



Beavertail cactus, *Opuntia basilaris*



Water lily, *Nymphaea odorata*



Blue flag iris, *Iris versicolor*

**FIGURE 23.20**  
**Flower diversity.**

Regardless of size and shape, flowers share certain features, as mentioned in text.



Snow trillium, *Trillium nivale*



Apple blossom, *Malus domestica*



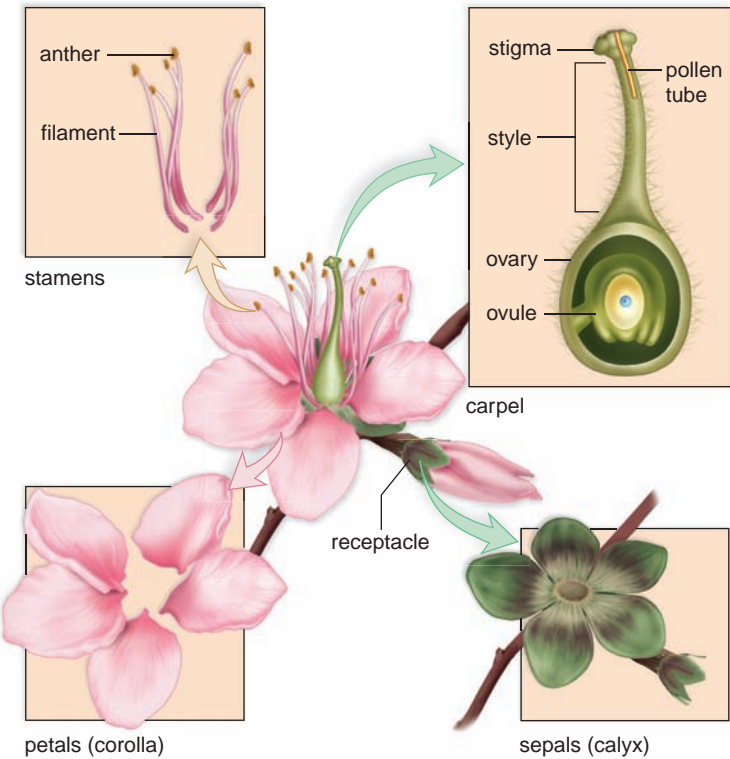
Butterfly weed, *Asclepias tuberosa*

drop off or may be colored like the petals. Usually, however, sepals are green and remain attached to the receptacle.

2. The **petals**, collectively called the **corolla**, are quite diverse in size, shape, and color. The petals often attract a particular pollinator.
3. Next are the **stamens**. Each stamen consists of two parts: the **anther**, a saclike container, and the **filament**, a slender stalk. Pollen grains develop from microspores produced in the anther.
4. At the very center of a flower is the **carpel**, a vasselike structure with three major regions: the **stigma**, an enlarged sticky knob; the **style**, a slender stalk; and the **ovary**, an enlarged base that encloses one or more ovules. The ovule becomes the seed, and the ovary becomes the fruit. Fruit is instrumental in the distribution of seeds.

It can be noted that not all flowers have all these parts (Table 23.3). A flower is said to be complete if it has all four parts; otherwise it is incomplete.

TABLE 23.3	
Other Flower Terminology	
Term	Type of Flower
Complete	All four parts (sepals, petals, stamens, and carpels) present
Incomplete	Lacks one or more of the four parts
Perfect	Has both stamens and (a) carpel(s)
Imperfect	Has stamens or (a) carpel(s), but not both
Inflorescence	A cluster of flowers
Composite	Appears to be a single flower but consists of a group of tiny flowers



**FIGURE 23.21** Generalized flower.

A flower has four main parts: sepals, petals, stamens, and carpels. A stamen has an anther and filament. A carpel has a stigma, style, and ovary. An ovary contains ovules.

## Flowering Plant Life Cycle

Figure 23.22 depicts the life cycle of a typical flowering plant. Like the gymnosperms, flowering plants are heterosporous, producing two types of spores. A **megaspore** located in an ovule within an ovary of a carpel develops into an egg-bearing female gametophyte called the embryo sac. In most angiosperms, the embryo sac

has seven cells; one of these is an egg, and another contains two polar nuclei. (These two nuclei are called the polar nuclei because they came from opposite ends of the embryo sac.)

**Microspores**, produced within anthers, become pollen grains that, when mature, are sperm-bearing male gametophytes. The full-fledged mature male gametophyte consists of only three cells: the tube cell and two sperm

**FIGURE 23.22** Flowering plant life cycle.

The parts of the flower involved in reproduction are the stamens and the carpel. Reproduction has been divided into significant stages of female gametophyte development, male gametophyte development, and also significant stages of sporophyte development.

### 7. The sporophyte:

The embryo within a seed is the immature sporophyte. When a seed germinates, growth and differentiation produce the mature sporophyte of a flowering plant.

### 6. The seed:

The ovule now develops into the seed, which contains an embryo and food enclosed by a protective seed coat. The wall of the ovary and sometimes adjacent parts develop into a fruit that surrounds the seed(s).

### 5. Double fertilization:

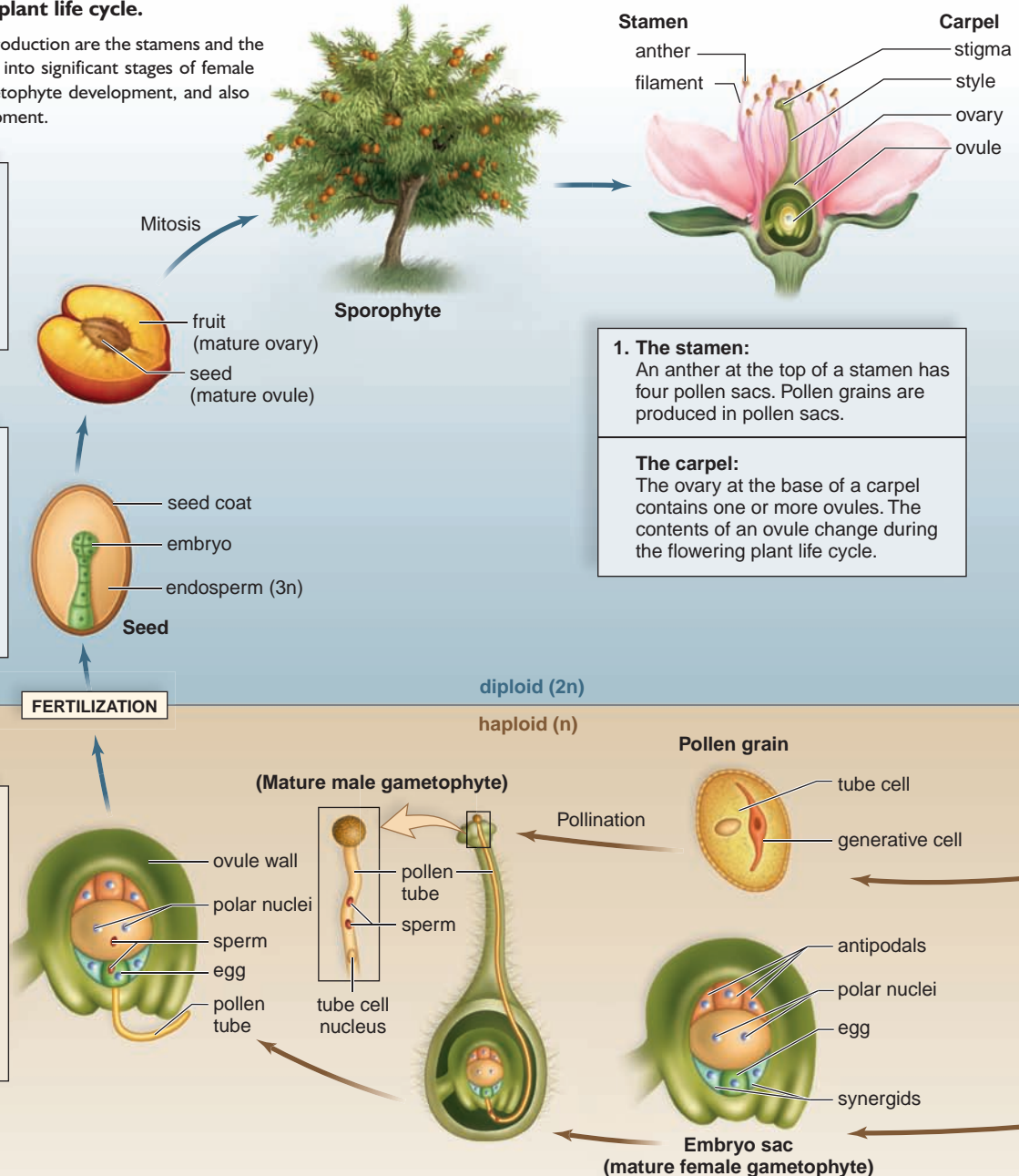
On reaching the ovule, the pollen tube discharges the sperm. One of the two sperm migrates to and fertilizes the egg, forming a zygote; the other unites with the two polar nuclei, producing a  $3n$  (triploid) endosperm nucleus. The endosperm nucleus divides to form endosperm, food for the developing plant.

### 4. The mature male gametophyte:

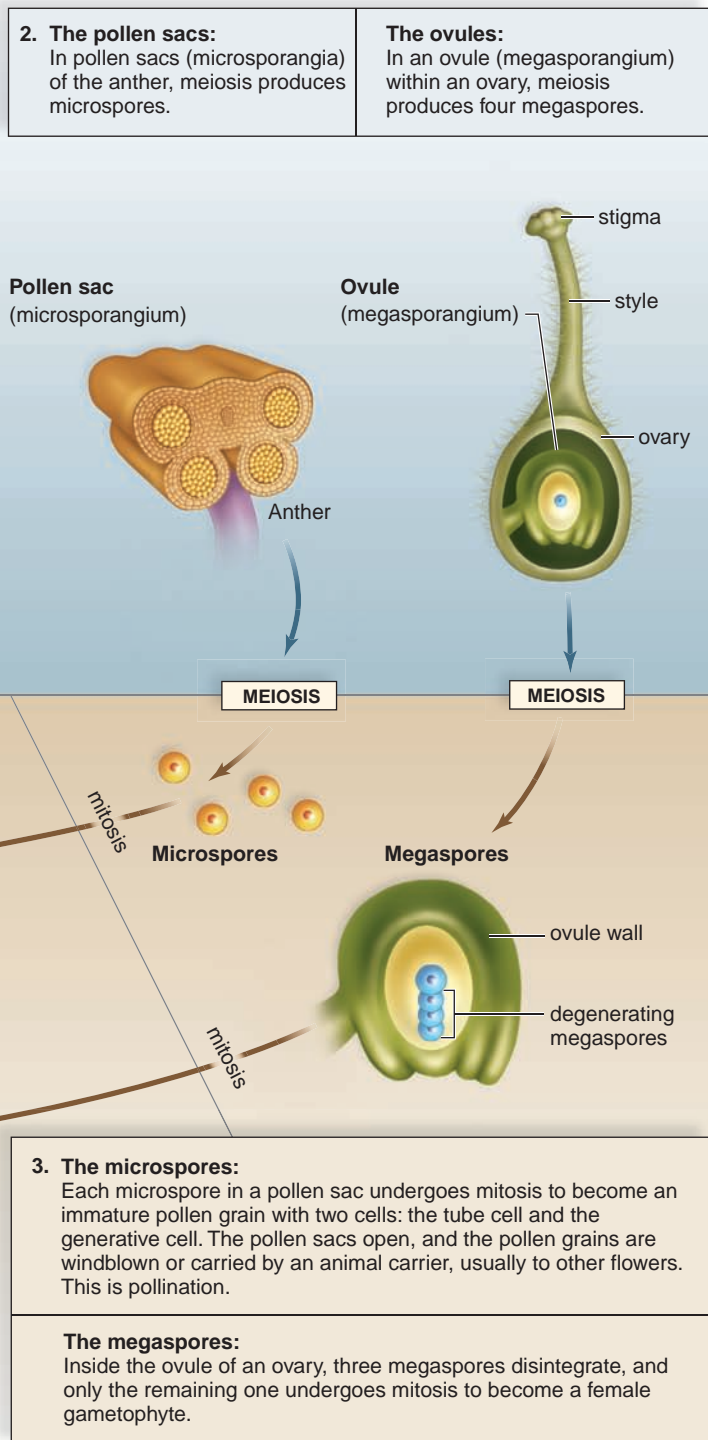
A pollen grain that lands on the carpel of the same type of plant germinates and produces a pollen tube, which grows within the style until it reaches an ovule in the ovary. Inside the pollen tube, the generative cell nucleus divides and produces two nonflagellated sperm. A fully germinated pollen grain is the mature male gametophyte.

### The mature female gametophyte:

The ovule now contains the mature female gametophyte (embryo sac), which typically consists of eight haploid nuclei embedded in a mass of cytoplasm. The cytoplasm differentiates into cells, one of which is an egg and another of which contains two polar nuclei.



cells. During pollination, a pollen grain is transported by various means from the anther to the stigma of a carpel, where it germinates. During germination, the tube cell produces a pollen tube. The **pollen tube** carries the two sperm to the micropyle (small opening) of an ovule. During double fertilization, one sperm unites with an egg, forming a diploid zygote, and the other unites with polar nuclei, forming a triploid endosperm nucleus.



Ultimately, the ovule becomes a seed that contains the embryo (the sporophyte of the next generation) and stored food enclosed within a seed coat. Endosperm in some seeds is absorbed by the cotyledons, whereas in other seeds endosperm is digested as the seed matures.

A **fruit** is derived from an ovary and possibly accessory parts of the flower. Some fruits such as apples and tomatoes provide a fleshy covering, and other fruits such as pea pods and acorns provide a dry covering for seeds.

## Flowers and Diversification

Flowers are involved in the production and development of spores, gametophytes, gametes, and embryos enclosed within seeds. Successful completion of sexual reproduction in angiosperms requires the effective dispersal of pollen and then seeds. The various ways pollen and seeds can be dispersed have resulted in many different types of flowers (see Chapter 27).

Wind-pollinated flowers are usually not showy, whereas insect-pollinated flowers and bird-pollinated flowers are often colorful. Night-blooming flowers attract nocturnal mammals or insects; these flowers are usually aromatic and white or cream-colored. Although some flowers disperse their pollen by wind, many are adapted to attract specific pollinators such as bees, wasps, flies, butterflies, moths, and even bats, which carry only particular pollen from flower to flower. For example, glands located in the region of the ovary produce nectar, a nutrient that is gathered by pollinators as they go from flower to flower. Bee-pollinated flowers are usually blue or yellow and have ultraviolet shadings that lead the pollinator to the location of nectar. The mouthparts of bees are fused into a long tube that is able to obtain nectar from the base of the flower.

The fruits of flowers protect and aid in the dispersal of seeds. Dispersal occurs when seeds are transported by wind, gravity, water, and animals to another location. Fleshy fruits may be eaten by animals, which transport the seeds to a new location and then deposit them when they defecate. Because animals live in particular habitats and/or have particular migration patterns, they are apt to deliver the fruit-enclosed seeds to a suitable location for seed germination (when the embryo begins to grow again) and development of the plant.

### Check Your Progress

### 23.5B

1. List the components of the stamen. Where is pollen formed?
2. List the components of the carpel. Which part becomes a seed? The fruit?
3. Which groups of plants produce seeds? Give examples of each group.
4. What features of the flowering plant life cycle are not found in any other group?
5. Which are more showy, wind-pollinated flowers or animal-pollinated flowers? Why?



## ecology focus

### Plants: Could We Do Without Them?

**P**lants define and are the producers in most ecosystems. Humans derive most of their sustenance from three flowering plants: wheat, corn, and rice (Fig. 23B). All three of these plants are in the grass family and are collectively, along with other species, called grains. Most of the Earth's 6.7 billion people live a simple way of life, growing their food on family plots. The continued growth of these plants is essential to human existence. A virus or other disease could hit any one of these three plants and cause massive loss of life from starvation.

Wheat, corn, and rice originated and were first cultivated in different parts of the globe. Wheat is commonly used in the United States to produce flour and bread. It was first cultivated in the Near East (Iran, Iraq, and neighboring countries) about 8000 BC; hence, it is thought to be one of the earliest cultivated plants. Wheat was brought to North America in 1520 by early settlers; now the United States is one of the world's largest producers of wheat. Corn, or what is properly called maize, was first cultivated in Central America about 7,000 years ago. Maize developed from a plant called teosinte, which grows in the highlands of central Mexico. By the time Europeans were exploring Central America, over 300 varieties were already in existence—growing from Canada to Chile. We now commonly grow six major varieties of corn: sweet, pop, flour, dent, pod, and flint. Rice had its origin in southeastern Asia several thousand years ago,

where it grew in swamps. Today we are familiar with white and brown rice, which differ in the extent of processing. Brown rice results when the seeds are threshed to remove the hulls—the seed coat and complete embryo remain. If the seed coat and embryo are removed, leaving only the starchy endosperm, white rice results. Unfortunately, the seed coat and embryo are a good source of vitamin B and fat-soluble vitamins. Today, rice is grown throughout the tropics and subtropics where water is abundant. It is also grown in some parts of western United States by flooding diked fields with irrigation water.

Do you have an “addiction” to sugar? This simple carbohydrate comes almost exclusively from two plants—sugarcane (grown in South America, Africa, Asia, and the Caribbean) and sugar beets (grown mostly in Europe and North America). Each provides about 50% of the world's sugar.

Many foods are bland or tasteless without spices. In the Middle Ages, wealthy Europeans spared no cost to obtain spices from the Near and Far East. In the fifteenth and sixteenth centuries, major expeditions were launched in an attempt to find better and cheaper routes for spice importation. The explorer Columbus convinced the Queen of Spain that he could find a shorter route to the Far East by traveling west by ocean rather than east by land. Columbus's idea was sound, but he encountered a little barrier, the New World. This discovery later provided Europe with a wealth of new crops, including corn, potatoes, peppers, and tobacco.

Our most popular drinks—coffee, tea, and cola—also come from flowering plants. Coffee originated in Ethiopia, where it was first used (along with animal fat) during long trips for sustenance and to relieve fatigue. Coffee as a drink was not developed until the thirteenth century in Arabia and Turkey, and it did not catch on in Europe until the seventeenth century. Tea is thought to have been developed somewhere in central Asia. Its earlier uses were almost exclusively medicinal, especially among the Chinese, who still drink tea for medical reasons. The drink as we now know it was not developed until the fourth century. By the mid-seventeenth century it had become popular in Europe. Cola is a common ingredient in tropical drinks and was used around the turn of the century, along with the drug coca (used to make cocaine), in the “original” Coca-Cola.

Plants have been used for centuries for a number of important household items



Wheat plants, *Triticum*



Corn plants, *Zea*



Rice plants, *Oryza*

**FIGURE 23B** Cereal grains.

*These three cereal grains are the principal source of calories and protein for our civilization.*





a. Dwarf fan palms, *Chamaerops*, for basket weaving



b. Rubber, *Hevea*, for auto tires



d. Tulips, *Tulipa*, for beauty

#### FIGURE 23C Uses of plants.

a. Dwarf fan palms can be used to make baskets. b. A rubber plant provides latex for making tires. c. Cotton can be used for clothing. d. Plants have aesthetic value.



c. Cotton, *Gossypium*, for cloth

(Fig. 23Ca), including the house itself. We are most familiar with lumber being used as the major structural portion in buildings. This wood comes mostly from a variety of conifers: pine, fir, and spruce, among others. In the tropics, trees and even herbs provide important components for houses. In rural parts of Central and South America, palm leaves are preferable to tin for roofs, since they last as long as ten years and are quieter during a rainstorm. In the Near East, numerous houses along rivers are made entirely of reeds.

Rubber is another plant that has many uses today (Fig. 23Cb). The product had its origin in Brazil from the thick, white sap (latex) of the rubber tree. Once collected, the sap is placed in a large vat, where acid is added to coagulate the latex. When the water is pressed out, the product is formed into sheets or crumbled and placed into bales. Much stronger rubber, such as that in tires, was made by adding sulfur and heating in a process called vulcanization; this produces a flexible material less sensitive to temperature changes. Today, though, much rubber is synthetically produced.

Before the invention of synthetic fabrics, cotton and other natural fibers were our only source of clothing (Fig. 23Cc). The 5,200-year-old remains of Ice Man found in the Alps had a cape made of grass. China is now the

largest producer of cotton. The cotton fiber itself comes from filaments that grow on the seed. In sixteenth-century Europe, cotton was a little-understood fiber known only from stories brought back from Asia. Columbus and other explorers were amazed to see the elaborately woven cotton fabrics in the New World. But by 1800, Liverpool was the world's center of cotton trade. (Interestingly, when Levi Strauss wanted to make a tough pair of jeans, he needed a stronger fiber than cotton, so he used hemp. Hemp is now known primarily as a hallucinogenic drug—marijuana—though there has been a resurgence in its use in clothing.) Over 30 species of native cotton now grow around the world, including the United States.

An actively researched area of plant use today is that of medicinal plants. Currently about 50% of all pharmaceutical drugs have their origins from plants. The treatment of

cancers appears to rest in the discovery of new plants. Indeed, the National Cancer Institute (NCI) and most pharmaceutical companies have spent millions (or, more likely, billions) of dollars to send botanists out to collect and test plant samples from around the world. Tribal medicine men, or shamans, of South America and Africa have already been of great importance in developing numerous drugs.

Over the centuries, malaria has caused far more human deaths than any other disease. After European scientists became aware that malaria can be treated by quinine, which comes from the bark of the cinchona tree, a synthetic form of the drug, chloroquine, was developed. But by the late 1960s, it was found that some of the malaria parasites, which live in red blood cells, had become resistant to the synthetically produced drug. Resistant parasites were first seen in Africa but are now showing up in Asia and the Amazon. Today, the only 100% effective drug for malaria treatment must come directly from the cinchona tree, common to northeastern South America.

Numerous plant extracts continue to be misused for their hallucinogenic or other effects on the human body: coca for cocaine and crack, opium poppy for morphine, and yam for steroids. In addition to all these uses of plants, we should not forget or neglect their aesthetic value (Fig. 23Cd). Flowers brighten any yard, ornamental plants accent landscaping, and trees provide cooling shade during the summer and break the wind of winter days. Plants also produce oxygen, which is so necessary for all plants and animals.

## Connecting the Concepts

Land plants share a common ancestor with the charophytes, who have traits that would have been useful to the first plants to invade land. Through the evolutionary process, land plants adapted to a dry environment and the threat of water loss (desiccation). Today, the bryophytes are generally small, and they are usually found in moist habitats. However, mosses can store large amounts of water and even become dormant during dry spells. The vascular plants, on the other hand, have specialized tissues to transport water and organic nutrients from one part of the body to

another. Therefore, they can grow tall. Small pores in their leaves and waxy cuticles open and close to control water loss.

Reproductive strategies in plants are also adapted to a land environment. Mosses and ferns produce flagellated sperm that require external water, but their windblown spores disperse offspring. In seed plants, pollen grains protect sperm until they fertilize an egg. The sporophyte even retains the egg-producing female gametophyte and a seed contains the resulting zygote. The seed protects the sporophyte embryo from drying

out until it germinates in a new location. Dispersal of plants by spores or seeds reduces competition for resources.

Humans use land plants for various purposes, including fuel. Massive amounts of biomass were submerged by swamps and covered by sediment during the Carboniferous period. Due to extreme pressure, this organic material became the fossil fuel coal, which, along with the other fuels, makes our way of life today possible. Also, we must not forget that plants produce food and oxygen, two resources that keep our biosphere functioning.

### summary

#### 23.1 The Green Algal Ancestor of Plants

Land plants evolved from a common ancestor with multicellular, freshwater green algae about 450 MYA. During the evolution of plants, protecting the embryo, apical growth, vascular tissue for transporting water and organic nutrients, possession of megaphylls, using seeds to disperse offspring, and having flowers were all adaptations to a land existence.

All plants have a life cycle that includes an alternation of generations. In this life cycle, a haploid gametophyte alternates with a diploid sporophyte. During the evolution of plants, the sporophyte gained in dominance, while the gametophyte became microscopic and dependent on the sporophyte.

#### 23.2 Evolution of Bryophytes: Colonization of Land

Ancient bryophytes were the first plants to colonize land. Today, the bryophytes consist of liverworts, hornworts, and mosses that lack well-developed vascular tissue. Sporophytes of bryophytes are nutritionally dependent on the gametophyte, which is more conspicuous and photosynthetic. The life cycle of the moss (see Fig. 23.8) demonstrates reproductive strategies such as flagellated sperm and dispersal by means of windblown spores. The bryophytes are not a monophyletic group.

#### 23.3 Evolution of Lycophytes: Vascular Tissue

Vascular plants, such as the rhyniophytes, evolved during the Silurian period. The sporophyte has two kinds of well-defined conducting tissues. Xylem is specialized to conduct water and dissolve minerals, and phloem is specialized to conduct organic nutrients. The lycophytes are descended from these first plants and they have vascular tissue. Ancient lycophytes also had the first leaves, which were microphylls; their life cycle is similar to that of the fern.

#### 23.4 Evolution of Pteridophytes: Megaphylls

In pteridophytes (ferns and their allies, horsetails and whisk ferns), and also lycophytes, the sporophyte is dominant and is separate from the tiny gametophyte, which produces flagellated sperm. Windblown spores are dispersal agents. Today's ferns have obvious megaphylls—horsetails and whisk ferns have reduced megaphylls.

Seedless vascular plant is a description that applies to lycophytes, ferns, and fern allies that grew to enormous sizes during the Carboniferous period when the climate was warm and wet. Today, seedless vascular plants that live in the temperate zone

use asexual propagation to spread into environments that are not favorable to a water-dependent gametophyte generation.

#### 23.5 Evolution of Seed Plants: Full Adaptation to Land

Seed plants also have an alternation of generations, but they are heterosporous, producing both microspores and megaspores. Gametophytes are so reduced that the female gametophyte is retained within an ovule. Microspores become the windblown or animal-transported male gametophytes—the pollen grains. Pollen grains carry sperm to the egg-bearing female gametophyte. Following fertilization, the ovule becomes the seed. A seed contains a sporophyte embryo, and therefore seeds disperse the sporophyte generation. Fertilization no longer uses external water, and sexual reproduction is fully adapted to the terrestrial environment.

The gymnosperms (cone-bearing plants) and also possibly angiosperms (flowering plants) evolved from woody seed ferns during the Devonian period. The conifers, represented by the pine tree, exemplify the traits of these plants. Gymnosperms have “naked seeds” because the seeds are not enclosed by fruit, as are those of flowering plants.

A woody shrub, *Amborella trichopoda*, has been identified as most closely related to the common ancestor for the angiosperms. In angiosperms, the reproductive organs are found in flowers; the ovules, which become seeds, are located in the ovary, which becomes the fruit. Therefore, angiosperms have “covered seeds.” In many angiosperms, pollen is transported from flower to flower by insects and other animals. Both flowers and fruits are found only in angiosperms and may account for the extensive colonization of terrestrial environments by the flowering plants. (See also Chapter 27.)

### understanding the terms

alternation of generations life cycle 412  
angiosperm 420, 424  
antheridium 412  
archegonium 412  
bryophyte 413  
carpel 425  
charophyte 410  
coal 423

cone 420  
conifer 420  
cotyledon 424  
cuticle 412  
cycad 420  
dioecious 422  
embryophyta 412  
eudicot 424  
Eudicotyledone 424



fern	418	phloem	416
flower	424	plant	410
frond	418	pollen grain	420
fruit	427	pollen tube	420, 427
gametophyte	412	pollination	420
ginkgo	422	pteridophyte	417
gnetophyte	422	receptacle	424
gymnosperm	420	rhizoid	414
heterosporous	420	rhizome	416
hornwort	414	seed	420
horsetail	417	seedless vascular plant	416
lignin	416	sepal	424
liverwort	414	sporangia (sing.,	
lycophyte	416	sporangium)	412
megaphyll	417	spore	412
megaspore	420, 426	sporophyll	416
microphyll	416	sporophyte	412
microspore	420, 426	sporopollenin	412
monocot	424	stamen	425
Monocotyledone	424	stigma	425
monoecious	420	stomata (sing., stoma)	412
moss	414	strobilus (pl., strobili)	416
nonvascular plant	413	style	425
ovary	425	vascular plant	416
ovule	420	vascular tissue	413
peduncle	424	whisk fern	418
petal	425	xylem	416

Match the terms to these definitions:

- \_\_\_\_\_ Diploid generation of the alternation of generations life cycle of a plant; meiosis produces haploid spores that develop into the gametophyte.
- \_\_\_\_\_ Flowering plant group; members have one embryonic leaf, parallel-veined leaves, scattered vascular bundles, and other characteristics.
- \_\_\_\_\_ Male gametophyte in seed plants.
- \_\_\_\_\_ Rootlike hair that anchors a nonvascular plant and absorbs minerals and water from the soil.

## reviewing this chapter

- Refer to Figure 23.1, and trace the evolutionary history of land plants. What traits do charophytes have that are shared by land plants? 410–11
- What is meant when it is said that a plant alternates generations? Distinguish between a sporophyte and a gametophyte. 412–13
- Describe the various types of bryophytes and the life cycle of mosses. Discuss the ecological and commercial importance of mosses. 413–15
- When do vascular plants appear in the fossil record, and why do lycophytes perhaps resemble the first vascular plants? Mention the importance of branching. 416–18
- Draw a diagram to describe the life cycle of a fern, pointing out significant features. What are the human uses of ferns? 419
- What features do all seed plants have in common? When do seed plants appear in the fossil record? 420
- List and describe the four phyla of gymnosperms. What are the human uses of gymnosperms? 420–22
- Use a diagram of the pine life cycle to point out significant features, including those that distinguish a seed plant's life cycle from that of a seedless vascular plant. 421

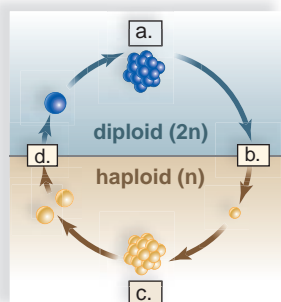
- What is known about the ancestry of flowering plants? 424
- How do monocots and eudicots differ? What are the parts of a flower? 424–25
- Use a diagram to explain and point out significant features of the flowering plant life cycle. 426–27
- Offer an explanation as to why flowering plants are the dominant plants today. 427

## testing yourself

Choose the best answer for each question.

- Which of these are characteristics of land plants?
  - multicellular with specialized tissues and organs
  - photosynthetic and contain chlorophylls *a* and *b*
  - protect the developing embryo from desiccation
  - have an alternation of generations life cycle
  - All of these are correct.
- In bryophytes, sperm usually move from the antheridium to the archegonium by
  - swimming.
  - flying.
  - insect pollination.
  - worm pollination.
  - bird pollination.
- Ferns have
  - a dominant gametophyte generation.
  - vascular tissue.
  - seeds.
  - Both a and b are correct.
  - Choices a, b, and c are correct.
- The spore-bearing structure that gives rise to a female gametophyte in seed plants is called a
  - microphyll.
  - spore.
  - megasporangium.
  - microsporangium.
  - sporophyll.
- A small, upright plant that resembles a tiny upright pine tree with club-shaped strobili and microphylls is a
  - whisk fern.
  - lycophyte.
  - conifer.
  - horsetail.
  - fern.
- Trends in the evolution of plants include all of the following except
  - from homospory to heterospory.
  - from less to more reliance on water for life cycle.
  - from nonvascular to vascular.
  - from nonwoody to woody.
- Gymnosperms
  - have flowers.
  - are eudicots.
  - are monocots.
  - do not have spores in their life cycle.
  - reproduce by seeds.
- In the moss life cycle, the sporophyte
  - consists of leafy green shoots.
  - is the heart-shaped prothallus.
  - consists of a foot, a stalk, and a capsule.
  - is the dominant generation.
  - All of these are correct.
- Microphylls
  - have a single strand of vascular tissue.
  - evolved before megaphylls.
  - evolved as extensions of the stem.
  - are found in lycophytes.
  - All of these are correct.

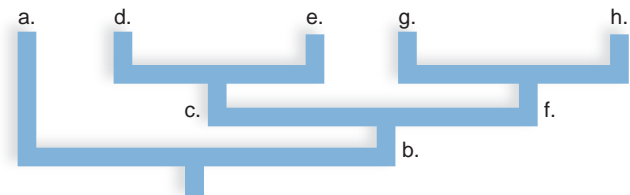
10. How are ferns different from mosses?
  - a. Only ferns produce spores as dispersal agents.
  - b. Ferns have vascular tissue.
  - c. In the fern life cycle, the gametophyte and sporophyte are both independent.
  - d. Ferns do not have flagellated sperm.
  - e. Both b and c are correct.
11. Which of these pairs is mismatched?
  - a. pollen grain—male gametophyte
  - b. ovule—female gametophyte
  - c. seed—immature sporophyte
  - d. pollen tube—spores
  - e. tree—mature sporophyte
12. In the life cycle of the pine tree, the ovules are found on
  - a. needle-like leaves.
  - b. seed cones.
  - c. pollen cones.
  - d. root hairs.
  - e. All of these are correct.
13. Monocotyledonous plants often have
  - a. parallel leaf venation.
  - b. flower parts in units of four or five.
  - c. leaves with petioles only.
  - d. flowers with stipules.
  - e. Choices b, c, and d are correct.
14. Which of these pairs is mismatched?
  - a. anther—produces microspores
  - b. carpel—produces pollen
  - c. ovule—becomes seed
  - d. ovary—becomes fruit
  - e. flower—reproductive structure
15. Which of these plants contributed the most to our present-day supply of coal?
  - a. bryophytes
  - b. seedless vascular plants
  - c. gymnosperms
  - d. angiosperms
  - e. Both b and c are correct.
16. Which of these is found in seed plants?
  - a. complex vascular tissue
  - b. pollen grains that are not flagellated
  - c. retention of female gametophyte within the ovule
  - d. roots, stems, and leaves
  - e. All of these are correct.
17. Which of these is a seedless vascular plant?
  - a. gymnosperm
  - b. angiosperm
  - c. fern
  - d. monocot
  - e. eudicot
18. Label this diagram of alternation of generations life cycle.



## thinking scientifically

1. Using as many terms as necessary (from both X and Y axes), fill in the proposed phylogenetic tree for vascular plants.

	ferns	conifers	ginkgos	monocots	eudicots
vascular tissue	X	X	X	X	X
seed plants		X	X	X	X
naked seeds		X	X		
needle-like leaves		X			
fan-shaped leaves			X		
enclosed seeds				X	X
one embryonic leaf				X	
two embryonic leaves					X



vascular tissue

2. Using Figure 23.1, distinguish between the (a) microphyll and the (b) megaphyll clade.

## bioethical issue

### Saving Plant Species

Pollinator populations have been decimated by pollution, pesticide use, and destruction or fragmentation of natural areas. Belatedly, we have come to realize that various types of bees are responsible for pollinating such cash crops as blueberries, cranberries, and squash and are partly responsible for pollinating apple, almond, and cherry trees.

Why are we so shortsighted when it comes to protecting the environment and living creatures like pollinators? Because pollinators are a resource held in common. The term *commons* originally meant a piece of land where all members of a village were allowed to graze their cattle. The farmer who thought only of himself and grazed more cattle than his neighbor was better off. The difficulty is, of course, that eventually the resource is depleted, and everyone loses.

So, a farmer or property owner who uses pesticides is only thinking of his or her field or lawn and not the good of the whole. The commons can only be protected if citizens have the foresight to enact rules and regulations by which all abide. DDT was outlawed in this country in part because it led to the decline of birds of prey. Similarly, we may need legislation to protect pollinators from factors that kill them off. Legislation to protect pollinators would protect the food supply for all of us.

## Biology website

The companion website for *Biology* provides a wealth of information organized and integrated by chapter. You will find practice tests, animations, videos, and much more that will complement your learning and understanding of general biology.

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# 24

## Flowering Plants: Structure and Organization

**a** stunning array of plant life covers the Earth, and over 80% of all living plants are flowering plants, or angiosperms. Therefore, it is fitting that we set aside a chapter of this text to examine the structure and the function of flowering plants. The organization of flowering plants allows them to photosynthesize on land. The elevated leaves have a shape that facilitates absorption of solar energy and carbon dioxide. Strong stems conduct water up to the leaves from the roots, which not only anchor the plant but also absorb water and minerals. All the vegetative organs of flowering plants have a role to play in photosynthesis.

When plants photosynthesize, they take in  $\text{CO}_2$ . Therefore, keeping our world green by preserving plants, particularly forests, is a way to remove  $\text{CO}_2$  from the atmosphere and reduce the dangers of global warming. Think of this when you study this chapter about the structure of roots, stems, and leaves.

The vegetative organs of a flowering plant consist of root, stems, and leaves.

### 24.1 ORGANS OF FLOWERING PLANTS

- Flowering plants usually have three vegetative organs: the roots, the stem, and the leaves. The roots are part of the root system; the stem and leaves are part of the shoot system. 434–35
- Flowering plants are classified into two groups, the monocots and the eudicots. 436

### 24.2 TISSUES OF FLOWERING PLANTS

- Plant cells are organized into three types of tissues: epidermal tissue, ground tissue, and vascular tissue. 437–39

### 24.3 ORGANIZATION AND DIVERSITY OF ROOTS

- In longitudinal section, it can be seen that a root tip has various zones, and in cross section, eudicot and monocot roots differ in the organization of their tissues. 440–41
- Some plants have a taproot and others a fibrous root. Both types may have adventitious roots. 442

### 24.4 ORGANIZATION AND DIVERSITY OF STEMS

- In cross section, eudicot and monocot herbaceous stems differ in the organization of their tissues. Dicot stems can be either herbaceous or woody. 444–47
- Stems are diverse, and some plants have horizontal aboveground stems and others have underground stems. 448

### 24.5 ORGANIZATION AND DIVERSITY OF LEAVES

- The bulk of a leaf is composed of cells that perform gas exchange and carry on photosynthesis. 450
- Leaves are diverse; some conserve water, some help a plant climb, and some help a plant capture food. 450–51





## 24.1 Organs of Flowering Plants

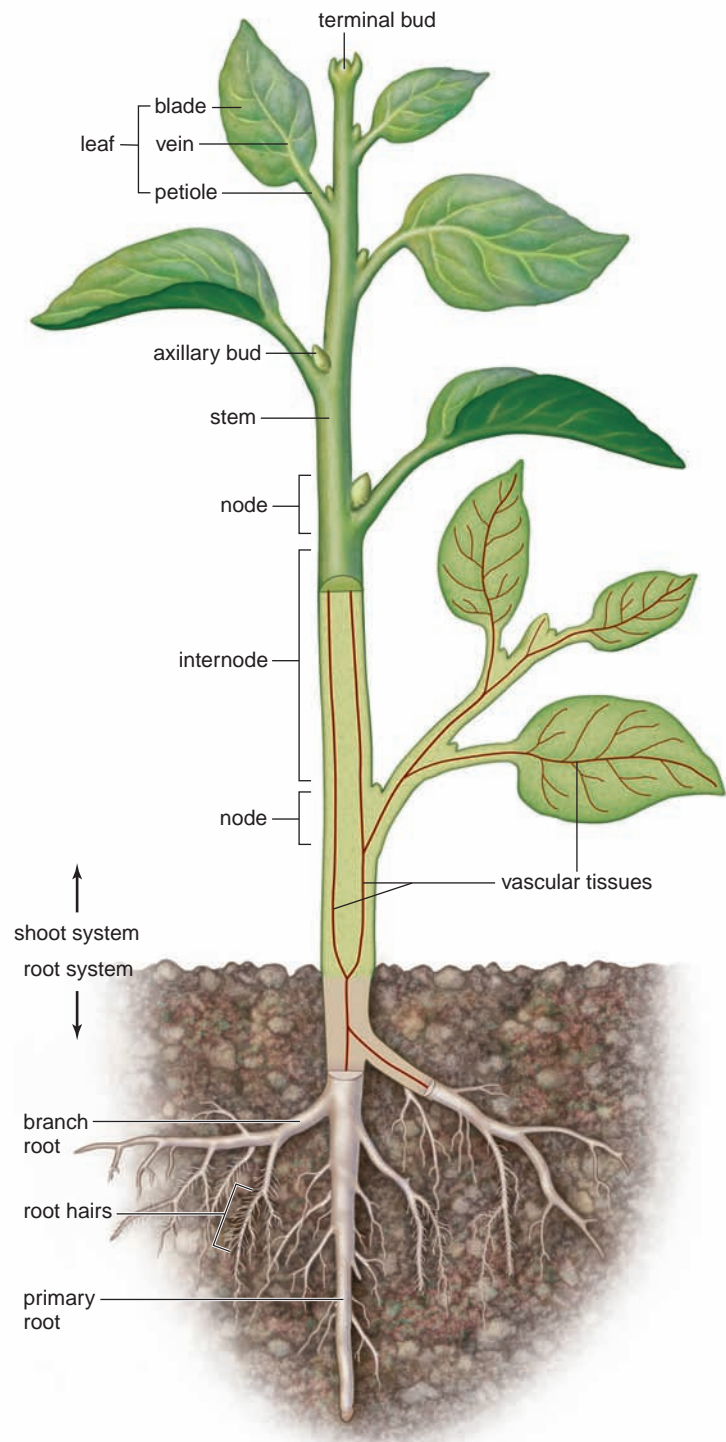
From cacti living in hot deserts to water lilies growing in a nearby pond, the flowering plants, or angiosperms, are extremely diverse. Despite their great diversity in size and shape, flowering plants share many common structural features. Most flowering plants possess a root system and a shoot system (Fig. 24.1). The **root system** simply consists of the roots, while the **shoot system** consists of the stem and leaves. A typical plant features three vegetative **organs** (structures that contain different tissues and perform one or more specific functions) that allow them to live and grow. The roots, stems, and leaves are the vegetative organs. **Veg-**  
**etative organs** are concerned with growth and nutrition and not reproduction. Flowers, seeds, and fruits are structures involved in reproduction.

### Roots

The root system in the majority of plants is located underground. As a rule of thumb, the root system is at least equivalent in size and extent to the shoot system. An apple tree has a much larger root system than a corn plant, for example. A single corn plant may have roots as deep as 2.5 m and spread out over 1.5 m, while a mesquite tree that lives in the desert may have roots that penetrate to a depth of over 20 m.

The extensive root system of a plant anchors it in the soil and gives it support (Fig. 24.2a). The root system absorbs water and minerals from the soil for the entire plant. The cylindrical shape of a root allows it to penetrate the soil as it grows and permits water to be absorbed from all sides. The absorptive capacity of a root is dependent on its many branches, which all bear root hairs in a special zone near the tip. Root hairs, which are projections from epidermal root-hair cells, are the structures that absorb water and minerals. Root hairs are so numerous that they tremendously increase the absorptive surface of a root. It has been estimated that a single rye plant has about 14 billion hair cells, and if placed end to end, the root hairs would stretch 10,626 km. Root-hair cells are constantly being replaced, so this same rye plant forms about 100 million new root-hair cells every day. A plant roughly pulled out of the soil will not fare well when transplanted; this is because small lateral roots and root hairs are torn off. Transplantation is more apt to be successful if you take a part of the surrounding soil along with the plant, leaving as much of the lateral roots and the root hairs intact as possible.

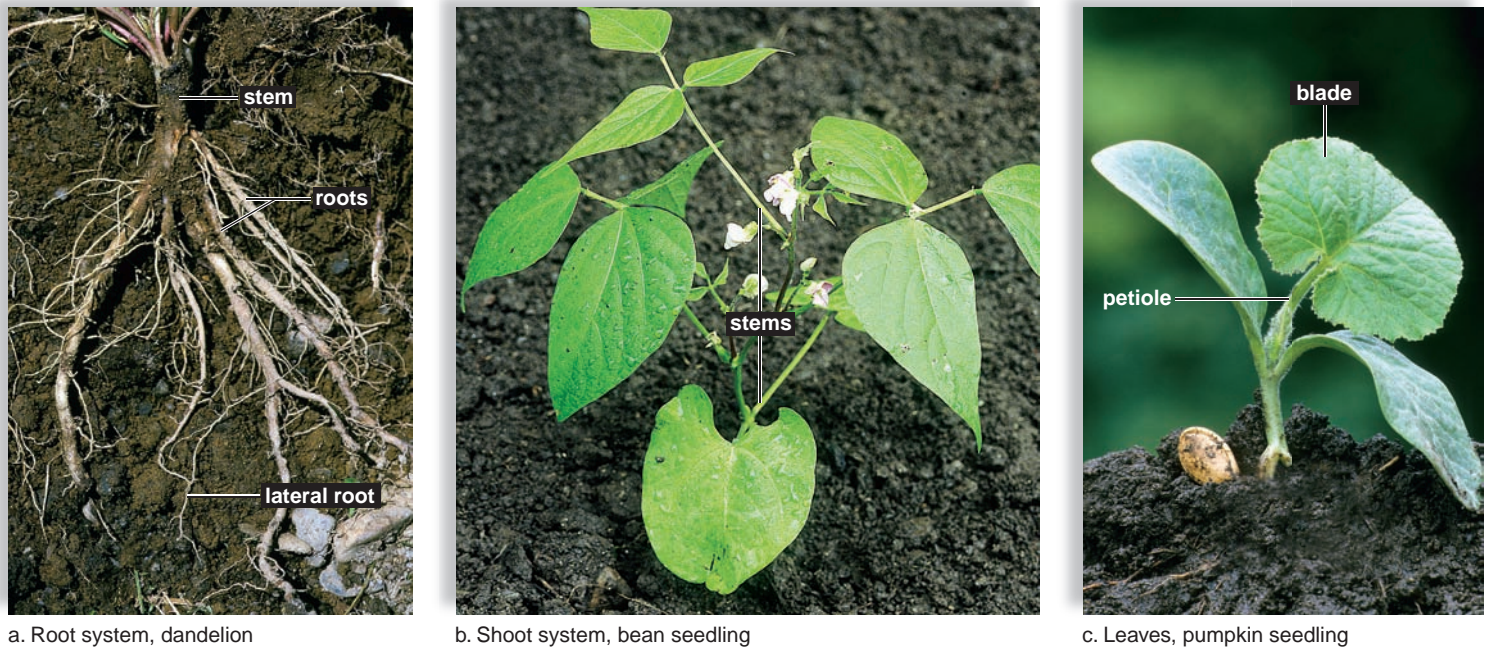
Roots have still other functions. Roots produce hormones that stimulate the growth of stems and coordinate their size with the size of the root. It is most efficient for a plant to have root and stem sizes that are appropriate to each other. **Perennial** plants have vegetative structures that live year after year. Herbaceous perennials, which live in temperate areas and die back, store the products of photosynthesis in their roots. Carrots and sweet potatoes are the roots of such plants.



**FIGURE 24.1** Organization of a plant body.

The body of a plant consists of a root system and a shoot system. The shoot system contains the stem and leaves, two types of plant vegetative organs. Axillary buds can develop into branches of stems or flowers, the reproductive structures of a plant. The root system is connected to the shoot system by vascular tissue (brown) that extends from the roots to the leaves.





**FIGURE 24.2** Vegetative organs of several eudicots.

**a.** The root system anchors the plant and absorbs water and minerals. **b.** The shoot system consists of a stem and its branches, which support the leaves and transport water and organic nutrients. **c.** The leaves, which may be broad and thin, carry on photosynthesis.

## Stems

The shoot system of a plant is composed of the stem, the branches, and the leaves. A **stem**, the main axis of a plant, has a terminal bud that allows the stem to elongate and produce new leaves (Fig. 24.2b). If upright, as most are, a stem supports leaves in a way that exposes each one to as much sunlight as possible. A **node** occurs where leaves are attached to the stem; the region between nodes is called an **internode** (see Fig. 24.1). An **axillary bud**, located at a node in the upper angle between the leaf and the stem can produce new branches of the stem (or flowers). The presence of nodes and internodes is used to identify a stem, even if it happens to be an underground stem. A horizontal underground stem, called a **rhizome**, sends out roots below and shoots above at the nodes as it grows. Therefore, a rhizome allows a plant, such as ginger and bamboo, to increase its territory.

In addition to supporting the leaves, a stem has vascular tissue that transports water and minerals from the roots through the stem to the leaves and transports the products of photosynthesis, usually in the opposite direction. Nonliving cells form a continuous pipeline for water and mineral transport, while living cells join end to end for organic nutrient transport. A cylindrical stem can sometimes expand in girth as well as length. As trees grow taller each year, they accumulate woody tissue that adds to the strength of their stems.

Stems may have functions other than those mentioned: increasing the length of shoot system and transporting water and nutrients. In some plants (e.g., cactus), the stem is the primary photosynthetic organ. The stem is also a water reservoir in succulent plants. Some underground branches of a stem, or a portion of the root called a tuber, store nutrients.

## Leaves

**Leaves** are the major part of a plant that carries on photosynthesis, a process that requires water, carbon dioxide, and sunlight. Leaves receive water from the root system by way of the stem. Stems and leaves function together to bring about water transport from the roots.

The size, shape, color, and texture of leaves are highly variable. These characteristics are fundamental in plant identification. The leaves of some aquatic duckweeds may be less than 1 mm in diameter, while some palms may have leaves that exceed 6 m in length. The shape of leaves can vary from cactus spines to deeply lobed white oak leaves. Leaves can exhibit a variety of colors from various shades of green to deep purple. The texture of leaves varies from smooth and waxy like a magnolia to coarse like a sycamore. Plants that bear leaves the entire year are called **evergreens** and those that lose their leaves every year are called **deciduous**.

Broad and thin plant leaves have the maximum surface area for the absorption of carbon dioxide and the collection of solar energy needed for photosynthesis. Also unlike stems, leaves are almost never woody. With few exceptions, their cells are living, and the bulk of a leaf contains tissue specialized to carry on photosynthesis.

The wide portion of a foliage leaf is called the **blade**. The **petiole** is a stalk that attaches the blade to the stem (Fig. 24.2c). The upper acute angle between the petiole and stem is the leaf axil where the axillary bud is found. Not all leaves are foliage leaves. Some are specialized to protect buds, attach to objects (tendrils), store food (bulbs), or even capture insects. Specialized leaves are discussed on page 451.

Monocot Versus Eudicot Plants

Flowering plants are divided into two groups, depending on the number of **cotyledons**, or seed leaves, in the embryonic plant (Fig. 24.3). Some have one cotyledon, and these plants are known as monocotyledons, or **monocots**. Other embryos have two cotyledons, and these plants are known as eudicotyledons, or **eudicots**. Cotyledons [Gk. *cotyledon*, cup-shaped cavity] of eudicots supply nutrients for seedlings, but the cotyledon of monocots acts as a transfer tissue, and the nutrients are derived from the endosperm before the true leaves begin photosynthesizing.

The vascular (transport) tissue is organized differently in monocots and eudicots. In the monocot root, vascular tissue occurs in a ring. In the eudicot root, the xylem, which transports water and minerals, is star-shaped; and the phloem, which transports organic nutrients, is located between the points of the star. In the monocot stem, the vascular bundles, which contain vascular tissue surrounded by a bundle sheath, are scattered. In a eudicot stem, the vascular bundles occur in a ring.

Leaf veins are vascular bundles within a leaf. Monocots exhibit parallel venation, and eudicots exhibit netted venation, which may be either pinnate or palmate. Pinnate venation means that major veins originate from points along the centrally placed main vein, and palmate venation means

that the major veins all originate at the point of attachment of the blade to the petiole:



Adult monocots and eudicots have other structural differences, such as the number of flower parts and the number of pores in the wall of their pollen grains. Monocots have their flower parts arranged in multiples of three, and eudicots have their flower parts arranged in multiples of four or five. Eudicot pollen grains usually have three pores, and monocot pollen grains usually have one pore.

Although the distinctions between monocots and eudicots may seem of limited importance, they do in fact affect many aspects of their structure. The eudicots are the larger group and include some of our most familiar flowering plants—from dandelions to oak trees. The monocots include grasses, lilies, orchids, and palm trees, among others. Some of our most significant food sources are monocots, including rice, wheat, and corn.


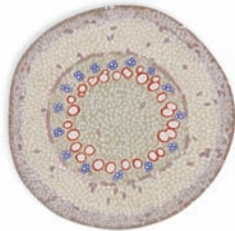
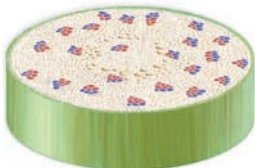


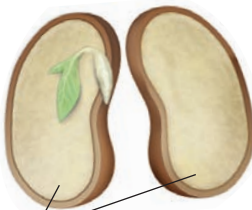
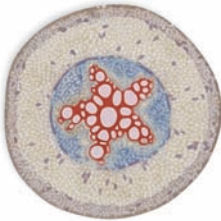
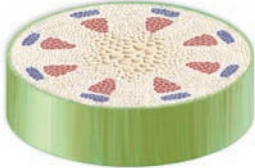


**FIGURE 24.3** Flowering plants are either monocots or eudicots.

Five features illustrated here are used to distinguish monocots from eudicots: number of cotyledons; the arrangement of vascular tissue in roots, stems, and leaves; and the number of flower parts.

Check Your Progress

24.1

1. List the three vegetative organs in a plant and state their major functions.
2. List significant differences between monocots and eudicots.

	Seed	Root	Stem	Leaf	Flower
Monocots	 One cotyledon in seed	 Root xylem and phloem in a ring	 Vascular bundles scattered in stem	 Leaf veins form a parallel pattern	 Flower parts in threes and multiples of three
Eudicots	 Two cotyledons in seed	 Root phloem between arms of xylem	 Vascular bundles in a distinct ring	 Leaf veins form a net pattern	 Flower parts in fours or fives and their multiples



## 24.2 Tissues of Flowering Plants

A flowering plant has the ability to grow its entire life because it possesses meristematic (embryonic) tissue. Apical **meristems** are located at or near the tips of stems and roots, where they increase the length of these structures. This increase in length is called primary growth. In addition to apical meristems, monocots have a type of meristem called intercalary [L. *intercalare*, to insert] meristem, which allows them to regrow lost parts. Intercalary meristems occur between mature tissues, and they account for why grass can so readily regrow after being grazed by a cow or cut by a lawnmower.

Apical meristem continually produces three types of meristem, and these develop into the three types of specialized primary tissues in the body of a plant: Protoderm gives rise to epidermis; ground meristem produces ground tissue; and procambium produces vascular tissue. The functions of these three specialized tissues include:

1. **Epidermal tissue** forms the outer protective covering of a plant.
2. **Ground tissue** fills the interior of a plant.
3. **Vascular tissue** transports water and nutrients in a plant and provides support.

### Epidermal Tissue

The entire body of both nonwoody (herbaceous) and young woody plants is covered by a layer of **epidermis** [Gk. *epi*, over, and *derma*, skin], which contains closely packed epidermal cells. The walls of epidermal cells that are exposed to air are covered with a waxy **cuticle** [L. *cutis*, skin] to minimize water loss. The cuticle also protects against bacteria and other organisms that might cause disease.

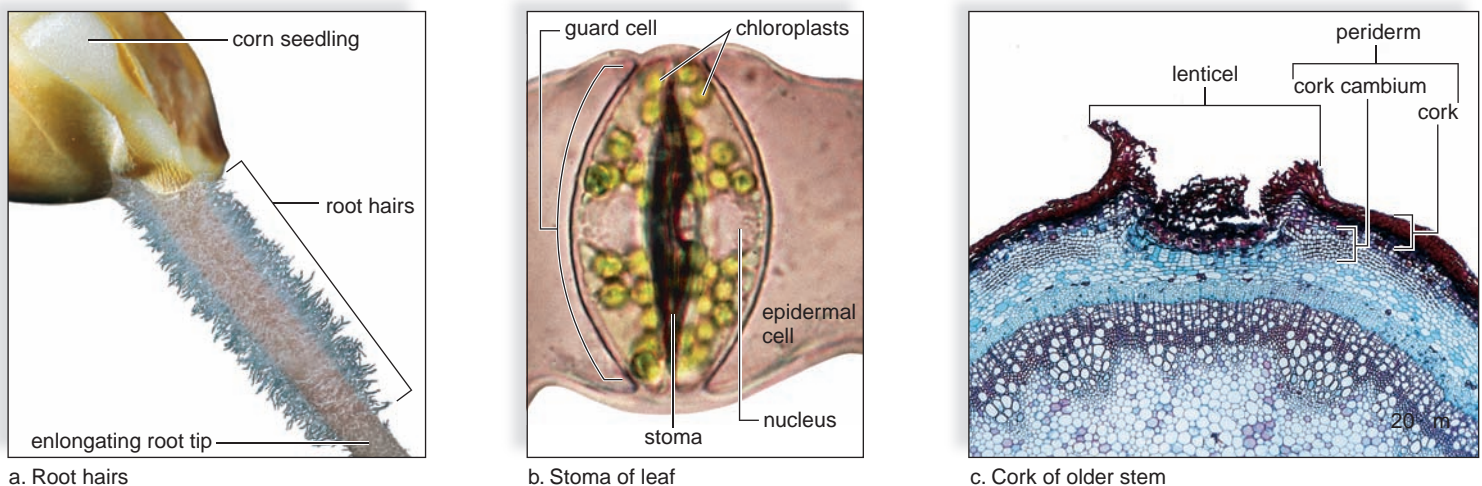
In roots, certain epidermal cells have long, slender projections called **root hairs** (Fig. 24.4a). As mentioned, the hairs increase the surface area of the root for absorption of water and minerals; they also help anchor the plant firmly in place.

On stems, leaves, and reproductive organs, epidermal cells produce hairs called **trichomes** [Gk. *trichos*, hair] that have two important functions: to protect the plant from too much sun and to conserve moisture. Sometimes trichomes, particularly glandular ones, help protect a plant from herbivores by producing a toxic substance. Under the slightest pressure the stiff trichomes of the stinging nettle lose their tips, forming “hypodermic needles” that inject an intruder with a stinging secretion.

In leaves, the lower epidermis of eudicots and both surfaces of monocots contain specialized cells called guard cells (Fig. 24.4b). Guard cells, which are epidermal cells with chloroplasts, surround microscopic pores called **stomata** (sing., stoma). When the stomata are open, gas exchange and water loss occur.

In older woody plants, the epidermis of the stem is replaced by **periderm** [Gk. *peri*, around; *derma*, skin]. The majority component of periderm is boxlike **cork** cells. At maturity, cork cells can be sloughed off (Fig. 24.4c). New cork cells are made by a meristem called **cork cambium**. As the new cork cells mature, they increase slightly in volume, and their walls become encrusted with suberin, a lipid material, so that they are waterproof and chemically inert. These nonliving cells protect the plant and make it resistant to attack by fungi, bacteria, and animals. Some cork tissues are commercially used for bottle corks and other products.

The cork cambium overproduces cork in certain areas of the stem surface; this causes ridges and cracks to appear. These features on the surface are called **lenticels**. Lenticels are important in gas exchange between the interior of a stem and the air.

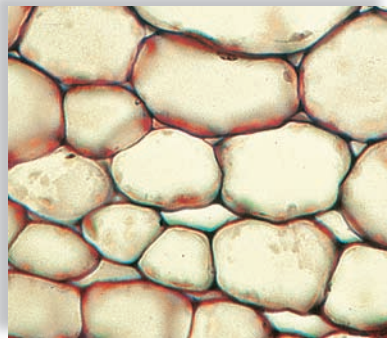


**FIGURE 24.4** Modifications of epidermal tissue.

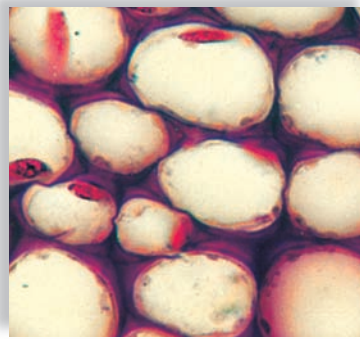
**a.** Root epidermis has root hairs to absorb water. **b.** Leaf epidermis contains stomata (sing., stoma) for gas exchange. **c.** Periderm includes cork and cork cambium. Lenticels in cork are important in gas exchange.

**FIGURE 24.5****Ground tissue cells.**

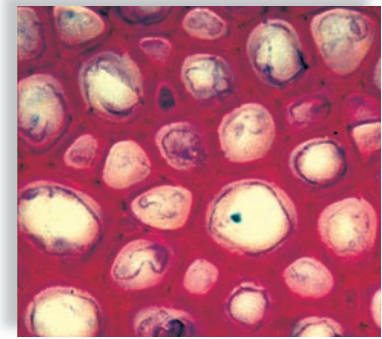
**a.** Parenchyma cells are the least specialized of the plant cells. **b.** Collenchyma cells. Notice how much thicker and irregular the walls are compared to those of parenchyma cells. **c.** Sclerenchyma cells have very thick walls and are nonliving—their only function is to give strong support.



a. Parenchyma cells



b. Collenchyma cells



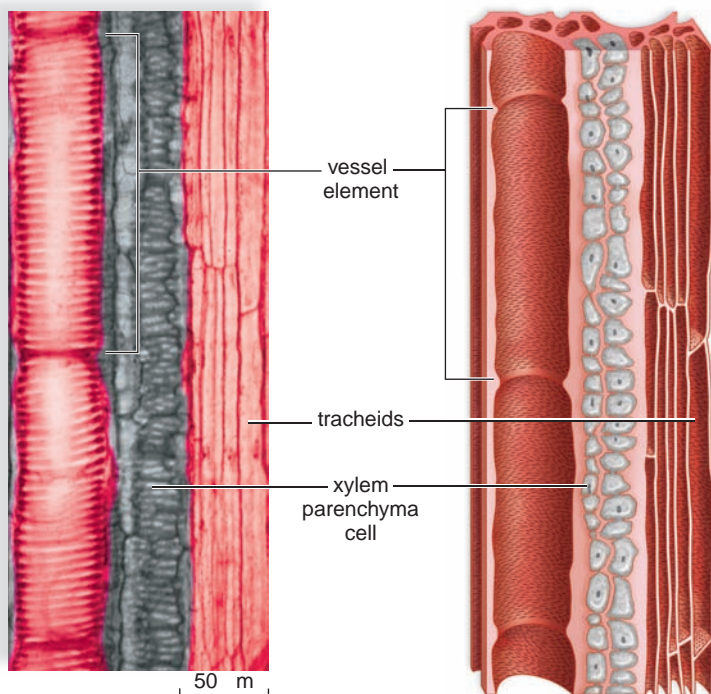
c. Sclerenchyma cells

**Ground Tissue**

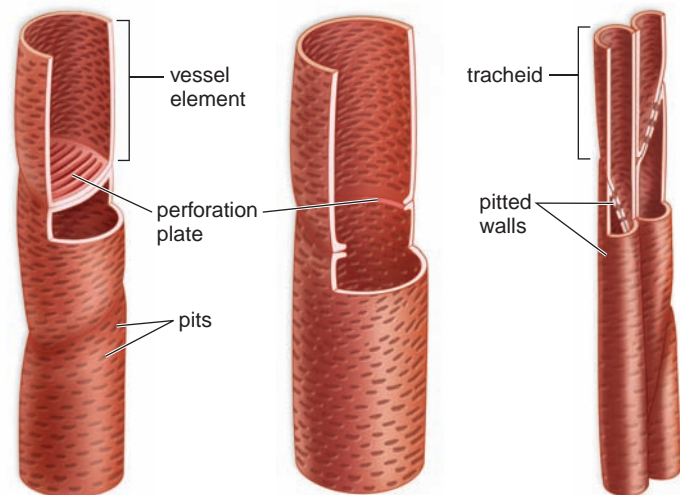
Ground tissue forms the bulk of a flowering plant and contains parenchyma, collenchyma, and sclerenchyma cells (Fig. 24.5). **Parenchyma** [Gk. *para*, beside, and *enchyma*, infusion] cells are the most abundant and correspond best to the typical plant cell. These are the least specialized of the cell types and are found in all the organs of a plant. They may contain chloroplasts and carry on photosynthesis (chlorenchyma), or they may contain colorless plastids that store the products of photosynthesis. A juicy bite from an apple yields mostly storage parenchyma cells. Parenchyma cells line the connected air spaces of a water lily and other aquatic plants. Parenchyma cells can divide and give rise to more specialized cells, such as when roots develop from stem cuttings placed in water.

**Collenchyma** cells are like parenchyma cells except they have thicker primary walls. The thickness is uneven and usually involves the corners of the cell. Collenchyma cells often form bundles just beneath the epidermis and give flexible support to immature regions of a plant body. The familiar strands in celery stalks (leaf petioles) are composed mostly of collenchyma cells.

**Sclerenchyma** cells have thick secondary cell walls impregnated with **lignin**, which is a highly resistant organic substance that makes the walls tough and hard. If we compare a cell wall to reinforced concrete, cellulose fibrils would play the role of steel rods, and lignin would be analogous to the cement. Most sclerenchyma cells are nonliving; their primary function is to support the mature regions of a plant. Two types of sclerenchyma cells are *fibers* and *sclereids*. Although



a. Xylem micrograph (left) and drawing (to side)



b. Two types of vessels

c. Tracheids

**FIGURE 24.6 Xylem structure.**

**a.** Photomicrograph of xylem vascular tissue and drawing showing general organization of xylem tissue. **b.** Drawing of two types of vessels (composed of vessel elements)—the perforation plates differ. **c.** Drawing of tracheids.



fibers are occasionally found in ground tissue, most are in vascular tissue, which is discussed next. Fibers are long and slender and may be grouped in bundles that are sometimes commercially important. Hemp fibers can be used to make rope, and flax fibers can be woven into linen. Flax fibers, however, are not lignified, which is why linen is soft. Sclereids, which are shorter than fibers and more varied in shape, are found in seed coats and nutshells. Sclereids, or “stone cells,” are responsible for the gritty texture of pears. The hardness of nuts and peach pits is due to sclereids.

## Vascular Tissue

There are two types of vascular (transport) tissue. **Xylem** transports water and minerals from the roots to the leaves, and **phloem** transports sucrose and other organic compounds, including hormones, usually from the leaves to the roots. Both xylem and phloem are considered **complex tissues** because they are composed of two or more kinds of cells. Xylem contains two types of conducting cells: tracheids and vessel elements (VE), which are modified sclerenchyma cells (Fig. 24.6). Both types of conducting cells are hollow and nonliving, but the **vessel elements** are larger, may have perforation plates in their end walls, and are arranged to form a continuous vessel for water and mineral transport. The elongated **tracheids**, with tapered ends, form a less obvious means of transport, but water can move across the end walls and side walls because there are **pits**, or depressions, where the secondary wall does not form. In addition to vessel elements and tracheids, xylem

contains additional sclerenchyma fibers that lend additional support and parenchyma cells that store various substances. Vascular rays, which are flat ribbons or sheets of parenchyma cells located between rows of tracheids, conduct water and minerals across the width of a plant.

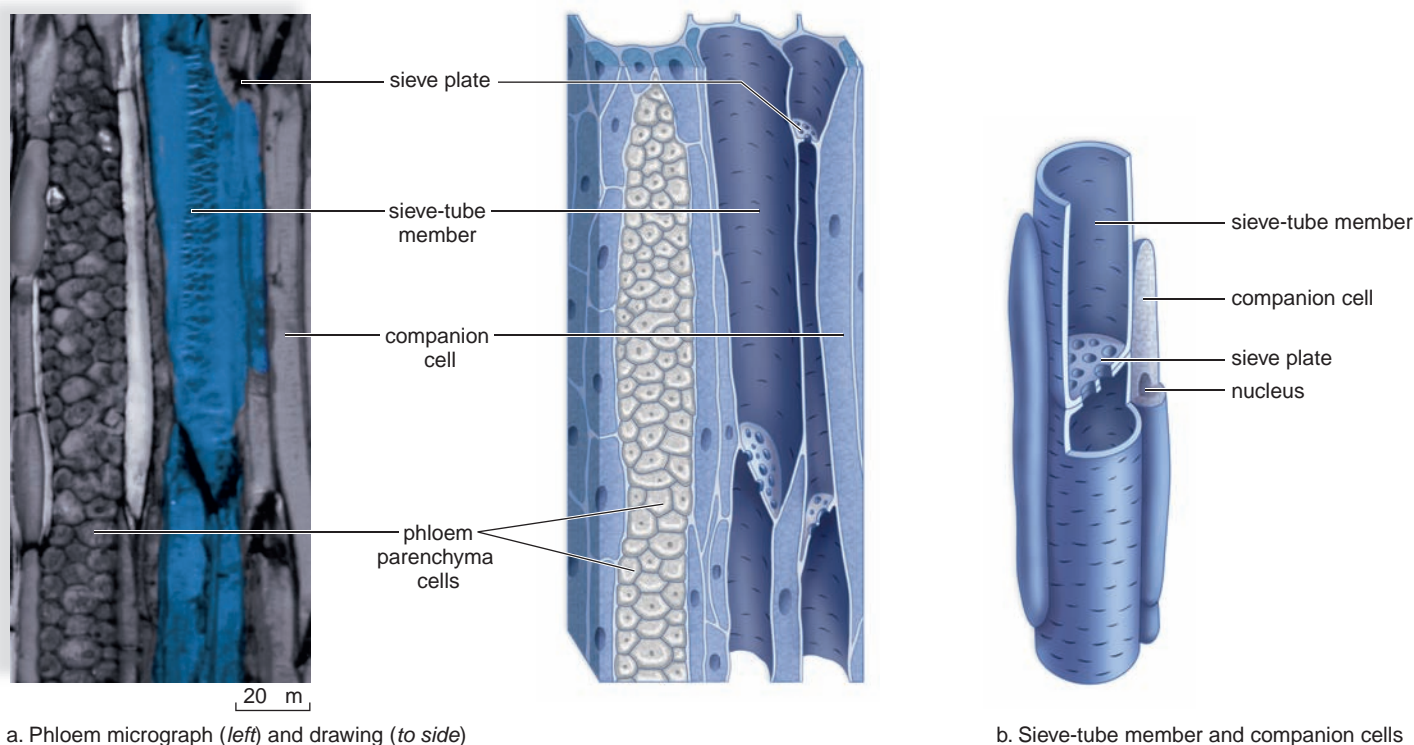
The conducting cells of phloem are specialized parenchyma cells called **sieve-tube members** arranged to form a continuous sieve tube (Fig. 24.7). Sieve-tube members contain cytoplasm but no nuclei. The term *sieve* refers to a cluster of pores in the end walls, which is known as a sieve plate. Each sieve-tube member has a companion cell, which does have a nucleus. The two are connected by numerous plasmodesmata, and the nucleus of the companion cell may control and maintain the life of both cells. The companion cells are also believed to be involved in the transport function of phloem. Sclerenchyma fibers also lend support to phloem.

It is important to realize that vascular tissue (xylem and phloem) extends from the root through stems to the leaves and vice versa (see Fig. 24.1). In the roots, the vascular tissue is located in the **vascular cylinder**; in the stem, it forms **vascular bundles**; and in the leaves, it is found in **leaf veins**.

### Check Your Progress

### 24.2

1. List the three specialized tissues in a plant and the cells that make up these tissues.
2. Compare the transport function of xylem and phloem.



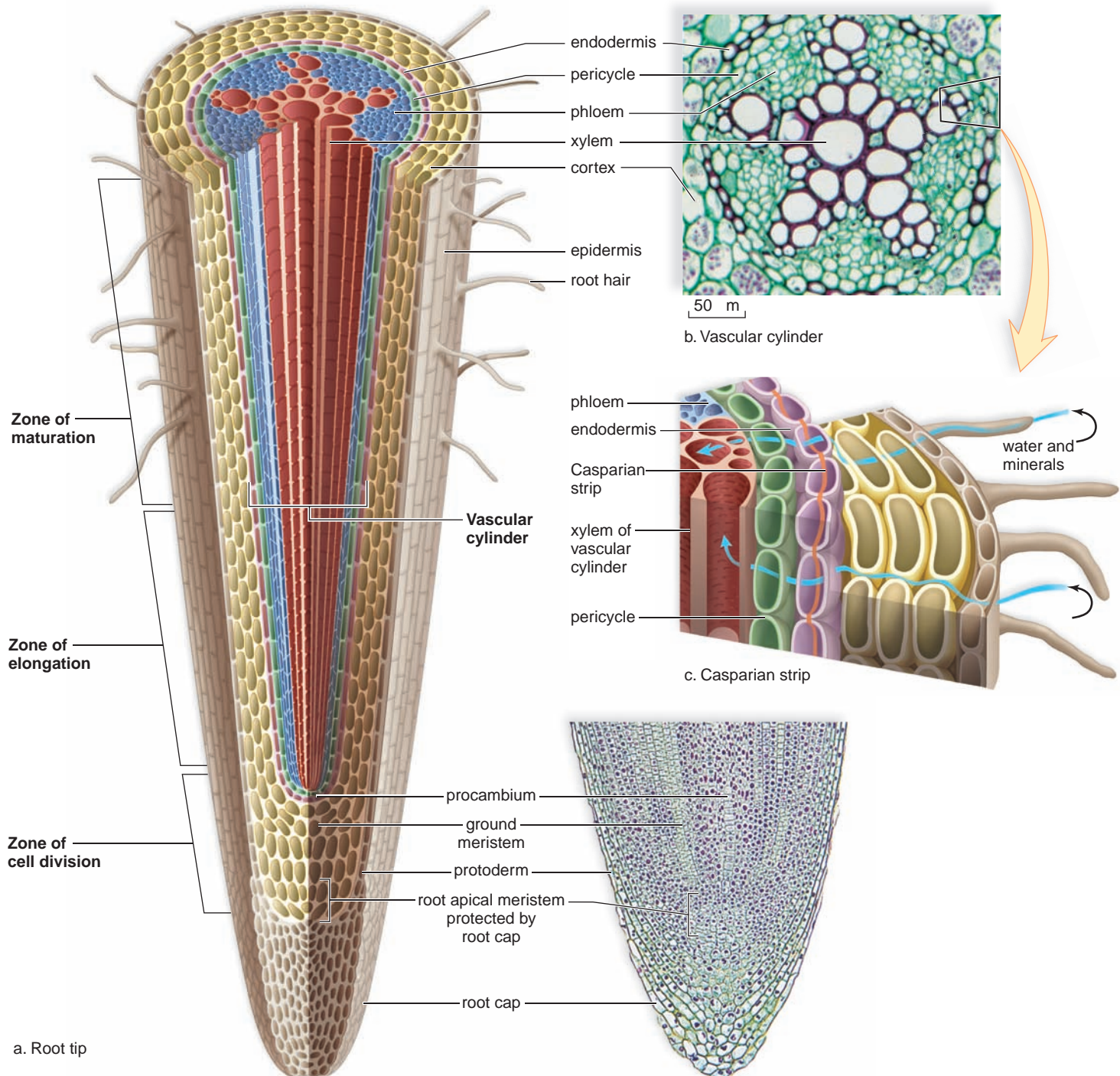
**FIGURE 24.7** Phloem structure.

**a.** Photomicrograph of phloem vascular tissue and drawing showing general organization of phloem tissue. **b.** Drawing of sieve tube (composed of sieve-tube members) and companion cells.

## 24.3 Organization and Diversity of Roots

Figure 24.8a, a longitudinal section of a eudicot root, reveals zones where cells are in various stages of differentiation as primary growth occurs. The root **apical meristem** is in the

region protected by the **root cap**. Root cap cells have to be replaced constantly because they get ground off by rough soil particles as the root grows. The primary meristems are in the zone of cell division, which continuously provides new cells to the zone of elongation. In the zone of elongation, the cells lengthen as they become specialized. The zone of maturation, which contains fully differentiated cells, is



**FIGURE 24.8** Eudicot root tip.

**a.** The root tip is divided into three zones. **b.** The vascular cylinder of a eudicot root contains the vascular tissue. **c.** Because of the Casparian strip, water and minerals must pass through the cytoplasm of endodermal cells in order to enter the xylem.



recognizable because here root hairs are borne by many of the epidermal cells.

## Tissues of a Eudicot Root

Figure 24.8a also shows a cross section of a root at the region of maturation. These specialized tissues are identifiable:

**Epidermis** The epidermis, which forms the outer layer of the root, consists of only a single layer of cells. The majority of epidermal cells are thin-walled and rectangular, but in the zone of maturation, many epidermal cells have root hairs. These project as far as 5–8 mm into the soil particles.

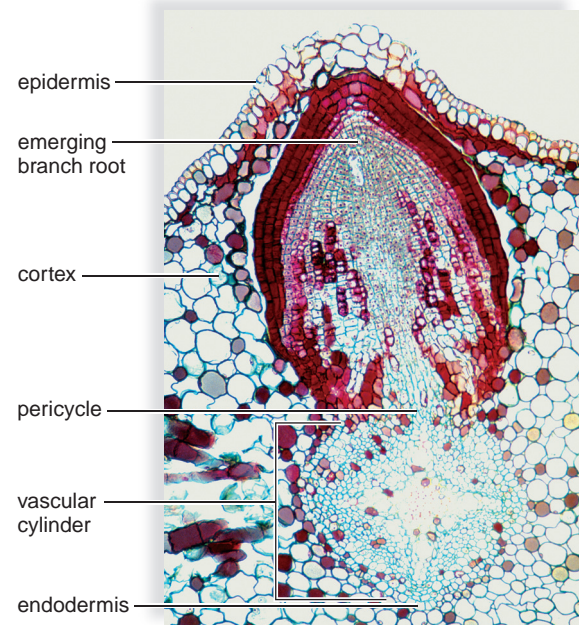
**Cortex** Moving inward, next to the epidermis, large, thin-walled parenchyma cells make up the **cortex** of the root. These irregularly shaped cells are loosely packed, and it is possible for water and minerals to move through the cortex without entering the cells. The cells contain starch granules, and the cortex functions in food storage.

**Endodermis** The **endodermis** [Gk. *endon*, within, and *derma*, skin] is a single layer of rectangular cells that forms a boundary between the cortex and the inner vascular cylinder. The endodermal cells fit snugly together and are bordered on four sides (but not the two sides that contact the cortex and the vascular cylinder) by a layer of impermeable lignin and suberin known as the **Casparian strip** (Fig. 24.8c). This strip prevents the passage of water and mineral ions between adjacent cell walls. Therefore, the only access to the vascular cylinder is through the endodermal cells themselves, as shown by the arrow in Figure 24.8c. This arrangement regulates the entrance of minerals into the vascular cylinder.

**Vascular tissue** The **pericycle**, the first layer of cells within the vascular cylinder, has retained its capacity to divide and can start the development of branch, or lateral, roots (Fig. 24.9). The main portion of the vascular cylinder contains xylem and phloem. The xylem appears star-shaped in eudicots because several arms of tissue radiate from a common center (see Fig. 24.8b). The phloem is found in separate regions between the arms of the xylem.

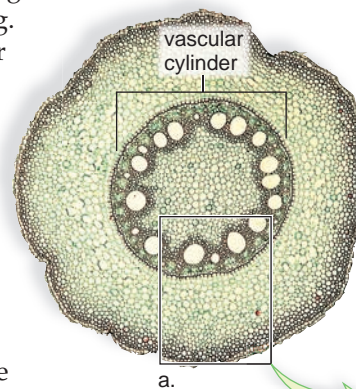
## Organization of Monocot Roots

Monocot roots have the same growth zones as eudicot roots, but they do not undergo secondary growth as many eudicot roots go through. Also, the organization of their tissues is slightly different. The ground tissue of a monocot root's **pith**, which is centrally located, is surrounded by a vascular ring composed of alternating xylem and phloem bundles (Fig. 24.10). Monocot roots also have pericycle, endodermis, cortex, and epidermis.



**FIGURE 24.9** Branching of eudicot root.

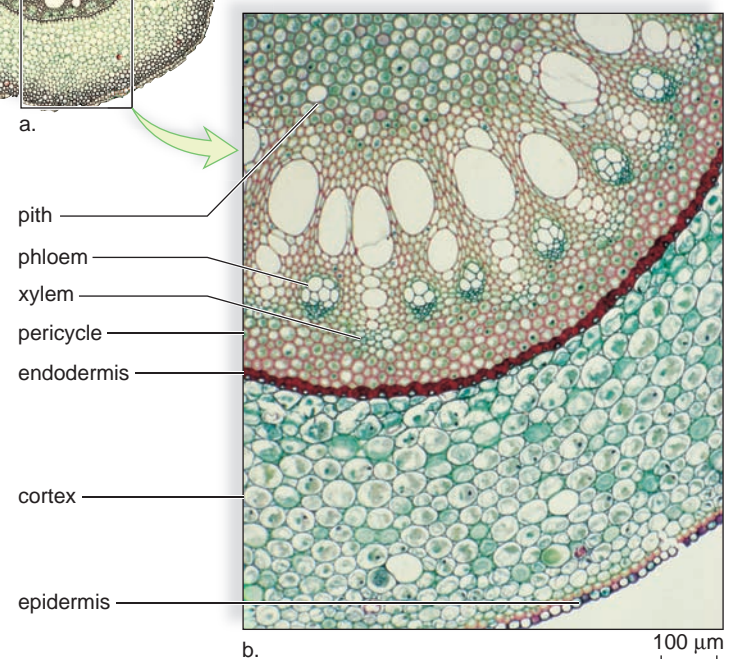
This cross section of a willow, *Salix*, shows the origination and growth of a branch root from the pericycle.



a.

**FIGURE 24.10** Monocot root.

a. In this overall cross section, it is possible to observe that a vascular ring surrounds a central pith.  
b. The enlargement shows the exact placement of various tissues.



b.

100 μm





a. Taproot



b. Fibrous root system



c. Prop roots, a type of adventitious root



d. Pneumatophores of black mangrove trees



e. Aerial roots of English ivy clinging to tree trunks



## FIGURE 24.11 Root diversity.

a. A taproot may have branch roots in addition to a main root. b. A fibrous root has many slender roots with no main root. c. Prop roots are specialized for support. d. The pneumatophores of a black mangrove tree allow it to acquire oxygen even though it lives in swampy water. e. (left) English ivy climbs up the trunk because (right) it has aerial roots that cling to tree bark.

## Root Diversity

Roots have various adaptations and associations to better perform their functions: anchorage, absorption of water and minerals, and storage of carbohydrates.

In some plants, notably eudicots, the first or **primary root** grows straight down and remains the dominant root of the plant. This so-called **taproot** is often fleshy and stores food (Fig. 24.11a). Carrots, beets, turnips, and radishes have taproots that we consume as vegetables. Sweet potato plants don't have taproots, but they do have roots that expand to store starch. We call these storage areas sweet potatoes.

In other plants, notably monocots, there is no single, main root; instead, there are a large number of slender roots. These grow from the lower nodes of the stem when the first (primary) root dies. These slender roots and their lateral branches make up a **fibrous root system** (Fig. 24.11b). Many have observed the fibrous root systems of grasses and have noted how these roots strongly anchor the plant to the soil.

## Root Specializations

When roots develop from organs of the shoot system instead of the root system, they are known as **adventitious roots**. Some adventitious roots emerge above the soil line, as they do in corn plants, in which their main function is to help anchor the plant. If so, they are called prop roots (Fig. 24.11c). Other examples of adventitious roots are those found on horizontal stems (see Fig. 24.19a) or at the nodes of climbing English ivy (Fig. 24.11e). As the vines climb, the rootlets attach the plant to any available vertical structure.

Black mangroves live in swampy water and have pneumatophores, root projections that rise above the water and acquire oxygen for cellular respiration (Fig. 24.11d).

Some plants, such as dodders and broomrapes, are parasitic on other plants. Their stems have rootlike projections called haustoria (sing., haustorium) that grow into the host plant and make contact with vascular tissue from which they extract water and nutrients (see Fig. 25.8a). **Mycorrhizae** are associations between roots and fungi that can extract water and minerals from the soil better than roots that lack a fungus partner. This is a mutualistic relationship because the fungus receives sugars and amino acids from the plant, while the plant receives water and minerals via the fungus.

Peas, beans, and other legumes have **root nodules** where nitrogen-fixing bacteria live. Plants cannot extract nitrogen from the air, but the bacteria within the nodules can take up and reduce atmospheric nitrogen. This means that the plant is no longer dependent on a supply of nitrogen (i.e., nitrate or ammonium) from the soil, and indeed these plants are often planted just to bolster the nitrogen supply of the soil.

## Check Your Progress

24.3

1. Describe the relationship between the root apical meristem and the root cap.
2. List the function of the cortex, the endodermis, and the pericycle in a root.



## ecology focus

## Paper Comes from Plants

The word *paper* takes its origin from papyrus, the plant Egyptians used to make the first form of paper. The Egyptians manually placed thin sections cut from papyrus at right angles and pressed them together to make a sheet of writing material. From that beginning some 5,500 years ago, the production of paper is now a worldwide industry of major importance (Fig. 24A). The process is fairly simple. Plant material is ground up mechanically to form a pulp that contains “fibers,” which biologists know come from vascular tissue. The fibers automatically form a sheet when they are screened from the pulp.

If wood is the source of the fibers, the pulp must be chemically treated to remove lignin. If only a small amount of lignin is removed, the paper is brown, as in paper bags. If more lignin is removed, the paper is white but not very durable, and it crumbles after a few decades. Paper is more durable when it is made from cotton or linen because the fibers from these plants are lignin-free.

Among the other major plants used to make paper are:

**Eucalyptus trees.** In recent years, Brazil has devoted huge areas of the Amazon region to the growing of cloned *Eucalyptus* seedlings, specially selected and engineered to be ready for harvest after about seven years.

**Temperate hardwood trees.** Plantation cultivation in Canada provides birch, beech, chestnut, poplar, and particularly aspen wood for paper making. Tropical hardwoods, usually from Southeast Asia, are also used.

**Softwood trees.** In the United States, several species of pine trees have been genetically improved to have a higher wood density and to be harvestable five years earlier than ordinary pines. Southern Africa, Chile, New Zealand, and Australia also devote thousands of acres to growing pines for paper pulp production.

**Bamboo.** Several Asian countries, especially India, provide vast quantities of bamboo pulp for the making of

paper. Because bamboo is harvested without destroying the roots, and the growing cycle is favorable, this plant, which is actually a grass, is expected to be a significant source of paper pulp despite high processing costs to remove impurities.

**Flax and cotton rags.** Linen and cotton cloth from textile and garment mills are used to produce rag paper, whose flexibility and durability are desirable in legal documents, high-grade bond paper, and high-grade stationery.

It has been known for some time that paper largely consists of the cellulose within plant cell walls. It seems reasonable to suppose, then, that paper could be made from synthetic polymers (e.g., rayon). Indeed, synthetic polymers produce a paper that has qualities superior to those of paper made from natural sources, but the cost thus far is

prohibitive. Another consideration, however, is the ecological impact of making paper from trees. Plantations containing stands of uniform trees replace natural ecosystems, and when the trees are clear-cut, the land is laid bare. Paper mill wastes, which include caustic chemicals, add significantly to the pollution of rivers and streams.

The use of paper for packaging and making all sorts of products has increased dramatically in the last century. Each person in the United States uses about 318 kg of paper products per year, and this compares to only 2.3 kg of paper per person in India. It is clear, then, that we should take the initiative in recycling paper. When newspaper, office paper, and photocopies are soaked in water, the fibers are released, and they can be used to make a new batch of paper. It's estimated that recycling the Sunday newspapers alone would save approximately 500,000 trees each week!

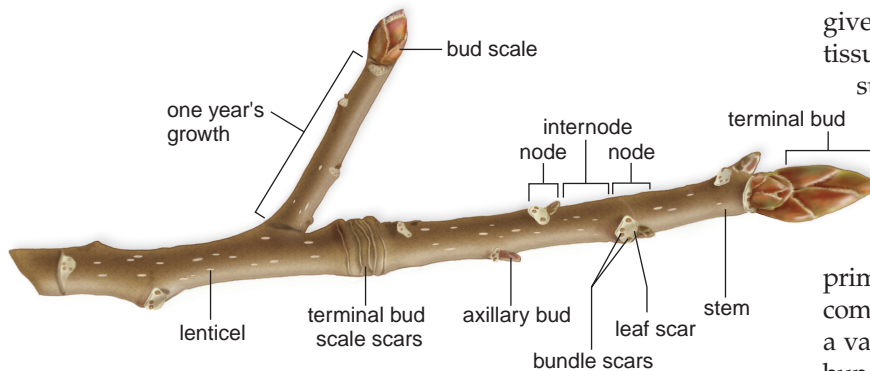


**FIGURE 24A Paper production.**

Today, a revolving wire-screen belt is used to deliver a continuous wet sheet of paper to heavy rollers and heated cylinders, which remove most of the remaining moisture and press the paper flat.

## 24.4 Organization and Diversity of Stems

The anatomy of a woody twig ready for next year's growth reviews for us the organization of a stem (Fig. 24.12). The **terminal bud** contains the shoot tip protected by bud scales, which are modified leaves. Each spring when growth resumes, bud scales fall off and leave a scar. You can tell the age of a stem by counting these bud scale scars because there is one for each year's growth. Leaf scars and bundle scars mark the location of leaves that have dropped. Dormant axillary buds that will give rise to branches or flowers are also found here.



**FIGURE 24.12** Woody twig.

The major parts of a stem are illustrated by a woody twig collected in winter.

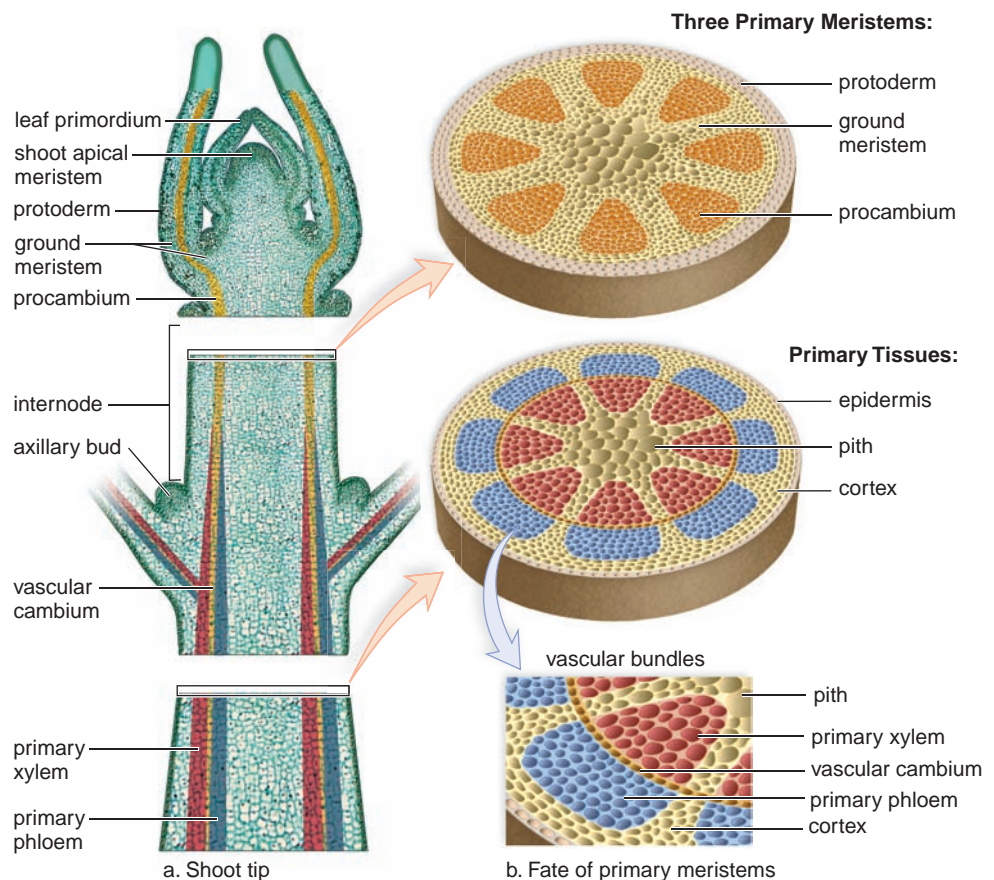
When growth resumes, primary growth continues. The apical meristem at the shoot tip produces new cells that elongate and thereby increase the height of the stem. The **shoot apical meristem** is protected within the terminal bud, where leaf primordia (immature leaves) envelop it (Fig. 24.13). The leaf primordia mark the location of a node; the portion of stem in between nodes is an internode. As a stem grows, the internodes increase in length.

In addition to leaf primordia, the three specialized types of primary meristem, mentioned earlier (see page 437), develop from a shoot apical meristem (Fig. 24.13b). These primary meristems contribute to the length of a shoot. As mentioned, the *protoderm*, the outermost primary meristem, gives rise to epidermis. The *ground meristem* produces two tissues composed of parenchyma cells. The parenchyma tissue in the center of the stem is the pith, and the parenchyma tissue between the epidermis and the vascular tissue is the cortex.

The *procambium*, seen as an obvious strand of tissue in Figure 24.13a, produces the first xylem cells, called primary xylem, and the first phloem cells, called primary phloem. Differentiation continues as certain cells become the first tracheids or vessel elements of the xylem within a vascular bundle. The first sieve-tube members of a vascular bundle do not have companion cells and are short-lived (some live only a day before being replaced). Mature vascular bundles contain fully differentiated xylem, phloem, and a lateral meristem called **vascular cambium** [L. *vasculum*, dim. of *vas*,

**FIGURE 24.13** Shoot tip and primary meristems.

**a.** The shoot apical meristem within a terminal bud is surrounded by leaf primordia. **b.** The shoot apical meristem produces the primary meristems: Protoderm gives rise to epidermis; ground meristem gives rise to pith and cortex; and procambium gives rise to vascular tissue, including primary xylem, primary phloem, and vascular cambium.





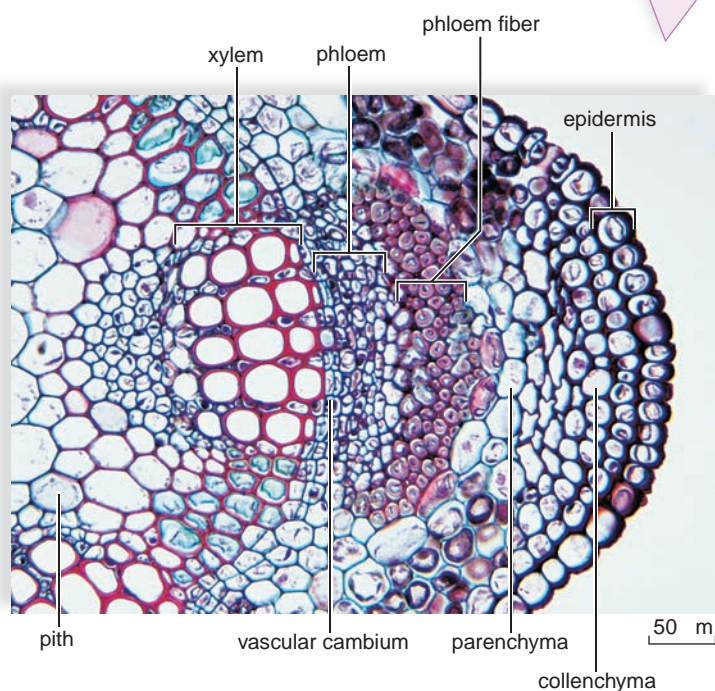
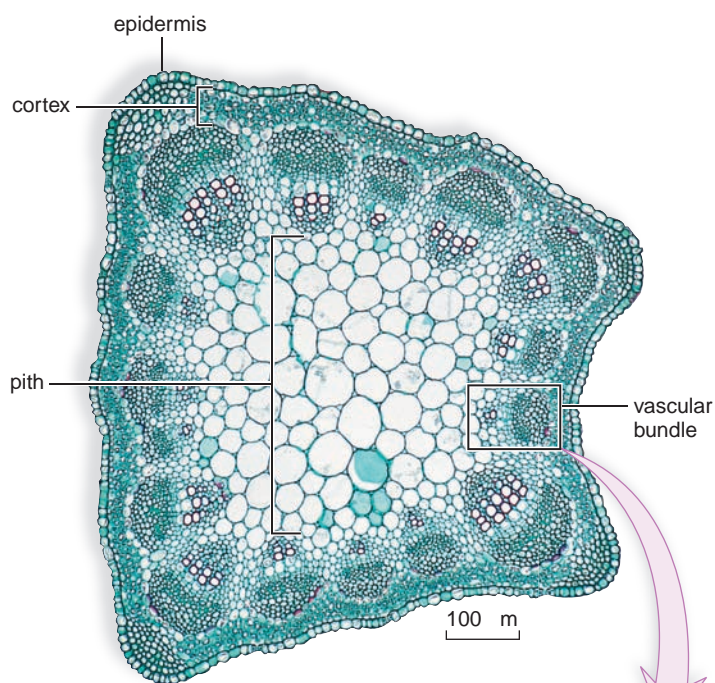
vessel, and *cambio*, exchange]. Vascular cambium is discussed more fully in the next section.

## Herbaceous Stems

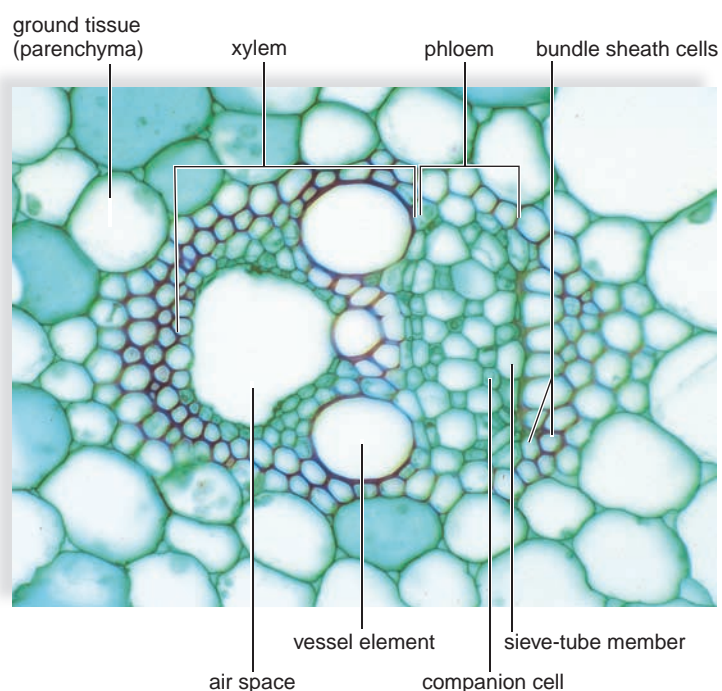
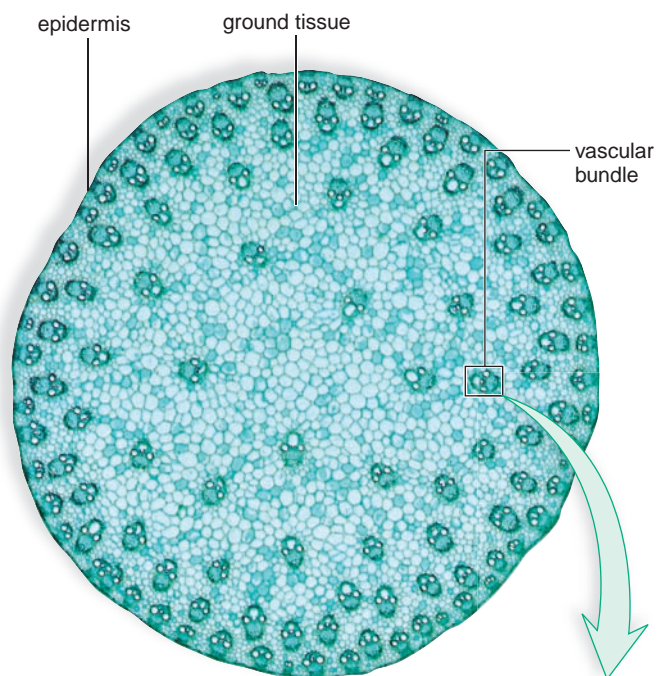
Mature nonwoody stems, called **herbaceous stems** [*L. herba*, vegetation, plant], exhibit only primary growth. The outermost tissue of herbaceous stems is the epidermis, which is covered by a waxy cuticle to prevent water loss. These stems have distinctive vascular bundles, where xylem and phloem are found. In each bundle, xylem is typically found

toward the inside of the stem, and phloem is found toward the outside.

In the herbaceous eudicot stem such as a sunflower, the vascular bundles are arranged in a distinct ring that separates the cortex from the central pith, which stores water and products of photosynthesis (Fig. 24.14). The cortex is sometimes green and carries on photosynthesis. In a monocot stem such as corn, the vascular bundles are scattered throughout the stem, and often there is no well-defined cortex or well-defined pith (Fig. 24.15).



**FIGURE 24.14** Herbaceous eudicot stem.



**FIGURE 24.15** Monocot stem.



## Woody Stems

A woody plant such as an oak tree has both primary and secondary tissues. Primary tissues are those new tissues formed each year from primary meristems right behind the shoot apical meristem. Secondary tissues develop during the first and subsequent years of growth from lateral meristems: vascular cambium and cork cambium. *Primary growth*, which occurs in all plants, increases the length of a plant, and *secondary growth*, which occurs only in conifers and woody eudicots, increases the girth of trunks, stems, branches, and roots.

Trees and shrubs undergo secondary growth because of a change in the location and activity of vascular cambium (Fig. 24.16). In herbaceous plants, vascular cambium is present between the xylem and phloem of each vascular bundle. In woody plants, the vascular cambium develops to form a ring of meristem that divides parallel to the surface of the plant, and produces new xylem toward the inside and phloem toward the outside each year.

Eventually, a woody eudicot stem has an entirely different organization from that of a herbaceous eudicot stem. A woody stem has no distinct vascular bundles and instead has three distinct areas: the bark, the wood, and the pith. Vascular cambium occurs between the bark and the wood, and it causes woody plants to increase in girth. Cork cambium, occurring first beneath the epidermis, is instrumental in the production of cork in woody plants.

You will also notice in Figure 24.16 the *xylem rays* and *phloem rays* that are visible in the cross section of a woody stem. Rays consist of parenchyma cells that permit lateral conduction of nutrients from the pith to the cortex and some storage of food. A phloem ray is actually a continuation of an xylem ray. Some phloem rays are much broader than other phloem rays.

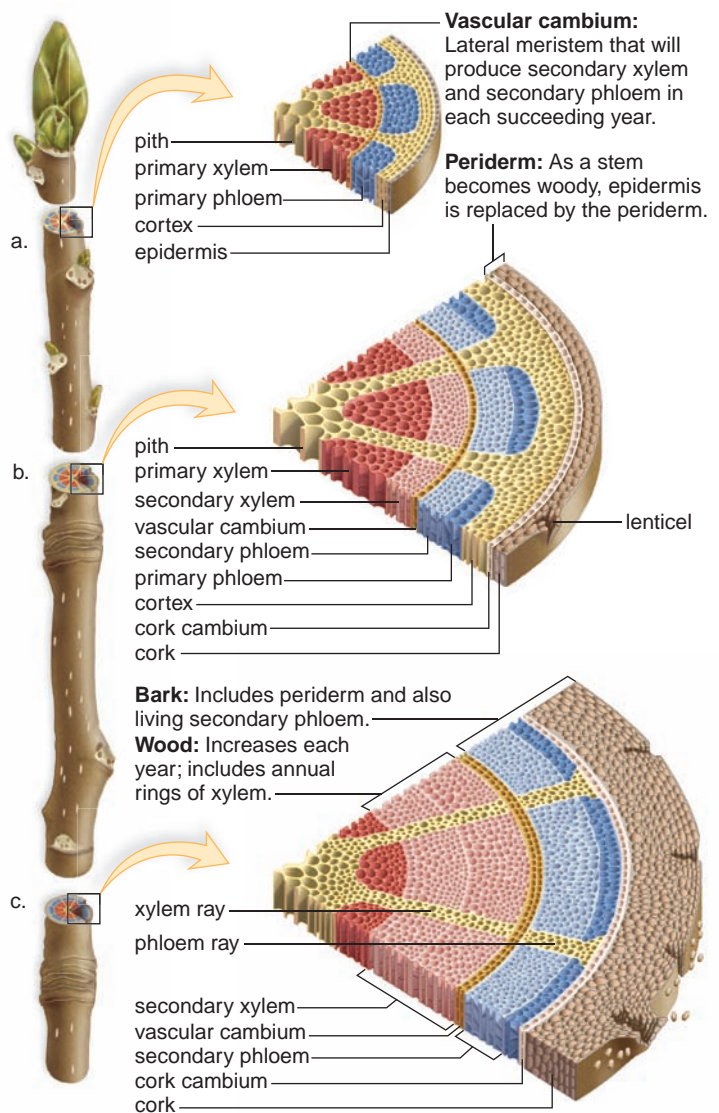
## Bark

The **bark** of a tree contains periderm (cork and cork cambium), and phloem. Although secondary phloem is produced each year by vascular cambium, phloem does not build up from season to season. The bark of a tree can be removed; however, this is very harmful because, without phloem, organic nutrients cannot be transported. Girdling, removing a ring of bark from around a tree, can be lethal to the tree. Some herbivores girdle trees, and it can also be deliberately done by humans who want to thin out a forest or fruit tree stand. Girdling kills trees.

At first, cork cambium is located beneath the epidermis, and then later, it is found beneath the periderm. When cork cambium first begins to divide, it produces tissue that disrupts the epidermis and replaces it with cork cells. Cork cells are impregnated with suberin, a waxy layer that makes them waterproof but also causes them to die. This is protective because it makes the stem less edible. But an impervious barrier means that gas exchange is impeded except at lenticels, which are pockets of loosely arranged cork cells not impregnated with suberin.

## Wood

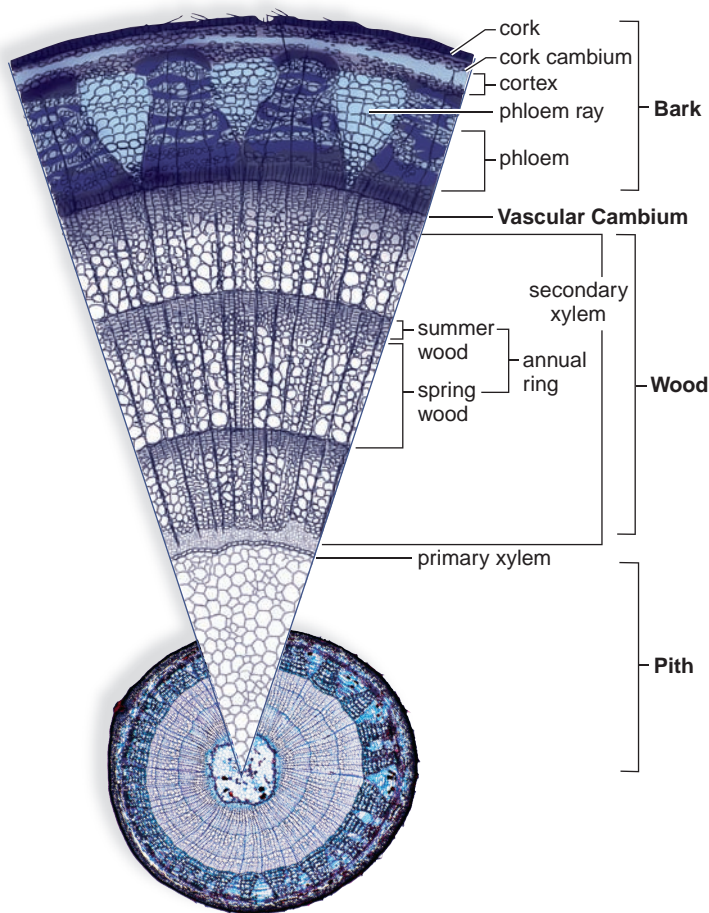
**Wood** is secondary xylem that builds up year after year, thereby increasing the girth of trees. In trees that have a growing season, vascular cambium is dormant during the winter. In the spring, when moisture is plentiful and leaves require much water for growth, the secondary xylem contains wide vessel elements with thin walls. In this so-called *spring wood*, wide vessels transport sufficient water to the growing leaves. Later in the season, moisture is scarce, and the wood at this time, called *summer wood*, has a lower proportion of vessels (Fig. 24.17). Strength is required because the tree is growing larger and summer wood contains numerous thick-walled tracheids. At the end of the



**FIGURE 24.16** Diagrams of secondary growth of stems.

**a.** Diagram showing eudicot herbaceous stem just before secondary growth begins. **b.** Diagram showing that secondary growth has begun. Periderm has replaced the epidermis. Vascular cambium produces secondary xylem and secondary phloem each year. **c.** Diagram showing a two-year-old stem. The primary phloem and cortex will eventually disappear, and only the secondary phloem (within the bark) produced by vascular cambium will be active that year. Secondary xylem builds up to become the annual rings of a woody stem.





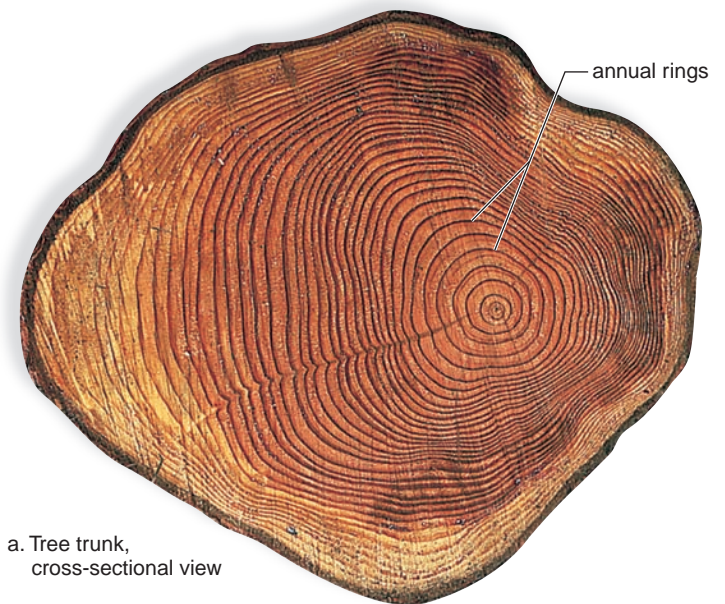
**FIGURE 24.17** Three-year-old woody twig.

The buildup of secondary xylem in a woody stem results in annual rings, which tell the age of the stem. The rings can be distinguished because each one begins with spring wood (large vessel elements) and ends with summer wood (smaller and fewer vessel elements).

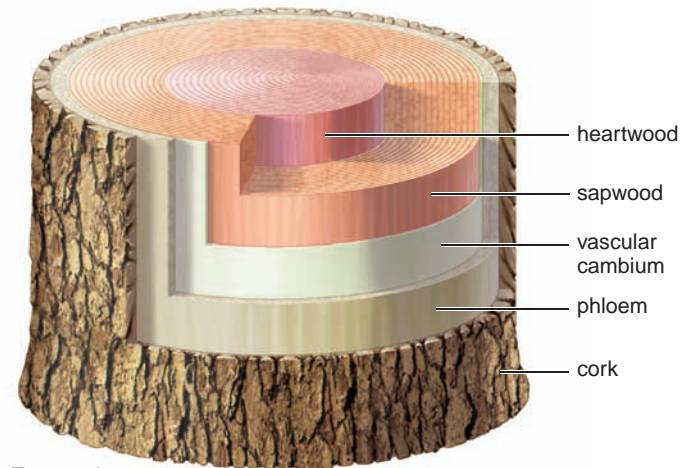
growing season, just before the cambium becomes dormant again, only heavy fibers with especially thick secondary walls may develop. When the trunk of a tree has spring wood followed by summer wood, the two together make up one year's growth, or an **annual ring**. You can tell the age of a tree by counting the annual rings (Fig. 24.18a). The outer annual rings, where transport occurs, are called sapwood.

In older trees, the inner annual rings, called the heartwood, no longer function in water transport. The cells become plugged with deposits, such as resins, gums, and other substances that inhibit the growth of bacteria and fungi. Heartwood may help support a tree, although some trees stand erect and live for many years after the heartwood has rotted away. Figure 24.18b shows the layers of a woody stem in relation to one another.

The annual rings are not only important in telling the age of a tree, they can serve as a historical record of tree growth. For example, if rainfall and other conditions were extremely favorable during a season, the annual ring may be wider than usual. If the tree were shaded on one side by another tree or building, the rings may be wider on the favorable side.



a. Tree trunk, cross-sectional view



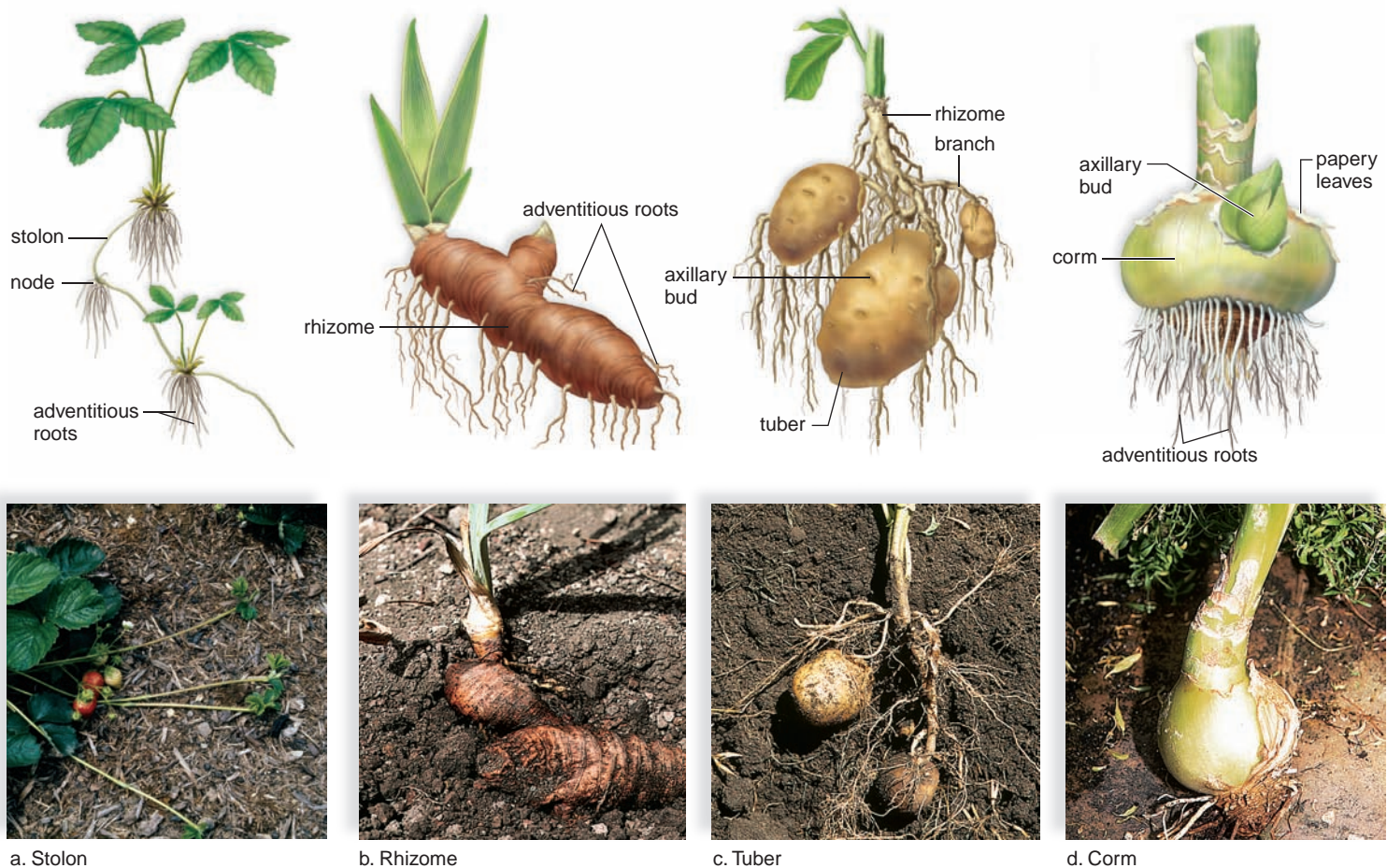
b. Tree trunk, longitudinal view

**FIGURE 24.18** Tree trunk.

a. A cross section of a 39-year-old larch, *Larix decidua*. The xylem within the darker heartwood is inactive; the xylem within the lighter sapwood is active.  
b. The relationship of bark, vascular cambium, and wood is retained in a mature stem. The pith has been buried by the growth of layer after layer of new secondary xylem.

**Woody Plants.** Is it advantageous to be woody? With adequate rainfall, woody plants can grow taller and have more growth because they have adequate vascular tissue to support and service their leaves. However, it takes energy to produce secondary growth and prepare the body for winter if the plant lives in the temperate zone. Also, woody plants need more defense mechanisms because a long-lasting plant that stays in one spot is likely to be attacked by herbivores and parasites. Then, too, trees don't usually reproduce until they have grown several seasons, by which time they may have succumbed to an accident or disease. In certain habitats, it is more advantageous for a plant to put most of its energy into simply reproducing rather than being woody.





**FIGURE 24.19** Stem diversity.

**a.** A strawberry plant has aboveground horizontal stems called stolons. Every other node produces a new shoot system. **b.** The underground horizontal stem of an iris is a fleshy rhizome. **c.** The underground stem of a potato plant has enlargements called tubers. We call the tubers potatoes. **d.** The corm of a gladiolus is a stem covered by papery leaves.

## Stem Diversity

Stem diversity is illustrated in Figure 24.19. Aboveground horizontal stems, called **stolons** [L. *stolo*, shoot] or runners, produce new plants where nodes touch the ground. The strawberry plant is a common example of this type of stem, which functions in vegetative reproduction.

Aboveground vertical stems can also be modified. For example, cacti have succulent stems specialized for water storage, and the tendrils of grape plants (which are stem branches) allow them to climb. Morning glory and relatives have stems that twine around support structures. Such tendrils and twining shoots help plants expose their leaves to the sun.

Underground horizontal stems, **rhizomes** [Gk. *rhiza*, root], may be long and thin, as in sod-forming grasses, or thick and fleshy, as in irises. Rhizomes survive the winter and contribute to asexual reproduction because each node bears a bud. Some rhizomes have enlarged portions called tubers, which function in food storage. Potatoes are tubers, in which the eyes are buds that mark the nodes.

Corms are bulbous underground stems that lie dormant during the winter, just as rhizomes do. They also

produce new plants the next growing season. Gladiolus corms are referred to as bulbs by laypersons, but the botanist reserves the term *bulb* for a structure composed of modified leaves attached to a short vertical stem. An onion is a bulb.

Humans make use of stems in many ways. The stem of the sugarcane plant is a primary source of table sugar. The spice cinnamon and the drug quinine are derived from the bark of *Cinnamomum verum* and various *Cinchona* species, respectively. And wood is necessary for the production of paper, as discussed in the Ecology Focus on page 443.

## Check Your Progress

## 24.4

1. What transport tissues are in a vascular bundle?
2. How are vascular bundles arranged in monocot stems? In eudicot stems?
3. Contrast primary growth with secondary growth.
4. List the components of bark.
5. Relate spring wood and summer wood to annual rings.



## science focus

### Defense Strategies of Trees

**R**ainstorms, ice, snow, animals, wind, excess weight, temperature extremes, and chemicals can all injure a tree. So can improper pruning. Pruning, which requires the cutting away of tree parts, can benefit a tree by improving its appearance and helping maintain its balance. But removing the top of a tree, called topping, removing a portion of the roots, and flush-cutting a number of branches at one time is injurious to trees. This is known because a tree reacts to improper pruning in the same manner it reacts to all injuries, no matter what the cause. The wounding of a tree subjects it to disease. Trees, like humans, have defensive strategies against bacterial and fungal invasions that occur when a tree is wounded.

A defense strategy is a mechanism that has arisen through the evolutionary process. In other words, members of the group with the strategy compete better than those that do not. We expect defense strategies to be beneficial—and they are—but the manner in which trees react to disease, called compartmentalization of decay, can still weaken them. Therefore, improper pruning practices should be avoided at all cost if you care about a tree!

Just as with humans, trees have a series of defense strategies against infection. Each one is better than the other at stopping the progress of disease organisms. First, when a tree is injured, the tracheids and vessel elements of xylem immediately plug up with chemicals that block them off above and below the site of the injury. In trees that fail to effectively close off vessel elements, long columns of rot (decay) run up and down the trunk and into branches, which eventually become hollow.

The second defense strategy is a result of tree trunk structure. As you know, a tree trunk has annual rings that tell its age. A dark region at the edge of an annual ring in the cross section of a trunk tells you that this tree was injured, and that disease organisms were unable to advance inward on their way to the pith. It appears, therefore, that disease organisms have a harder time moving across a trunk due to annual ring construction than they do moving through the trunk in vessel elements.

The third defense strategy involves rays. Rays take their name from the fact that they project radially from vascular cambium. Just like the slices of a pie, rays divide the trunk of a tree. Disease organisms can't cross rays



Turkey oak, *Quercus laevis*



Weeping willow, *Salix babylonica*

#### FIGURE 24B Defense strategies.

An oak tree is better at defense against infection than is a weeping willow tree. The oak tree never has to employ the defense strategy (right) that resulted in this dark ring in the trunk, which can lead to cracks and collapse of the tree.

either, and this keeps them in a small pie piece of the trunk and prevents them from moving completely around the trunk.

The fourth defense strategy is a so-called reaction zone that develops in the region of the injury along the inner portion of the cambium next to the youngest annual ring. The reaction zone can extend from a few inches to a few feet above and below the injury, and partway or all the way around the trunk. The reaction zone doesn't wall off any annual rings that develop after the injury, but it does wall off any annual rings that were present before the injury occurred. Figure 24B (right) shows a cross section of a tree that was topped seven years before it was cut down. The reaction zone is seen as a dark circle that, in this case, extends from the top of the tree to the root system.

Although the fourth defense strategy more effectively retards disease, it has a severe disadvantage. Cracks can develop along the reac-



Cross section of a damaged tree trunk.

tion zone, and radial cracks also occur from the reaction zone to and through the bark. Cracks can severely weaken a tree and make it more susceptible to breaking. A closure crack is one that occurs at the site of the wound. Sometimes this crack never actually closes.

Some trees are better defenders against disease than others. Trees that effectively carry out strategies 1–3 need never employ strategy 4, which can lead to cracking. Oak trees, *Quercus* (Fig. 24B), are examples of trees that are good at defending themselves, while willows, *Salix*, are not as good.



## 24.5 Organization and Diversity of Leaves

Leaves are the organs of photosynthesis in vascular plants such as flowering plants. As mentioned earlier, a leaf usually consists of a flattened blade and a petiole connecting the blade to the stem. The blade may be single or composed of several leaflets. Externally, it is possible to see the pattern of the leaf veins, which contain vascular tissue. Leaf veins have a net pattern in eudicot leaves and a parallel pattern in monocot leaves (see Fig. 24.3).

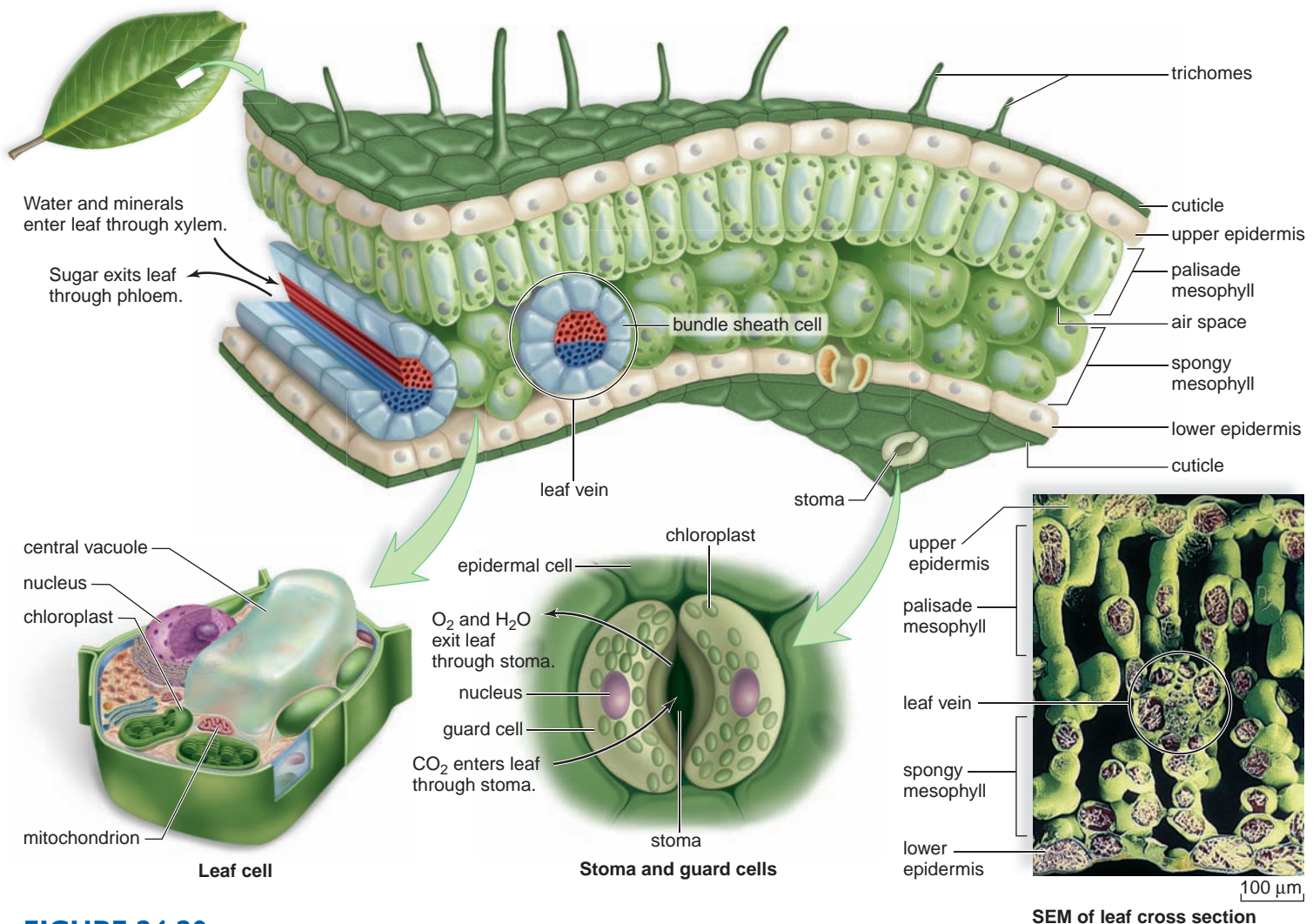
Figure 24.20 shows a cross section of a typical eudicot leaf of a temperate zone plant. At the top and bottom are layers of epidermal tissue that often bear trichomes, protective hairs often modified as glands that secrete irritating substances. These features may prevent the leaf from being eaten by insects. The epidermis characteristically has an outer, waxy cuticle that helps keep the leaf from drying out. The cuticle also prevents gas exchange because it is not gas permeable. However, the lower epidermis of eudicot and both surfaces of monocot leaves contain stomata that allow gases to move into and out of the leaf. Water loss also occurs at stomata, but

each stoma has two guard cells that regulate its opening and closing, and stomata close when the weather is hot and dry.

The body of a leaf is composed of **mesophyll** [Gk. *mesos*, middle, and *phyllon*, leaf] tissue. Most eudicot leaves have two distinct regions: **palisade mesophyll**, containing elongated cells, and **spongy mesophyll**, containing irregular cells bounded by air spaces. The parenchyma cells of these layers have many chloroplasts and carry on most of the photosynthesis for the plant. The loosely packed arrangement of the cells in the spongy layer increases the amount of surface area for gas exchange.

### Leaf Diversity

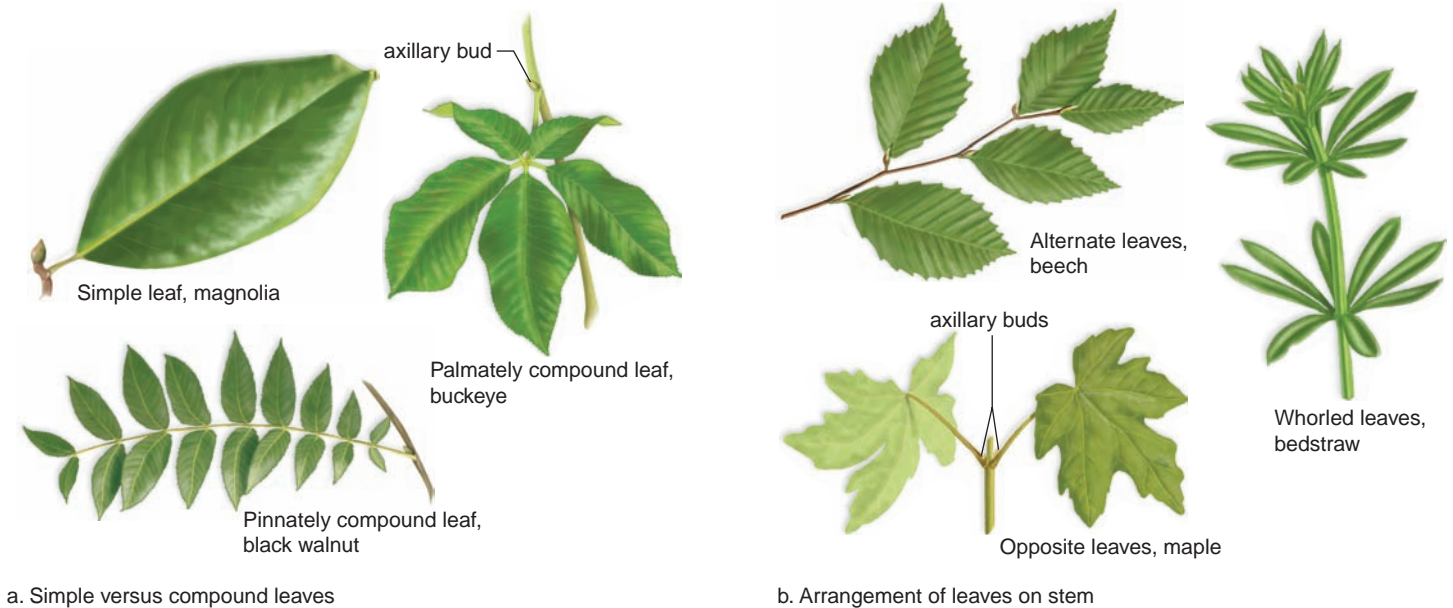
The blade of a leaf can be simple or compound (Fig. 24.21). A simple leaf has a single blade in contrast to a compound leaf, which is divided in various ways into leaflets. An example of a plant with simple leaves is a magnolia, and a tree with compound leaves is a pecan tree. Pinnately compound leaves have the leaflets occurring in pairs, such as in a black walnut tree, while palmately compound leaves have all of the leaflets attached to a single point, as in a buckeye tree.



**FIGURE 24.20** Leaf structure.

Photosynthesis takes place in mesophyll tissue of leaves. The leaf is enclosed by epidermal cells covered with a waxy layer, the cuticle. Leaf hairs are also protective. The veins contain xylem and phloem for the transport of water and solutes. A stoma is an opening in the epidermis that permits the exchange of gases.





a. Simple versus compound leaves

b. Arrangement of leaves on stem

**FIGURE 24.21** Classification of leaves.

a. Leaves are either simple or compound, being either pinnately compound or palmately compound. Note the one axillary bud per compound leaf. b. Leaf arrangement on stem can be alternate, opposite, or whorled.

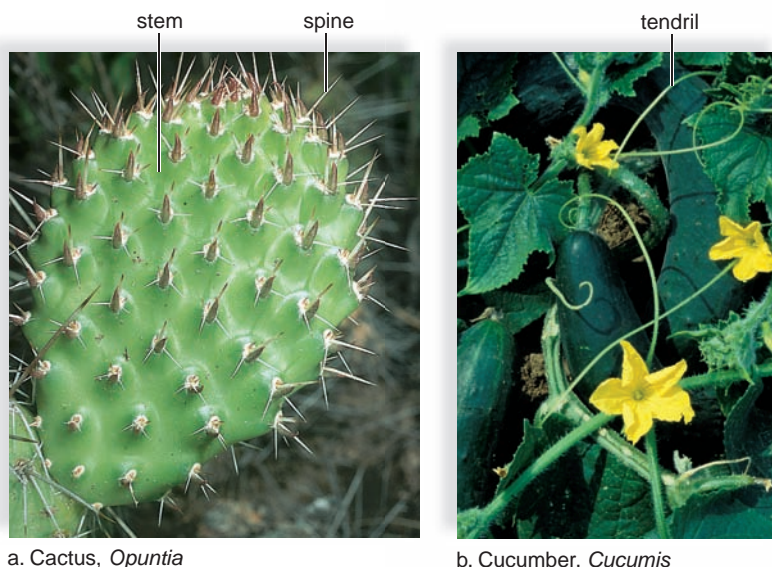
Leaves can be arranged on a stem in three ways: alternate, opposite, or whorled. The leaves are alternate in the American beech; in a maple, the leaves are opposite, being attached to the same node. Bedstraw has a whorled leaf arrangement with several leaves originating from the same node. Leaves are adapted to environmental conditions. Shade plants tend to have broad, wide leaves, and desert plants tend to have reduced leaves with sunken stomata. The leaves of a cactus are the spines attached to the succulent (water-containing) stem (Fig. 24.22a).

An onion bulb is made up of leaves surrounding a short stem. In a head of cabbage, large leaves overlap one another. The petiole of a leaf can be thick and fleshy, as in celery and rhubarb. Climbing leaves, such as those of peas and cucumbers, can be modified into tendrils that can attach to nearby objects (Fig. 24.22b). The leaves of a few plants are specialized

for catching insects. A sundew has sticky trichomes that trap insects and others that secrete digestive enzymes. The Venus's flytrap has hinged leaves that snap shut and interlock when an insect triggers sensitive trichomes that project from inside the leaves (Fig. 24.22c). Certain leaves of a pitcher plant resemble a pitcher and have downward-pointing hairs that lead insects into a pool of digestive enzymes secreted by trichomes. Insectivorous plants commonly grow in marshy regions, where the supply of soil nitrogen is severely limited. The digested insects provide the plants with a source of organic nitrogen.

**Check Your Progress****24.5**

- I. What is the importance of the leaf tissue called mesophyll to a plant?

a. Cactus, *Opuntia*b. Cucumber, *Cucumis***FIGURE 24.22** Leaf diversity.

a. The spines of a cactus plant are modified leaves that protect the fleshy stem from animal predation. b. The tendrils of a cucumber are modified leaves that attach the plant to a physical support. c. The modified leaves of the Venus's flytrap serve as a trap for insect prey. When triggered by an insect, the leaf snaps shut. Once shut, the leaf secretes digestive juices that break down the soft parts of the insect's body.

c. Venus's flytrap, *Dionaea*

## Connecting the Concepts

In Chapter 23, we saw how land plants became adapted to reproducing in a terrestrial environment. Many other types of adaptations are also required to live on land. Because even humid air is drier than a living cell, the prevention of water loss is critical for land plants. The epidermis, the trichomes, and the cuticle it produces help prevent water loss and overheating in sunlight. (The epidermis and glandular trichomes also protect against invasion by bacteria, fungi, and small insects.) Gas exchange in leaves depends on the presence of stomata, which close when a plant is water-stressed. The cork of woody plants is especially protective against water loss, but when cork is interrupted by lenticels, gas exchange is still possible.

In an aquatic environment, water buoys up plants and keeps them afloat, but land plants had to evolve a way to oppose the force of gravity. The stems of land plants contain strong-walled sclerenchyma fibers, tracheids, and vessel elements. The accumulation of secondary xylem allows a tree to grow in diameter and offers even more support.

Also, in an aquatic environment, water is available to all cells, but on land it is adaptive to have a means of water uptake and transport. In land plants, the roots absorb water and have special extensions called root hairs that facilitate water uptake. Xylem transports water to all plant parts, including the leaves.

In Chapter 25, we will see how the drying effect of air allows water to move from the roots to the leaves in the conducting cells of xylem. Roots are buried in soil, where, with the help of mycorrhizae, they can absorb water. In that chapter, we will also see how the properties of water allow phloem to transport sugars from the leaves to the roots and to any other plant part in need of sustenance.

The many adaptations of land plants allow them to carry on photosynthesis and be homeostatic in the terrestrial environment. Homeostatic mechanisms also involve regulation by hormones and defense mechanisms, discussed in Chapter 26.

## summary

### 24.1 Organs of Flowering Plants

A flowering plant has three vegetative organs. A root anchors a plant, absorbs water and minerals, and stores the products of photosynthesis. Stems produce new tissue, support leaves, conduct materials to and from roots and leaves, and help store plant products. Leaves are specialized for gas exchange, and they carry on most of the photosynthesis in the plant.

Flowering plants are divided into the monocots and eudicots according to the number of cotyledons in the seed, the arrangement of vascular tissue in roots, stems, and leaves, and the number of flower parts.

### 24.2 Tissues of Flowering Plants

Flowering plants have apical meristem plus three types of primary meristem. Protoderm produces epidermal tissue. In the roots, epidermal cells bear root hairs; in the leaves, the epidermis contains guard cells. In a woody stem, epidermis is replaced by periderm.

Ground meristem produces ground tissue. Ground tissue is composed of parenchyma cells, which are thin-walled and capable of photosynthesis when they contain chloroplasts. Collenchyma cells have thicker walls for flexible support. Sclerenchyma cells are hollow, nonliving support cells with secondary walls fortified by lignin.

Procambium produces vascular tissue. Vascular tissue consists of xylem and phloem. Xylem contains two types of conducting cells: vessel elements and tracheids. Vessel elements, which are larger and have perforation plates, form a continuous pipeline from the roots to the leaves. In elongated tracheids with tapered ends, water must move through pits in end walls and side walls. Xylem transports water and minerals. In phloem, sieve tubes are composed of sieve-tube members, each of which has a companion cell. Phloem transports sucrose and other organic compounds including hormones.

### 24.3 Organization and Diversity of Roots

A root tip has a zone of cell division (containing the primary meristems), a zone of elongation, and a zone of maturation.

A cross section of a herbaceous eudicot root reveals the epidermis, which protects; the cortex, which stores food; the endodermis, which regulates the movement of minerals; and the vascular cylinder, which is composed of vascular tissue. In the vascular cylinder of a eudicot, the xylem appears star-shaped, and the phloem is found in separate regions, between the points of the star. In contrast, a monocot root has a ring of vascular tissue with alternating bundles of xylem and phloem surrounding the pith.

Roots are diversified. Taproots are specialized to store the products of photosynthesis; a fibrous root system covers a wider area. Prop roots are adventitious roots specialized to provide increased anchorage.

### 24.4 Organization and Diversity of Stems

The activity of the shoot apical meristem within a terminal bud accounts for the primary growth of a stem. A terminal bud contains internodes and leaf primordia at the nodes. When stems grow, the internodes lengthen.

In a cross section of a nonwoody eudicot stem, epidermis is followed by cortex tissue, vascular bundles in a ring, and an inner pith. Monocot stems have scattered vascular bundles, and the cortex and pith are not well defined.

Secondary growth of a woody stem is due to vascular cambium, which produces new xylem and phloem every year, and cork cambium, which produces new cork cells when needed. Cork, a part of the bark, replaces epidermis in woody plants. In a cross section of a woody stem, the bark is all the tissues outside the vascular cambium. It consists of secondary phloem, cork cambium, and cork. Wood consists of secondary xylem, which builds up year after year and forms the annual rings.

Stems are diverse. There are horizontal aboveground and underground stems. Corms and some tendrils are also modified stems.

### 24.5 Organization and Diversity of Leaves

The bulk of a leaf is mesophyll tissue bordered by an upper and lower layer of epidermis; the epidermis is covered by a cuticle and may bear trichomes. Stomata tend to be in the lower layer. Vascular tissue is present within leaf veins. Leaves are diverse: The spines of a cactus are leaves. Other succulents have fleshy leaves. An onion is a bulb with fleshy leaves, and the tendrils of peas are leaves. The Venus's flytrap has leaves that trap and digest insects.



## understanding the terms

adventitious root 442	parenchyma 438
annual ring 447	perennial 434
apical meristem 440	pericycle 441
axillary bud 435	periderm 437
bark 446	petiole 435
blade 435	phloem 439
Casparian strip 441	pit 439
collenchyma 438	pith 441
complex tissue 439	primary root 442
cork 437	rhizome 448
cork cambium 437	root cap 440
cortex 441	root hair 437
cotyledon 436	root nodule 442
cuticle 437	root system 434
deciduous 435	sclerenchyma 438
endodermis 441	shoot apical meristem 444
epidermal tissue 437	shoot system 434
epidermis 437, 441	sieve-tube member 439
eudicot 436	spongy mesophyll 450
evergreen 435	stem 435
fibrous root system 442	stolon 448
ground tissue 437	stomata (sing., stoma) 437
herbaceous stem 445	taproot 442
internode 435	terminal bud 444
leaf 435	tracheid 439
leaf vein 439	trichome 437
lenticel 437	vascular bundle 439
lignin 438	vascular cambium 444
meristem 437	vascular cylinder 439
mesophyll 450	vascular tissue 437
monocot 436	vegetative organ 434
mycorrhiza 442	vessel element 439
node 435	wood 446
organ 434	xylem 439
palisade mesophyll 450	

Match the terms to these definitions:

- \_\_\_\_\_ Inner, thickest layer of a leaf; the site of most photosynthesis.
- \_\_\_\_\_ Lateral meristem that produces secondary phloem and secondary xylem.
- \_\_\_\_\_ Seed leaf for embryonic flowering plant; provides nutrient molecules before the leaves begin to photosynthesize.
- \_\_\_\_\_ Stem that grows horizontally along the ground and establishes plantlets periodically when it contacts the soil (e.g., the runners of a strawberry plant).
- \_\_\_\_\_ Vascular tissue that contains vessel elements and tracheids.

## reviewing this chapter

- Name and discuss the vegetative organs of a flowering plant. 434–35
- List five differences between monocots and eudicots. 436
- Epidermal cells are found in what type of plant tissue? Explain how epidermis is modified in various organs of a plant. Contrast an epidermal cell with a cork cell. 437
- Contrast the structure and function of parenchyma, collenchyma, and sclerenchyma cells. These cells occur in what type of plant tissue? 438

- Contrast the structure and function of xylem and phloem. Xylem and phloem occur in what type of plant tissue? 439
- Name and discuss the zones of a root tip. Trace the path of water and minerals across a root from the root hairs to xylem. Be sure to mention the Casparian strip. 440–41
- Contrast a taproot with a fibrous root system. What are adventitious roots? 442
- Describe the primary growth of a stem. 444–45
- Describe cross sections of a herbaceous eudicot, a monocot, and a woody stem. 445–47
- Discuss the diversity of stems by giving examples of several adaptations. 448
- Describe the structure and organization of a typical eudicot leaf. 450
- Note the diversity of leaves by giving examples of several adaptations. 450–51

## testing yourself

Choose the best answer for each question.

- Which of these is an incorrect contrast between monocots (stated first) and eudicots (stated second)?
  - one cotyledon—two cotyledons
  - leaf veins parallel—net veined
  - vascular bundles in a ring—vascular bundles scattered
  - flower parts in threes—flower parts in fours or fives
  - All of these are correct contrasts.
- Which of these types of cells is most likely to divide?
  - parenchyma
  - meristem
  - epidermis
  - xylem
  - sclerenchyma
- Which of these cells in a flowering plant is apt to be nonliving?
  - parenchyma
  - collenchyma
  - sclerenchyma
  - epidermal cells
  - guard cells
- Root hairs are found in the zone of
  - cell division.
  - elongation.
  - maturation.
  - apical meristem.
  - All of these are correct.
- Cortex is found in
  - roots, stems, and leaves.
  - roots and stems.
  - roots and leaves.
  - stems and leaves.
  - roots only.
- Between the bark and the wood in a woody stem, there is a layer of meristem called
  - cork cambium.
  - vascular cambium.
  - apical meristem.
  - the zone of cell division.
  - procambium preceding bark.
- Which part of a leaf carries on most of the photosynthesis of a plant?
  - epidermis
  - mesophyll
  - epidermal layer
  - guard cells
  - Both a and b are correct.
- Annual rings are the
  - internodes in a stem.
  - rings of vascular bundles in a monocot stem.
  - layers of xylem in a woody stem.
  - bark layers in a woody stem.
  - Both b and c are correct.