will perch on an elevated site or hover while searching for prey. When it spots prey, it dives at speeds of up to 320 kilometers per hour (200 mph) and strikes its prey in the air.

As with many other predatory birds, the population of peregrine falcons was severely reduced by the accumulation of DDT, an insecticide commonly used from about 1940 to 1972. DDT caused egg shells to be thin, and few offspring were raised successfully. Consequently populations of the American subspecies that nests in Canada, the United States, and Mexico fell from an estimated 3,875 pairs in the 1900s to 324 pairs in 1975. The ban on the use of DDT in 1972 and the passage of the Endangered Species Act in the United States helped to save it. Captive breeding programs were instituted to rebuild the population and, in 1999, the peregrine falcon was removed from the list of endangered species. Today, there are between 2,000 and 3,000 nesting pairs in North America.

One of the interesting sidelights to this successful recovery is that many pairs of birds have adapted to urban settings. Some were purposely released in urban settings but wild birds have also taken up an urban lifestyle. Tall buildings and bridges provide nesting sites similar to their normal nesting sites on cliffs. The areas between buildings provide suitable open space for hunting and the abundant supply of urban birds (particularly pigeons and starlings) provides a ready food source.

- **Why is the thickness of the egg shell important?**
- **Why are birds and mammals more likely than insects to be on endangered species lists?**
- **DDT is still used in some countries to control mosquitoes that carry malaria. Should it be banned in those countries?**

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Background Check

Concepts you should already know to get the most out of this chapter:

- The processes of natural selection and evolution (chapter 13)
- That structural and life history characteristics are used to classify organisms (chapter 20)
- That cells are specialized to perform certain functions (chapter 4)

23.1 What Is an Animal?

Animals are eukaryotic, multicellular organisms whose cells lack cell walls. Like plants, animals have cells that are specialized for specific purposes. Functions such as ingesting food, exchanging gases, and removing wastes are more complicated in animals than in one-celled protists. In one-celled organisms, any exchange between the organism and the external environment occurs through the plasma membrane. However, because animals are multicellular, most of their cells are not on the body surface and, therefore, not in direct contact with the external environment. Thus, animals must have specialized ways to exchange materials between their internal and external environments.

Some simple animals, such as sponges and jellyfish, have a few kinds of specialized cells, whereas other, more complex animals, such as insects and mollusks, have bodies composed of groups of cells organized into tissues, organs, and organ systems. The more complex animals have gills, lungs, or other structures used to exchange gases; various kinds of structures are involved in capturing and digesting food; and there are usually special structures for getting rid of waste products. Like plants, many of the larger animals have a method of transporting materials throughout the body.

Animals are heterotrophs that eat other organisms to obtain organic molecules, and many are specialized for consuming certain kinds of food organisms. Although there are many ways of capturing and consuming food, all of them involve movement.

Movement is a characteristic associated with all animals; it involves specialized muscle cells that shorten. Many animals have appendages (e.g., legs; wings; tentacles; spines; or soft, muscular organs) that bend or change shape. Often, these structures are involved in moving the animal from place to place, but they are also used to capture food, to clean the animals' surfaces, and to move things in the animals' environment.

Sexual reproduction is important in all groups of animals. The methods vary greatly—from the release of sperm and eggs into the water, for many aquatic organisms, to fertilization inside the body, for most terrestrial organisms. A few kinds, such as birds and mammals, provide a great deal of care for their offspring. Asexual reproduction is also an important part of the life cycle of many of the more primitive animals. Those that reproduce asexually also reproduce sexually at other times in their life cycle.

Animals also have sensory structures on their surface that detect changes in the environment. A system of nerve cells integrates information about the environment and coordinates movements, so that movements occur at appropriate times and with a proper orientation. Figure 23.1 shows a variety of animals.

Frog

Jellyfish

Praying mantis

Snail

Starfish

FIGURE 23.1 Variety of Animals

Animals show an amazing variety of body forms and lifestyles.

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23.1 CONCEPT REVIEW

1. List three characteristics shared by all animals.

23.2 The Evolution of Animals

Scientists estimate that the Earth is at least 4.5 billion years old and that life originated in the ocean about 3.8 to 3.7 billion years ago. The earliest animal-like fossils date to about 600 million years ago. Most of the earliest animals were probably either small organisms that floated or swam in the ocean or wormlike organisms that crawled on the bottom or through the sediment on the ocean floor.

Because they lived in the ocean, these animals did not require special mechanisms to deal with rapid or extreme changes in the environment and they did not have a problem with dehydration. Because the concentration of salts in the early ocean approximated that of the animals' cells, the animals did not need to expend energy to keep their cells in osmotic balance. Furthermore, their body temperature was that of the water in which they lived.

The early evolution of animals was rapid. Scientists have found examples of all the major groups of animals as far back as the Cambrian period, 540 to 490 million years ago. They were all marine animals, and many groups, such as sponges, jellyfish, mollusks, crustaceans, starfish, and many kinds of fish—are still primarily marine animals. The evolution of organisms that inhabit freshwater and terrestrial environments is a more recent development. The first terrestrial animals (arthropods) are found in the fossils of the Silurian period, 443 to 417 million years ago. Major changes in the kinds of terrestrial animals occurred after that time. Two groups—arthropods (particularly the insects) and vertebrates (especially reptiles, birds, and mammals)—were extremely successful in terrestrial habitats.

The evolution of animals led to great diversity, and today animals are adapted to live in just about any environment. They live in all the oceans, on the shores of oceans, and in shallow freshwater. They live in the bitter cold of the Arctic, the dryness of the desert, and the driving rains of tropical forests. Some animals eat only other animals, some are parasites, some eat both plants and other animals, and some feed only on plants. They show a remarkable variety of form, function, and activity. They can be found in an amazing variety of sizes, colors, and body shapes.

It is common to divide animals into two categories. Animals with backbones made of vertebrae are called **vertebrates** and include various kinds of fishes, amphibians, reptiles, birds, and mammals. Those without backbones are called **invertebrates.** All early animals lacked backbones, and invertebrates still constitute 99.9% of all animal species in existence today (Outlooks 23.1).

The evolution of animals is complex and often difficult to interpret. Figure 23.2 shows the current knowledge of how various groups of animals are related.

23.2 CONCEPT REVIEW

2. Where did all the various groups of animal life originate?
3. How are invertebrates and vertebrates different?

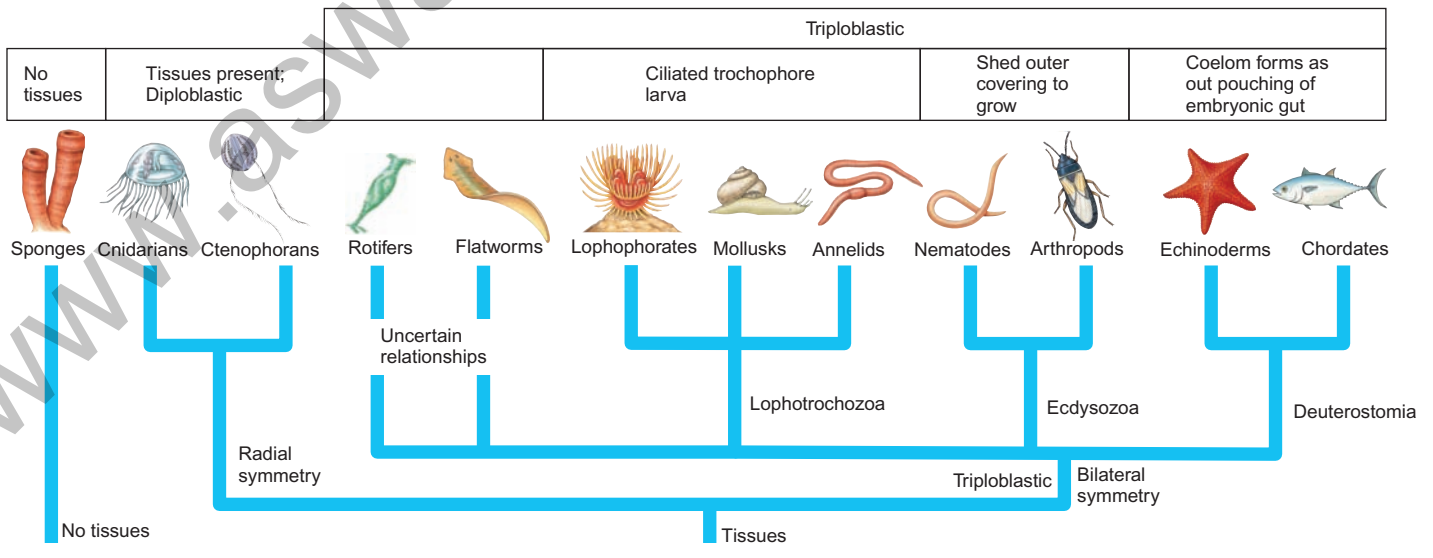

FIGURE 23.2 Animal Evolution
This diagram shows the current thinking about how the major groups of animals are related to one another. There are about 30 recognized phyla. Only the major phyla are shown here.

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OUTLOOKS 23.1

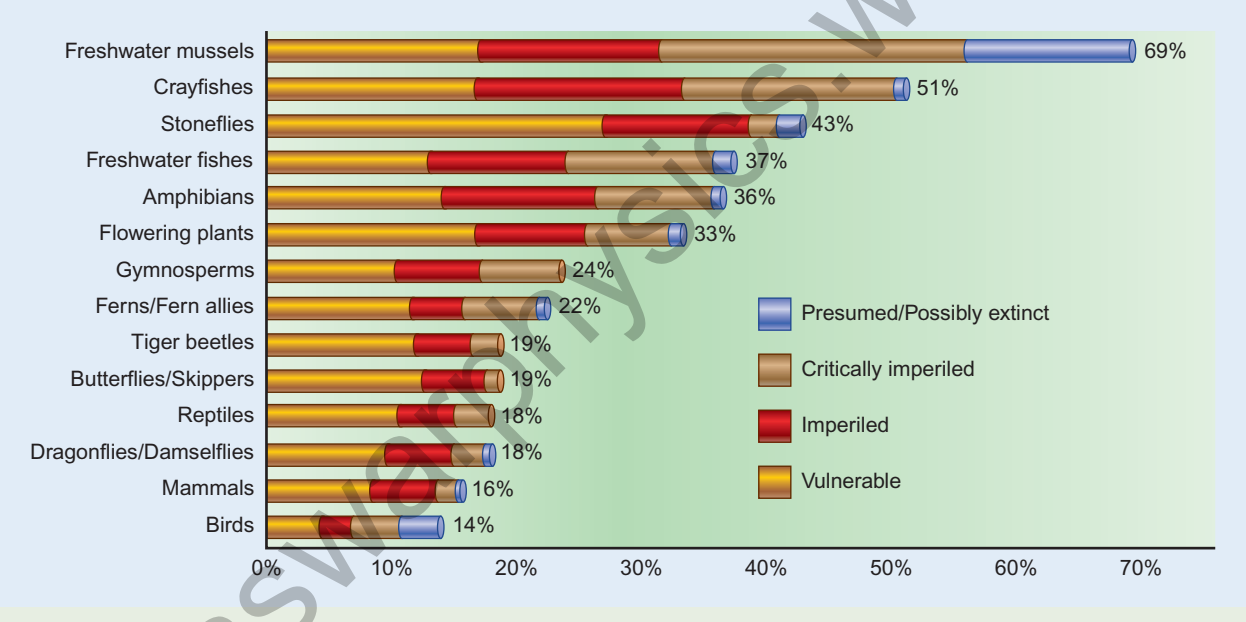
The Problem of Image

We humans are vertebrate mammals. We unconsciously view all other animals by comparing them with ourselves. If other animals are like us, we feel we understand them and can empathize with them. If they are not mammals like us, we often consider them to be weird.

Mammals make up less than 0.04 percent of all the animals that exist; thus, mammals are a minor ingredient in the whole collection of animals in the world in terms of numbers and in significance. Because certain species are able to grab the attention of the public, often they are called charismatic species.

Our narrow, biased view of the world is evidenced in subtle ways. For example, most of the endangered species listed are vertebrate animals like us. About 7% of the known species of vertebrates are designated as endangered. On the other hand, less than 0.2% of invertebrate species are known to be endangered. The lack of invertebrates on lists of endangered species is primarily because we know so little about them. We don't even know how many different species there are, let alone if species are going extinct or not.

We have organizations to save whales, pandas, and wild horses (which are not endangered), but we do not have organizations to save the poison arrow frog or endangered native crayfish and clams. In actuality, in North America the most vulnerable category of organisms consists of freshwater species of mussels (clams), crayfish, fish, and stoneflies. The least vulnerable are birds and mammals, yet birds and mammals capture most of the public's interest and governmental financial support, and are highlighted by the U.S. Fish and Wildlife Service on its endangered species website.



Source: Data from Natureserve, Prescious Heritage.

23.3 Temperature Regulation

The temperature of an organism affects the rate at which its metabolic reactions take place. Some animals do little to regulate their temperature, whereas others expend considerable energy to maintain a constant temperature.

Poikilotherms are organisms whose body temperature varies with the environmental temperature. When the water or air temperature changes, so does the temperature of the organism. All microbes and plants and most animals, including insects, worms, and reptiles, are poikilotherms. This is significant because, at colder body temperatures, poikilotherms have lower metabolic rates; at higher body temperatures, they have higher metabolic rates. A low metabolic rate means that all of their body functions, such as movement and rate of digestion of food, are slowed. However, an organism with a low metabolic rate requires less food.

Homeotherms are animals that maintain a constant body temperature that is generally higher than the environmental temperature, regardless of the external temperature (figure 23.3). These animals—birds and mammals—have high metabolic rates, because they use metabolic energy to maintain their

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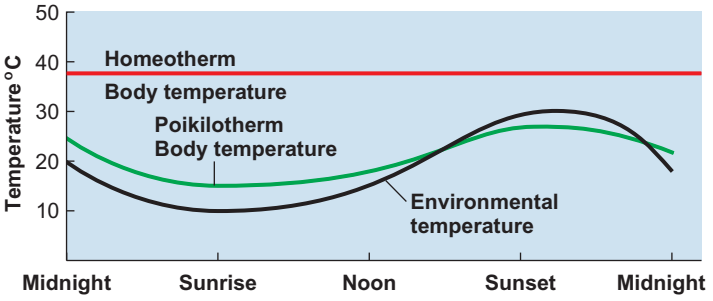

FIGURE 23.3 Regulating Body Temperature
The body temperature of a homeotherm remains relatively constant, regardless of changes in environmental temperature. The body temperature of a poikilotherm varies considerably, depending on the environmental temperature.

constant body temperature. This means that homeotherms have higher food demands than poikilotherms but are able to remain active at low environmental temperatures. Among homeotherms, the smaller animals have higher body temperatures and higher metabolic rates than the larger animals. This is in part because small animals lose heat faster than large animals, because small animals have a larger surface area compared to their volume.

Sometimes, the terms *ectotherm* and *endotherm* are used to describe the same relationship from a slightly different point of view. **Ectotherms** are organisms whose body temperatures depend on the external temperature, and **endotherms** are animals that have internal heat-generating mechanisms and can maintain a relatively constant body temperature in spite of wide variations in the temperature of their environment.

However, poikilotherms or ectotherms are not necessarily totally at the mercy of their environment. Many poikilotherms use behavioral means to regulate body temperature. One simple method is to position the body so that it absorbs heat from its surroundings. Many kinds of reptiles and insects "sun" themselves. By placing themselves in the Sun or on rocks or other surfaces that have been heated by the Sun, they can raise their body temperature above that of their environment. Similarly, many poikilotherms can generate heat by contracting their muscles. In cold weather, bumblebees often beat their wings prior to flying, raising their body temperature. Body temperature is important, because the rate at which the wings can beat is determined by body temperature.

23.3 CONCEPT REVIEW

4. How does the body temperature of a poikilotherm affect its metabolism?
5. List an advantage and a disadvantage of maintaining a constant body temperature.

23.4 Body Plans

Although animals come in a variety of sizes and shapes, you can see certain evolutionary trends and a few basic body plans.

Symmetry

Symmetrical objects have similar parts that are arranged in a particular pattern. For example, the parts of a daisy flower and a bicycle are arranged symmetrically.

Asymmetry is a condition in which there is no pattern to the individual parts. Asymmetrical body forms are rare and occur only in certain species of sponges, which are the simplest kinds of animals.

Radial symmetry occurs when a body is constructed around a central axis. Any division of the body along this axis results in two similar halves. Although many animals with radial symmetry are capable of movement, they do not always lead with the same portion of the body; that is, there is no anterior, or head, end. Starfish and jellyfish are examples of organisms with radial symmetry.

Bilateral symmetry exists when an animal is constructed with equivalent parts on both sides of a plane. Animals with bilateral symmetry have a head and a tail region. There is only one way to divide bilateral animals into two mirrored halves. Animals with bilateral symmetry move head first, and the head typically has sense organs and a mouth. The feature of having an anterior head end is called *cephalization* (*cephal* = head). It appears that bilateral symmetry was an important evolutionary development since most animals have bilateral symmetry (figure 23.4).

Embryonic Cell Layers

Animals differ in the number of layers of cells of which they are composed. When we look at the development of embryos we find that the embryos of the simplest animals (sponges) do not form distinct, tissuelike layers. However, jellyfishes and their relatives have embryos that consist of two layers. The **ectoderm** is the outer layer and the **endoderm** is the inner layer. Because their embryos are composed of two layers, these animals are said to be **diploblastic.** In adults, these embryonic cell layers give rise to an outer, protective layer and an inner layer that forms a pouch and is involved in processing food.

All the other major groups of animals have embryos that are *triploblastic*. **Triploblastic** animals have three layers of cells in their embryos. Sandwiched between the ectoderm and endoderm is a third layer, the **mesoderm.** In the adult body, the ectoderm gives rise to the skin or other surface covering, the endoderm gives rise to the lining of the digestive system, and the mesoderm gives rise to muscles, connective tissue, and other organ systems involved in the excretion of waste, the circulation of material, the exchange of gases, and body support (figure 23.5).

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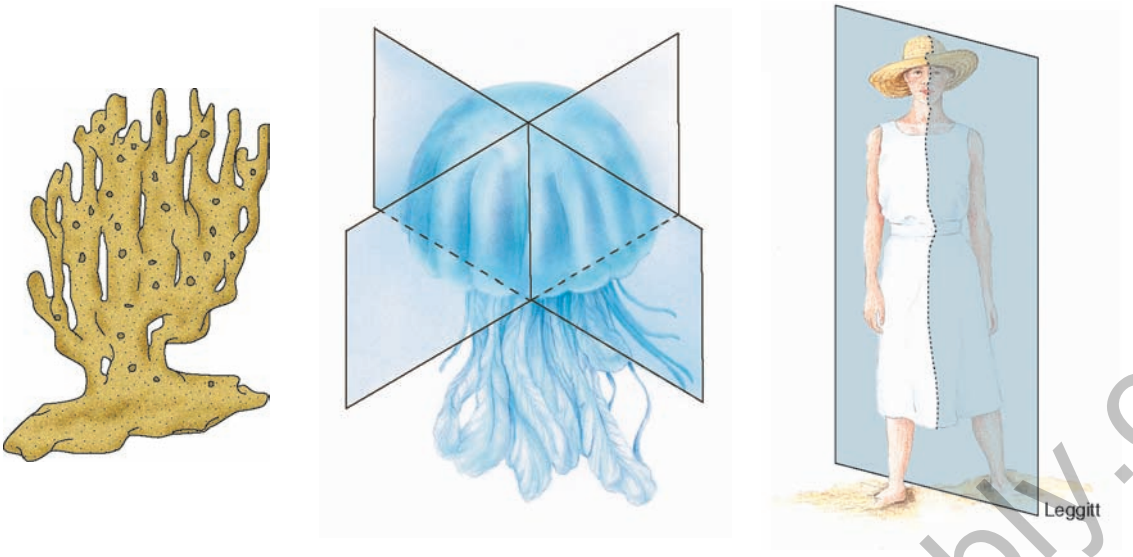

FIGURE 23.4 Kinds of Symmetry

(a) This sponge has a body that cannot be divided into symmetrical parts and is therefore asymmetrical. *(b)* In animals such as this jellyfish with radial symmetry, any cut along the central body axis results in similar halves. *(c)* In animals with bilateral symmetry, only one cut along one plane results in similar halves.

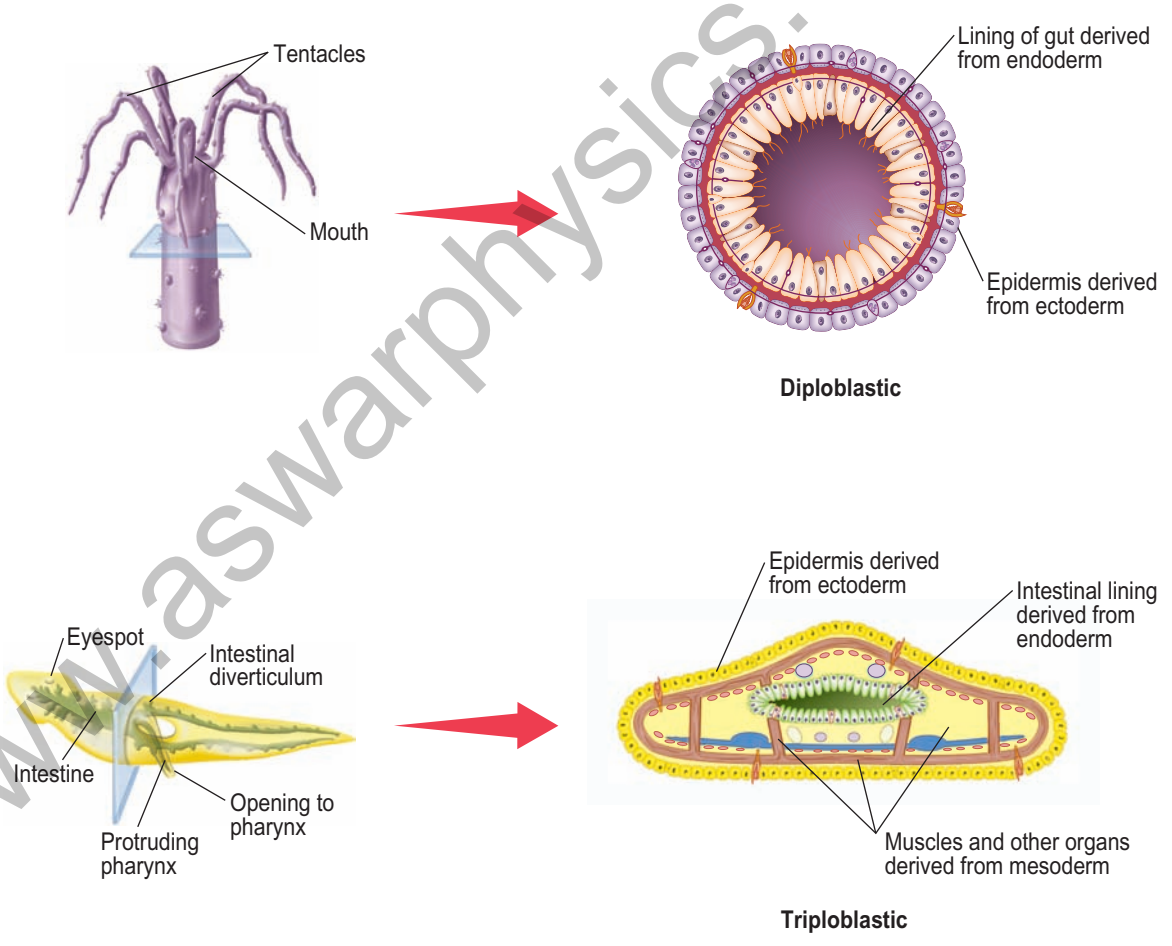

FIGURE 23.5 Embryonic Cell Layers

Diploblastic organisms have two embryonic cell layers. The outer ectoderm becomes the epidermis and the inner endoderm becomes the lining of the gut. Triploblastic organisms have three embryonic cell layers: the ectoderm, endoderm, and mesoderm. The mesoderm forms most of the tissues and organs of the body.

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Body Cavities

A **coelom** is a fluid-filled body cavity that separates the outer body wall of the organism from the gut and internal organs. The development of a coelom was an important step in animal evolution.

Simple animals, such as jellyfish and flatworms, are **acoelomate,** which means that they have no space separating their outer surface from their internal organs. However, most animals have some form of a coelom. Because organs such as the gut and heart are not embedded in a mass of cells but are suspended in a space (the coelom), they have a greater freedom of movement than the organs of acoelomate animals. Organs are not loose in the coelom; they are held in place by sheets of connective tissue called **mesenteries.** Mesenteries also support the blood vessels connecting the various organs.

It is often difficult to visualize the presence of a coelom as a cavity, because the cavity is filled with organs and a small amount of fluid. Perhaps a common example will help.

The coelom in a turkey is the cavity where you stuff the dressing. In the living bird this cavity contains a number of organs, including those of the digestive, excretory, and circulatory systems.

Some animals do not have a true coelom but have a similar space called a *pseudocoelom*. A **pseudocoelom** differs from a true coelom in that it is located between the lining of the gut and the outer body wall. In other words, animals with a pseudocoelom do not have muscles around their digestive system. In addition, there are no mesenteries suspending the gut from the outer body wall. Nematode worms and several related groups of animals have a pseudocoelom (figure 23.6).

Segmentation

Many kinds of bilaterally symmetrical organisms have segmented bodies. **Segmentation** is the separation of an animal's body into a number of recognizable units from its anterior to its posterior end. Segmentation is associated with the specialization of certain parts of the body. Three common groups of animals show segmentation: annelid worms, arthropods, and chordates. Annelid worms have a series of very similar segments with minor differences between them. Segmentation in arthropods is modified so that several segments are specialized as a head region and more posterior segments are less specialized. Many of the posterior segments have legs and other appendages. Among the arthropods, insects show a great deal of specialization of segments. In chordates, the segmentation is of a different sort but is obvious in the arrangement of muscles and the vertebral column (figure 23.7). Studies of the genes that control development show that all bilaterally symmetrical

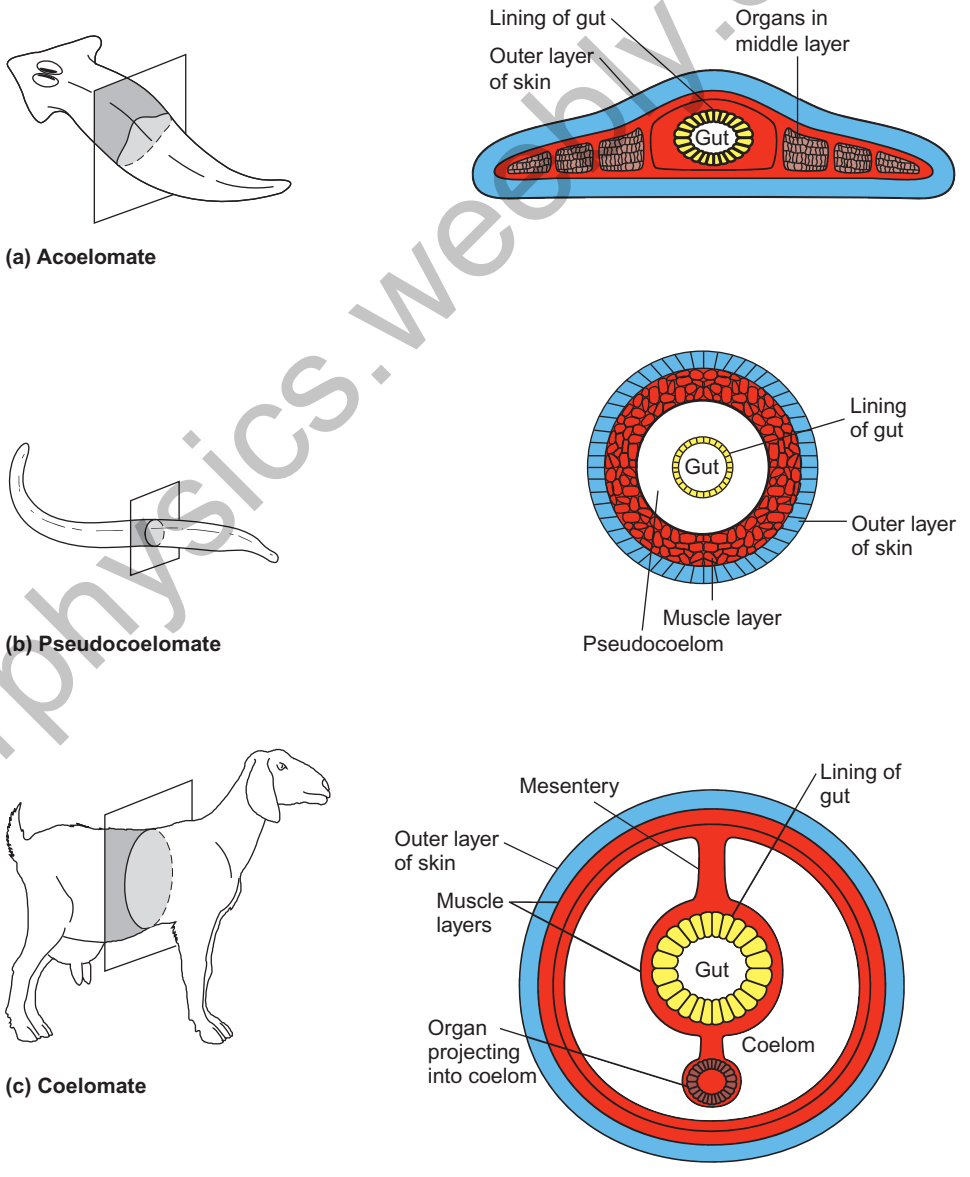

FIGURE 23.6 Body Cavities
(a) Acoelomate animals, such as flatworms, have no open space between the gut and outer body layer. *(b)* Roundworms, commonly found in soil, have a body cavity called a pseudocoelom. It contains some cells, and there are no muscles surrounding the gut. *(c)* Other animals, including all vertebrates, have a coelom, which is a fluid-filled space that separates internal organs from the outer body wall. In addition, the coelom is lined with connective tissue of mesodermal origin. Organs project into the coelom and are held in place by thin sheets of connective tissue called mesenteries.

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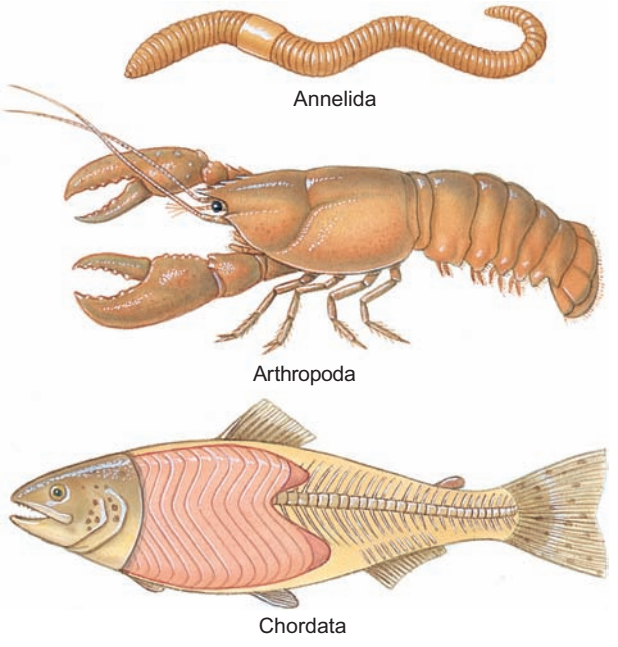

FIGURE 23.7 Segmentation
Segmentation is associated with the specialization of certain parts of the body. Annelid worms show many segments with little specialization. Arthropods show a highly developed head region, with the more posterior segments less specialized. Chordates show the segmentation of muscles and skeletal structures.

animals have essentially the same genes controlling their development and how different regions or segments of the body develop (How Science Works 23.1).

Skeletons

A **skeleton** is the part of an organism that provides structural support. Most animals have a skeleton. It serves as strong scaffolding, to which other organs can be attached. In particular, the skeleton provides places for muscle attachment and, if the skeleton has joints, the muscles can move one part of the skeleton with respect to others. Some aquatic organisms, such as sea anemones and many kinds of worms, are generally supported by the dense medium in which they live and lack well-developed skeletons. However, most aquatic animals have a skeleton. Most terrestrial animals have a strong structure that supports them in the thin medium of the atmosphere.

There are two major types of skeletons: internal skeletons (**endoskeletons**) and external skeletons (**exoskeletons**) (figure 23.8). The vertebrates (fish, amphibians, reptiles, birds, mammals), echinoderms (starfish, sea urchins, etc.), and some other groups have internal skeletons. The various organs are attached to and surround the skeleton, which grows in size as the animal grows. Arthropods (crustaceans, spiders, insects, millipedes, centipedes), nematodes, and some

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HOW SCIENCE WORKS 23.1

Genes, Development, and Evolution

One of the important discoveries of modern molecular genetics is the remarkable similarity in the kinds of genes found in all organisms. This has important implications for understanding the evolution of organisms. It appears that once a new, valuable gene is created through the process of mutation, it is preserved in evolutionary descendants. One example is a group of genes known as *homeotic genes*. These genes regulate how an organism's body is formed by helping to define which end of the developing embryo is the head and which is the tail. As the embryo develops and regular body segments form, the homeotic genes also help define what each segment becomes. In insects, one segment might give rise to antennae, while another gives rise to wings or legs. Homeotic genes were first discovered in the fruit fly (*Drosophila melanogaster*), which has been a favorite species for students of animal genetics for 100 years (see photo). Fruit flies are ideal for genetic studies for several reasons: They are easy and inexpensive to raise in the lab, a new generation can be produced every 10 days, and large numbers of offspring are produced.

It is now known that homeotic genes control the same developmental processes in all organisms that are bilaterally symmetrical (their left side mirrors their right side). This trend is so overwhelming that some scientists have suggested that the presence of one type of homeotic genes, the *Hox* genes, should be used to define the Animal kingdom.

Essentially the same genes with the same functions can be found in widely different animals, such as fruit flies, earthworms, sea urchins, tapeworms, and humans. This means that the study of fruit flies can be used to discover how the same genes function in humans and other animals. Because homeotic genes are involved in regulating embryonic development and cellular differentiation, these studies can be used to help identify the causes of human embryonic development abnormalities and other diseases like cancer.

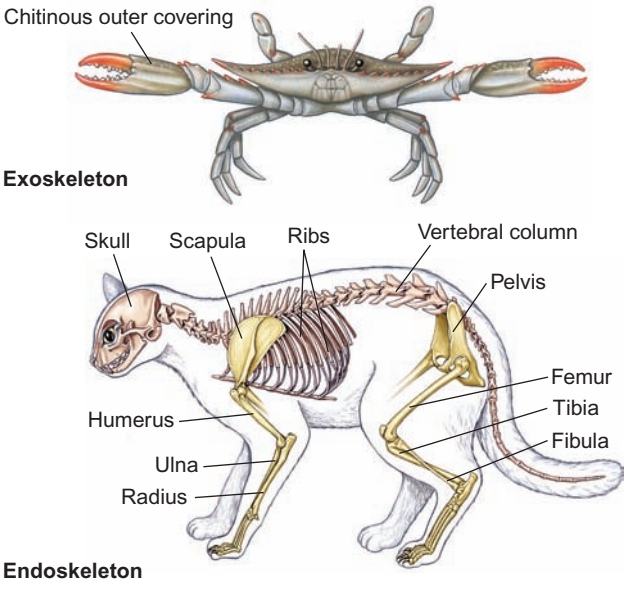

FIGURE 23.8 Skeletons
There are two major types of skeletons; endoskeletons and exoskeletons. Endoskeletons are typical of vertebrates and echinoderms, and exoskeletons are typical of arthropods and their relatives.

other groups have an external skeleton that surrounds all the organs. It is generally hard and has joints. These animals accommodate growth by shedding the old skeleton and producing a new, larger one. This period in the life of an arthropod is dangerous, because for a short period it is without its hard, protective outer layer. Many other animals have structures that have a supportive or protective function (such as clams, snails, and corals) and these are sometimes called skeletons, but they do not have joints.

Some organisms use water as a kind of supportive skeleton. Annelid worms and some other animals have fluid-filled coeloms. Because water is not compressible, but it is movable, compressive forces by muscles can cause the animal's shape to change. This is similar to what happens with a water-filled balloon; compression in one place causes it to bulge out somewhere else.

23.4 CONCEPT REVIEW

6. Describe body forms that show asymmetry, radial symmetry, and bilateral symmetry.
7. Give an example of an animal that has a coelom and one with a pseudocoelom.
8. Give an example of an animal with an exoskeleton, and one with an endoskeleton.
9. How does an animal with an exoskeleton grow?
10. How do diploblastic and triploblastic animals differ?
11. What is one advantage of segmentation?

23.5 Marine Lifestyles

All groups of animals originated in the ocean, and most still call the oceans home. Marine animals exhibit several kinds of lifestyles.

Zooplankton

Zooplankton is a mixture of different kinds of small animals that drift with currents and feed on phytoplankton and other zooplankton. Crustaceans make up approximately 70% of the zooplankton. These include copepods, krill (small, shrimplike organisms), and other kinds of crustaceans. In addition, jellyfish and comb jellies are common. Other kinds of zooplankton include protozoa, several kinds of worms, a group of mollusks, and the larvae (immature, free–living offspring) of many animals, including fish and primitive chordate relatives.

Nekton

Nekton includes many kinds of aquatic animals that are large enough and strong enough to be able to swim against currents and tides and go where they want to. They are carnivores that feed either on plankton or other nekton. Like the zooplankton, this is a diverse group of organisms, including some actively swimming jellyfish, squid and cuttlefish, shrimp, sharks, bony fish, turtles, sea snakes, birds (penguins, cormorants, and other diving birds), and several kinds of mammals (whales, porpoises, seals, sea otters, walruses, and so on).

Benthic Animals

A major ecological niche in the oceans includes large numbers of bottom-dwelling (benthic) organisms. Among the benthic organisms are such animals as sponges, corals, and sea anemones; segmented worms; clams and snails; lobsters, crabs, and shrimp; starfish and sea urchins; and many kinds of fish. Benthic marine organisms fall into two general categories: those that move about in search of food and those that are filter feeders. Common animals that move about the bottom are crabs, many worms, fish, starfish and some mollusks.

Filter feeders are sessile—permanently attached to the substrate. They feed by creating water currents with cilia or appendages that bring food to them. Sponges, corals, tube worms, clams, barnacles, and crinoids are examples of filter feeders.

Sexual reproduction presents special problems for sessile animals because they cannot move to find mates. However, because they are in an aquatic environment, the sperm can swim to the egg and fertilize it. The fertilized egg develops into a larval stage—the juvenile stage (figure 23.9). The larvae are usually ciliated or have appendages that enable them to move, even though the adults are sessile. The free-swimming larval stages allow the animal to disperse through its environment.

The larva differs from the sessile adult not only because it is free-swimming but also because it usually uses a different source of food and often becomes part of the plankton community. The larval stages of most organisms are subjected

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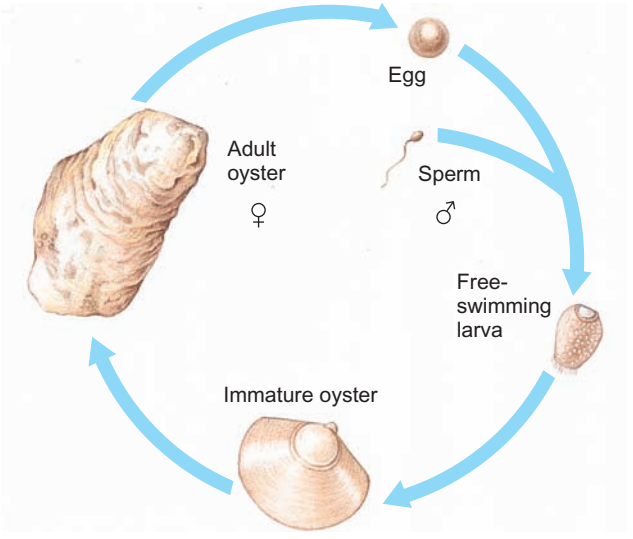

FIGURE 23.9 The Life Cycle of an Oyster
Each oyster can be either male or female at different times in its life. Sperm are released and swim to the egg. Fertilization results in the formation of a free-swimming larva. This larva undergoes several changes during the first 12 to 14 days and eventually develops into an immature oyster, which becomes attached and develops into the adult oyster.

to predation, and the mortality rate is high. The larvae move to new locations, settle down, and develop into adults.

Even many marine animals that do not have sessile stages produce free-swimming larvae. For example, crabs, starfish, and eels move about freely and produce free-swimming larvae.

23.5 CONCEPT REVIEW

12. What is a sessile filter feeder?
13. How do plankton and nekton organisms differ?
14. What is a benthic organism?

23.6 Primitive Marine Animals

Members of the Porifiera (sponges) and Cnidaria (jellyfish, corals, and relatives) are the simplest multicellular animals. Fossils of these kinds of animals have been found that date to about 580 million years ago. Nearly all of the animals in these groups are found in saltwater environments. There are a few freshwater species.

Porifera—Sponges

Even though sponges are classified as multicellular, in many ways they are similar to colonial protozoa. In particular, a group of flagellated protozoa known as choanoflagellates have a structure that is very similar to the flagellated cells (called choanocytes) found in sponges. Sponges have two layers of cells, with the choanocytes on the inside and flat, platelike cells (pinacocytes) on the outside. There are also a few other kinds of cells present. There is a jellylike layer between the two kinds of cells. The cells of sponges are rather loosely connected and can move about, and some even change their function. Because of this loosely defined organization, sponges are not considered to have tissues, which are groups of cells with specific functions.

All adult sponges are benthic, sessile (permanently attached) filter feeders. The flagellated choanocytes cause a current of water to circulate through the organism. All the cells engulf entire food particles directly from the water just as most protozoa do (figure 23.10). Although some sponges are radially symmetrical, most sponges are asymmetrical. Sponges have structures, called spicules, in a jellylike material between the two layers of cells. Some species have spicules of calcium carbonate, others of silicon dioxide, and some of a protein material. It is the skeletons composed of protein spicules that are used as bath sponges. (Actually, most sponges we buy are manufactured from various forms of plastic.)

Asexual reproduction in sponges can occur by fragmentation. Wave action may tear off a part of a sponge, which eventually settles down, attaches itself, and begins to grow. Sponges also reproduce by **budding,** a type of asexual reproduction in which the new organism is an outgrowth of the parent. Sexual reproduction involves the release of sperm, which are carried to adjacent sponges where fertilization takes place. The fertilized egg develops into a free-swimming, flagellated larval stage. The larva swims in the plankton and eventually settles to the bottom, attaches, and grows into an adult sponge.

Cnidaria—Jellyfish, Corals, and Sea Anemones

Members of the Cnidaria (pronounced *nid'-air-e-ah*) include the jellyfish, corals, and sea anemones. They are diploblastic with an outer epidermis and an inner layer that forms digestive cavity. Because the cells of these two layers are specialized, the cnidarians are considered to have a tissue level of development. There is a jellylike material between the two layers of cells; it is very thick in jellyfishes. Cnidarians show radial symmetry, and all species have a single opening leading into a saclike digestive cavity. Surrounding the opening is a series of tentacles (figure 23.11). These long, flexible, armlike tentacles have specialized cells that produce structures called *nematocysts,* which can sting and paralyze small organisms. Nematocysts are unique to the Cnidaria. The cells that produce the nematocysts are known as cnidocytes and are responsible for the name of the group—Cnidaria. Even though they are primitive organisms, cnidarians are carnivorous.

Many species of Cnidaria exhibit alternation of generations and have both sexual and asexual stages of reproduction. The **medusa** is a free-swimming adult stage that reproduces sexually. The **polyp** is a benthic, sessile larval stage that reproduces asexually (figure 23.12). Sea anemones and corals are polyps. Some species lack a medusa stage in their life cycles and the polyps produce eggs and sperm. Corals

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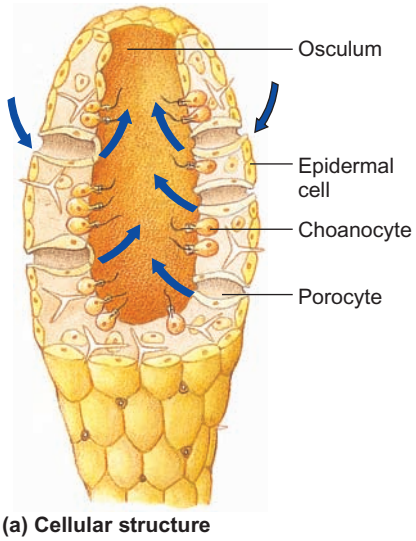
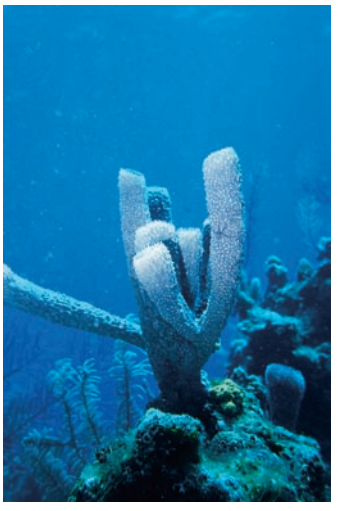


(a) Cellular structure



(b) Vase-shaped sponge

(c) Asymmetrical sponge

FIGURE 23.10 Sponge Structure and Function

(a) Sponges consist of an outer epidermal layer and an inner layer of flagellated cells called choanocytes. These flagella create a current, which brings water in through the openings formed by the porocyte cells, and propels it out through the osculum. The current brings food and oxygen to the inner layer of the cells. The food is filtered from the water as it passes through the animal. *(b)* Some sponges have a "vase shape"; however, *(c)* most sponges are asymmetrical and have no distinct form.

Jellyfish

Sea anemone

Coral

FIGURE 23.11 Phylum Cnidaria

There are three major types of cnidarians: jellyfish, sea anemones, and corals. The fuzzy appearance of the coral is because the polyps are extended.

secrete an external skeleton of calcium carbonate or other material. The polyp lives in a depression in the skeleton into which it can withdraw. Polyps extend from the depression when they feed. Jellyfish are free-swimming medusas; they often produce small polyp stages during their life cycle.

Ctenophora—Comb Jellies

Members of Ctenophora (pronounced *tin'-off-er-ah*) are similar to cnidarians in that they are diploblastic and have radial symmetry. They have rows of cilia that allow them to swim, and many have two long, armlike appendages, which help them gather food (figure 23.13).

23.6 CONCEPT REVIEW

15. How do sponges feed?
16. What are spicules?
17. What are the differences between a polyp and a medusa?
18. List three structural characteristics of cnidarians.

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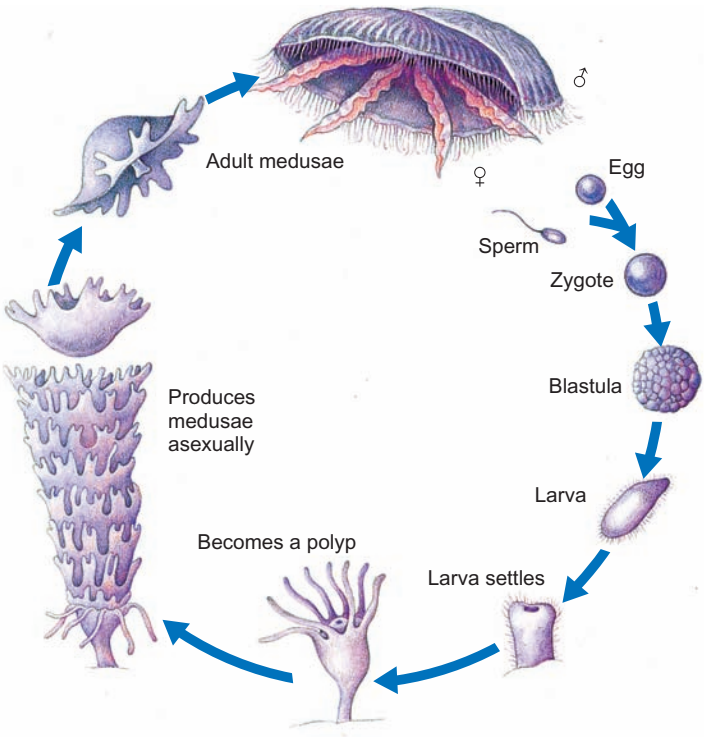

FIGURE 23.12 A Cnidarian Life Cycle
The life cycle of *Aurelia* is typical of the alternation of generations seen in most species of Cnidaria. The free-swimming adult medusa (jellyfish) reproduces sexually, and the resulting larva develops into a polyp. The polyp undergoes asexual reproduction, which produces the free-swimming medusa stage.

FIGURE 23.13 Ctenophora
Ctenophorans are marine, planktonic organisms that swim with rows of cilia. Many are bioluminescent.

23.7 Platyhelminthes—Flatworms

The simplest bilaterally symmetrical animals are the flatworms. Because they are also triploblastic, they represent a major increase in complexity over the sponges and cnidarians. They are considered more primitive than other bilaterally symmetrical, triploblastic animals because they lack a coelom and have only one opening to the gut. They have no circulatory or respiratory system. Their flat structure allows for the diffusion of gases between their environment and the internal cells.

There are three basic types of flatworms. Turbellaria is a class of free-living flatworms (often called *planarians*). The other two groups are parasitic: Trematoda (flukes) and Cestoda (tapeworms). These parasitic kinds constitute the majority of species of flatworms (figure 23.14). We may consider this form of nutrition rather unusual, but of all the kinds of animals in the world, more are parasites than not.

Turbellarians are free-living flatworms that are bottom dwellers in marine waters or freshwater. A few species are found in moist terrestrial habitats. They are carnivores or scavengers that feed on dead organisms. The food that enters

(a) Turbellarian

(b) Tapeworm

(c) Fluke

FIGURE 23.14 Flatworm Diversity
(a) Turbellarians are free-swimming, nonparasitic flatworms that inhabit marine and freshwater. (This is a marine species.) *(b)* Adult tapeworms are parasites found in the intestines of many carnivores. *(c)* Some flukes live attached to the outside surface of animals, but most are internal parasites of the lungs, liver, and intestine of vertebrate animals.

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the gut is partly broken down; then, the food particles are engulfed by the cells that line the gut. Many marine species are brightly colored.

Flukes are common parasites. Some flukes are external parasites on the gills and scales of fish, but most are internal parasites. Most flukes have a complex life cycle involving more than one host. Typically, the larval stage infects an invertebrate host (usually a mollusk), whereas the adult parasite infects a vertebrate host. They are commonly found in the gut, liver, or lungs of vertebrate hosts.

For example, the disease schistosomiasis is caused by adult *Schistosoma mansoni* flukes, which live in the blood vessels of the human digestive system. This disease is common in tropical countries. The presence of the worms in the body causes diarrhea, liver damage, anemia, and a lowering of the body's resistance to other diseases. Fertilized eggs pass out with the feces. Eggs released into the water hatch into free-swimming larvae. If a larva infects a snail, it undergoes additional asexual reproduction and produces a second larval stage. A single infected snail may be the source of thousands of larvae. These new larvae swim freely in the water. If they encounter a human, the larvae bore through the skin and enter the circulatory system, which carries them to the blood vessels of the intestine (figure 23.15).

In North America, people often encounter this kind of parasite as swimmer's itch. Swimmer's itch is caused by the larval stages of a species of *Schistosoma* burrowing into the skin. However, the normal hosts for the parasite are species of ducks. Humans are not ducks, so the larvae that have burrowed into the skin die and a rash often develops. In sensitive individuals, the reaction can be extreme and require medical attention.

Tapeworms are parasites that have a completely different structure and way of life from flukes. The life cycle involves two hosts. One of the hosts is an herbivore and the other is an omnivore or a carnivore. Both hosts are usually vertebrate animals. An herbivore eats tapeworm eggs that have been passed from an infected carnivore host through its feces. The eggs contaminate the vegetation and are eaten along with the vegetation the herbivore uses for food. An egg develops into a larval stage, which migrates to the herbivore's muscle and forms a cyst. When the herbivore is eaten by a carnivore, the tapeworm cyst develops into the adult form in the carnivore's intestine. The adult worm is highly specialized. It has no digestive system, but it has hooks and suckers for holding onto the intestine of its host. It produces a series of sections, called proglottids, by asexual reproduction. Each proglottid has a complete set of reproductive organs. It is important not to confuse proglottids with the segments seen in other kinds of organisms. Proglottids are not segments, but are asexually produced buds. Mating takes place between proglottids within the intestine, and the proglottids become filled with fertilized eggs. The end proglottids break off and pass out with the feces. As the proglottids dry out, they rupture and disperse the eggs into the environment (figure 23.16).

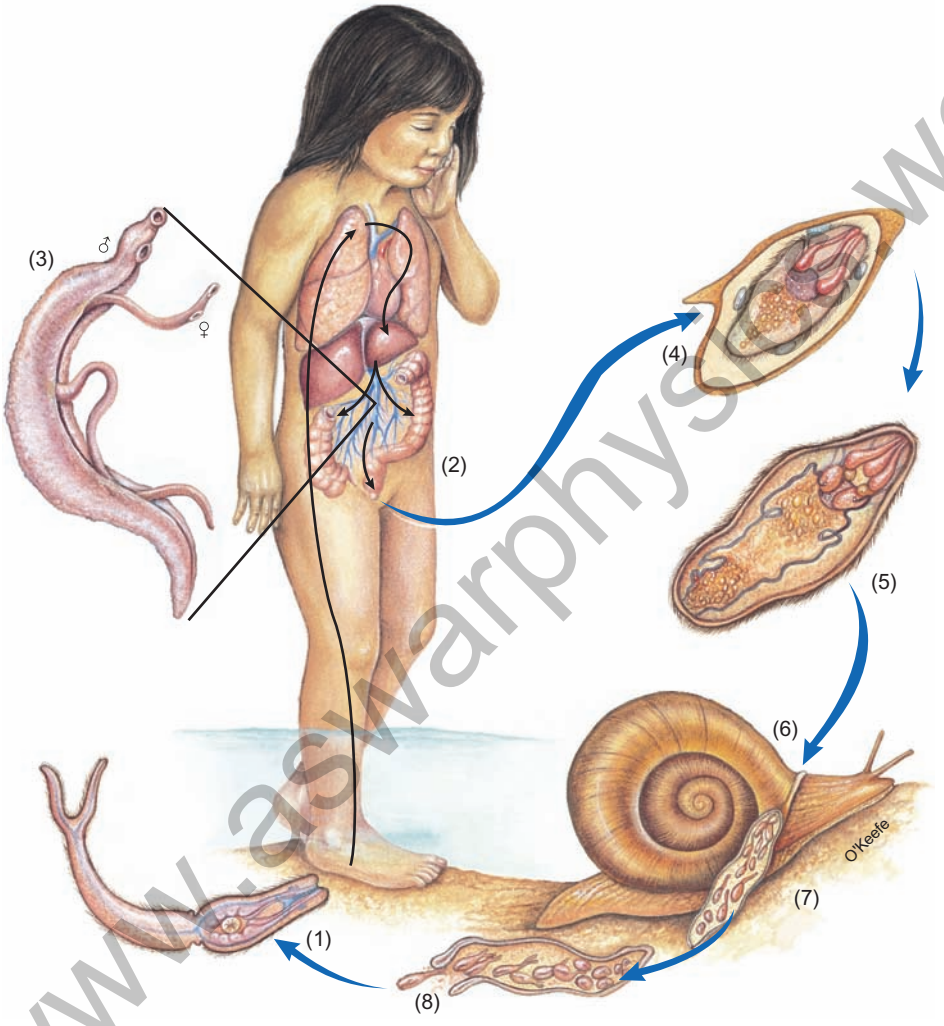

FIGURE 23.15 The Life History of *Schistosoma mansoni*
(1) Cercaria larvae in water penetrate human skin and are carried through the circulatory system to the veins of the intestine. They develop into *(2)* adult worms, which live in the blood vessels of the intestine. *(3)* Copulating worms are shown. The female produces eggs, which enter the intestine and leave with the feces. *(4)* A miracidium larva within an eggshell is shown. *(5)* The miracidium larva hatches in water and burrows into a snail *(6)*, where it develops into a mother sporocyst *(7)*. The mother sporocyst produces many daughter sporocysts *(8)*, each of which produces many cercaria larvae. These leave the snail's body and enter the water, thus completing the life cycle.

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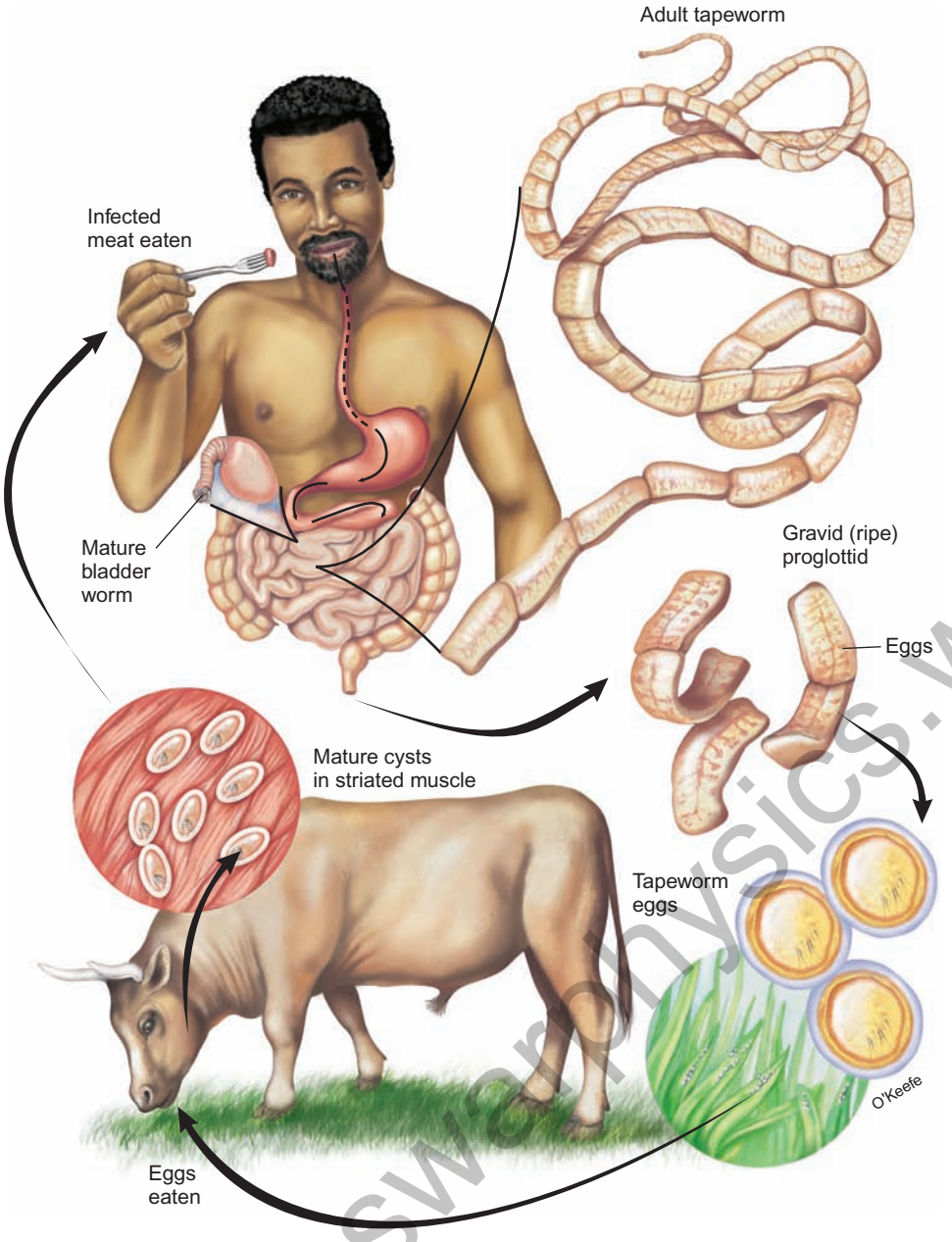

FIGURE 23.16 The Life Cycle of a Tapeworm
The adult beef tapeworm lives in the human small intestine. Proglottids, individual segments containing male and female sex organs, are the site of egg production. When the eggs are ripe, the proglottids drop off the tapeworm and pass out in the feces. If a cow eats an egg, the egg will develop into a cyst in the cow's muscles. When humans eat the cyst in raw or poorly cooked meat, the cyst develops into an adult tapeworm.

23.7 CONCEPT REVIEW

19. List three structural characteristics typical of flatworms.
20. Describe the life cycle of a fluke.
21. Describe the life cycle of a tapeworm.

23.8 Nematoda—Roundworms

Members of the Nematoda are extremely common animals, often called roundworms or nematodes. They have a simple, unsegmented, elongated body structure that consists of an outer epidermis covered by a thick, flexible cuticle. The cuticle is shed periodically as the animal grows. Nematodes are triploblastic and have a pseudocoelom (figure 23.17). Their gut is continuous, with a mouth at one end and an anus at the other. Few animals are found in as many diverse habitats or in such numbers as the roundworms. They live in marine and freshwater habitats, moist soil, and many live within other organisms as parasites. Soil nematodes are extremely common.

Although most roundworms are free-living, many are economically important parasites. Some are parasitic on plants, whereas others infect animals; collectively, they do billions of dollars worth of damage to crops and livestock. Roundworm parasites of animals range from the relatively harmless human intestinal pinworms *Enterobius*, which may cause irritation but do no serious harm, to *Dirofilaria*, which can cause heartworm disease in dogs. If untreated, this infection can be fatal. Often, the amount of damage inflicted by roundworms is directly proportional to their number. For example, hookworms (figure 23.18) feed on the host's blood. A slight infestation often results in mild anemia, but a heavy infestation of hookworms can result in mental or physical retardation in children because of the severe anemia it causes.

23.8 CONCEPT REVIEW

22. Describe the general body structure of a nematode.

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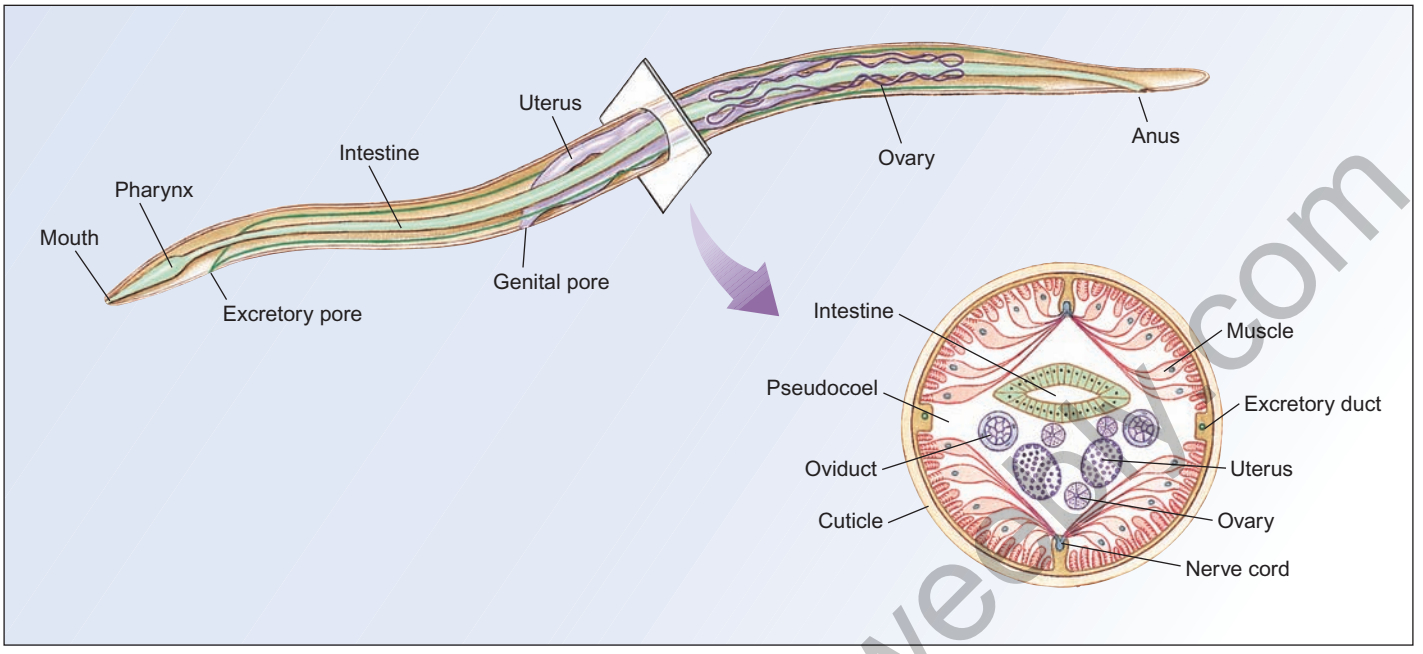

FIGURE 23.17 Nematode Worms
Nematode worms have a simple structure but have a complete gut with a mouth and an anus. Their body cavity is a pseudocoelom.

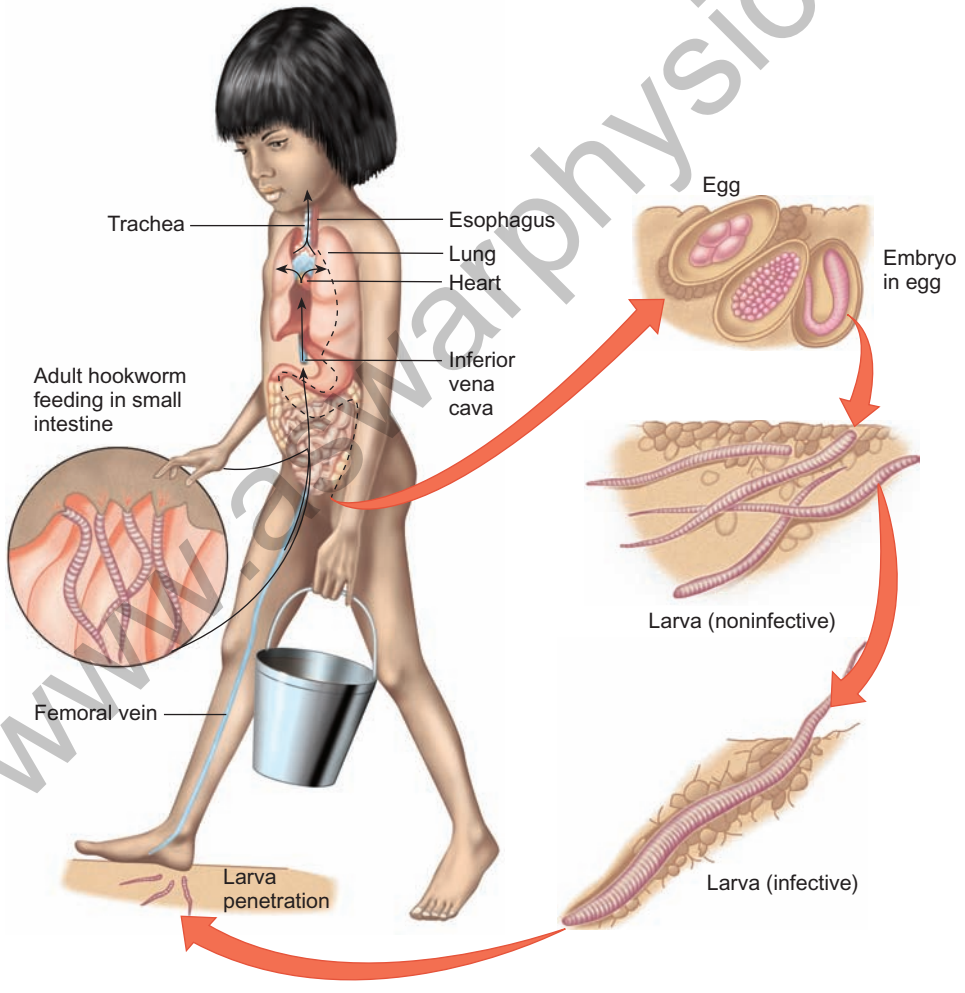

FIGURE 23.18 The Life Cycle of a Hookworm
Fertilized hookworm eggs pass out of the body in the feces and develop into larvae. In the soil, the larvae feed on bacteria. The larvae bore through the skin of humans and develop into adults. The adult hookworms live in the digestive system, where they suck blood from the host. The loss of blood can result in anemia, mental and physical retardation, and a loss of energy.

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