

CHAPTER OUTLINE

Plant Tissues 32
 Meristems 32
 Dermal Tissue 32
 Ground Tissue 32
 Vascular Tissue 33

Plant Organs 35
 Stems 35
 Roots 37

A CLOSER LOOK 3.1 Studying
 Ancient Tree Rings 38
 Leaves 39

A CLOSER LOOK 3.2 Plants That
 Trap Animals 42

Vegetables: Edible Plant Organs 44
 Carrots 44

A CLOSER LOOK 3.3 Supermarket
 Botany 45
 Lettuce 45
 Radishes 45
 Asparagus 46

Chapter Summary 47
Review Questions 47
Further Reading 48

KEY CONCEPTS

1. Tissues are groups of cells that perform a common function and have a common origin and structure.
2. Flowering plants are made up of three basic tissue types: dermal, ground, and vascular.
3. These tissues make up the vegetative organs of higher plants: roots, stems, and leaves.



CHAPTER

3

The Plant Body

Nepenthes is a group of carnivorous vines from the Asian tropics that forms pitchers, modified leaves that can trap and digest a variety of animals.

The earliest life forms were unicellular, and that single cell was capable of carrying out all the necessary functions of life. When multicellular organisms evolved, certain cells became specialized in structure and function, leading to a division of labor. Groups of specialized cells performing specific functions are usually referred to as **tissues**. In flowering plants, various tissues compose the familiar organs: roots, stems, and leaves.

PLANT TISSUES

Meristems

All flowering plants are multicellular, with the cells all originating from regions of active cell division. These regions are known as **meristems**. Plant growth is localized in meristems. The cells originating from meristems give rise to the various tissue types that make up a plant, such as the cells of the epidermis that form the protective layer in a plant. The three basic tissue types in higher plants are **dermal**, **ground**, and **vascular**.

Apical meristems are located at the tips of all roots and stems and contribute to the increase in length of the plant. Tissues that develop from these apical meristems are part of the **primary growth** of the plant and give rise to the leaves and nonwoody stems and roots. Some plants have additional meristematic tissues that contribute to increases in diameter. These are the **vascular cambium** and **cork cambium**. Tissues developing from them are considered part of the plant's **secondary growth** (fig. 3.1).

Dermal Tissue

Dermal tissues are the outermost layers in a plant. In young plants and nonwoody plant parts, the outermost surface is the **epidermis** (fig. 3.2a). It is usually a single layer of flattened cells. Epidermal cells in leaves and stems secrete **cutin**, a wax-like substance that makes up the **cuticle** on the external surface. The cuticle prevents evaporative water loss from the plant by acting as a waterproof barrier. In many leaves, the cuticle is so thick that the leaf has a shiny surface; this is especially true in succulents such as the jade plant and tropical plants such as philodendron.

In some plants, **hairs (trichomes)** may be present on the epidermis (fig. 3.2b). Although usually microscopic, they may be abundant enough to give a fuzzy appearance and texture to leaves or stems. Trichomes may also be glandular, often imparting an aroma when they are brushed, as you can experience by rubbing a geranium or tomato leaf.

Scattered through the leaf epidermis are pores known as **stomata** (sing., **stoma**). Gases such as carbon dioxide, oxygen, and water vapor are exchanged through these stomata. A pair of sausage-shaped cells, **guard cells**, occur on either side of the pore and regulate the opening and closing of each stoma (fig. 3.2a). The guard cells are the only epidermal cells with chloroplasts. Stomata and guard cells can also be found in the epidermis of some stems.

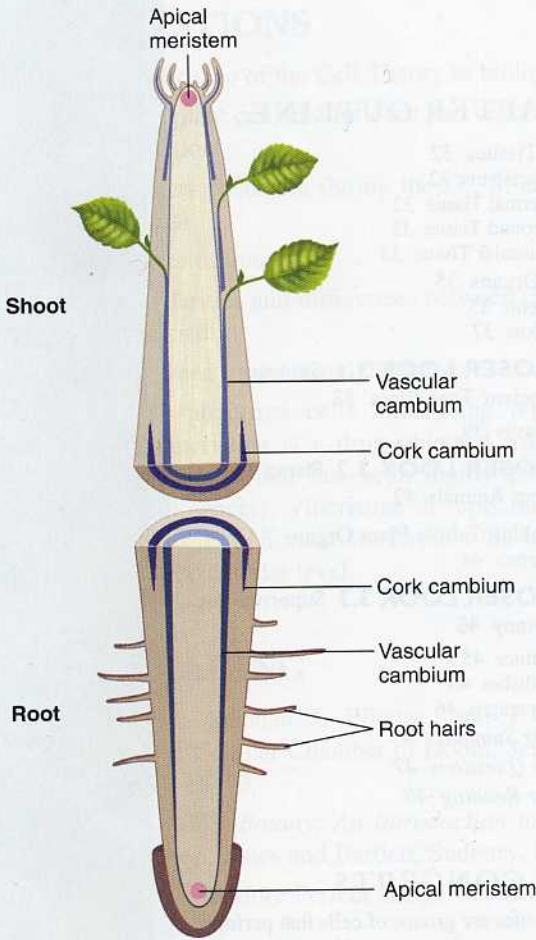


Figure 3.1 Plant meristematic tissues in a diagram of a shoot tip and root tip. Apical meristems contribute to increases in the length of the plant, or primary growth. Vascular cambium and cork cambium are present in plants that have secondary growth, an increase in the girth of the plant body.

In plant parts that become woody, the epidermis cracks and is replaced by a new surface layer, the **periderm**, which is continuously produced by the cork cambium as the tree increases in girth. The periderm, which consists of cork cells, the cork cambium, and sometimes other cells, makes up the outer bark seen on mature trees (fig. 3.2c). In fact, the cork in wine bottles is the periderm from *Quercus suber*, the cork oak tree native to the western Mediterranean. Cork is principally made up of dead cells whose walls contain **suberin**, another waterproofing fatty substance. It prevents water loss and protects underlying tissues (see Chapter 18).

Ground Tissue

Ground tissues make up the bulk of nonwoody plant organs and perform a variety of functions. The three categories of ground tissue are **parenchyma**, **collenchyma**, and **sclerenchyma**. The most versatile of these is parenchyma. Although often described as a thin-walled 14-sided polygon, parenchyma cells can be almost any shape or

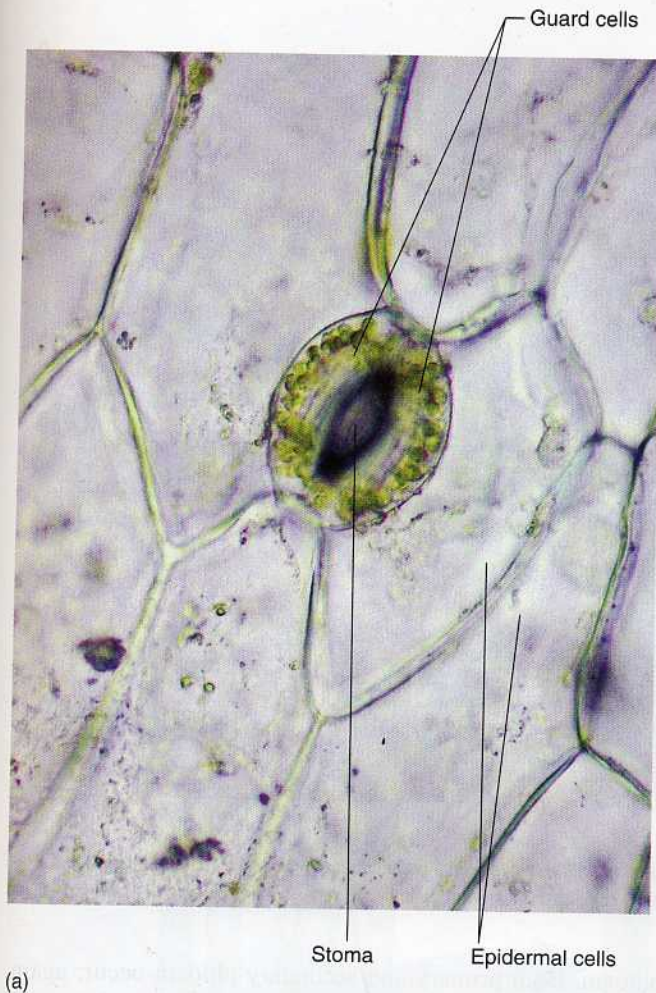
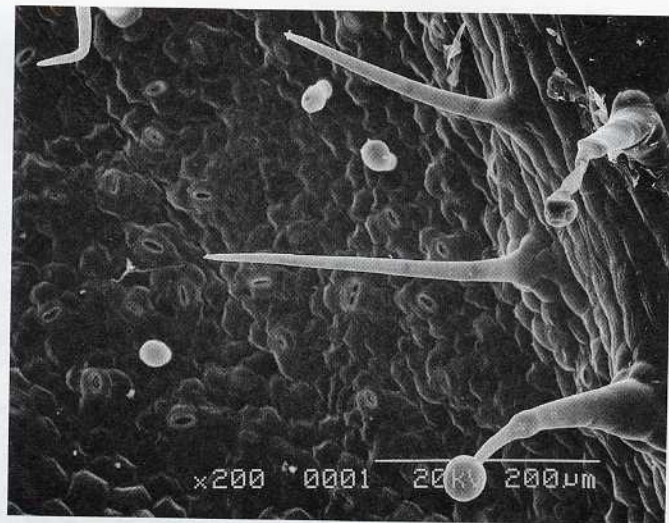
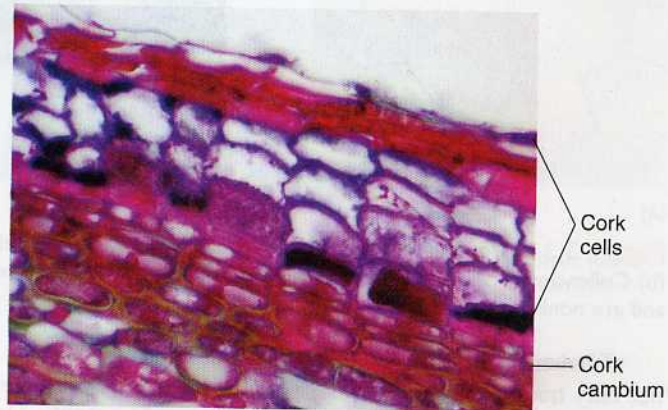


Figure 3.2 Dermal Tissues. (a) Leaf epidermis contains stomata for gas exchange. (b) Trichomes. (c) Periderm is a complex tissue consisting of a thick outer layer of cork cells that arise from the cork cambium.



(b)



(c)

size. Usually parenchyma tissue is loosely arranged, with many intercellular spaces. Parenchyma cells are capable of performing many different functions (fig. 3.3a). They are the photosynthetic cells in leaves and green stems and the storage cells in all plant organs. The starch in potato tubers, the water in cactus stems, and the sugar in sugar beet roots are all stored in parenchyma cells.

Collenchyma cells are the primary support tissue in young plant organs. They can be found in stems, leaves, and petals. Collenchyma cells are elongated cells with unevenly thickened primary cell walls, often with the walls thickest at the corners (fig. 3.3b). They are found tightly packed together just below the epidermis. The tough strings in celery are actually strands of collenchyma cells.

Sclerenchyma tissue has two cell types: fibers and sclereids. Like collenchyma cells, the fibers are elongated cells that function in support. Unlike collenchyma, they are nonliving at maturity and have thickened secondary walls (fig. 3.3c). For centuries, people have used leaf and stem fibers from many plants in the making of cloth and rope (see Chapter 18). Sclereids have many shapes but are seldom elongate like fibers. The major function of these cells is to

provide mechanical support and protection. The extremely thick secondary walls of sclereids account for the hardness in walnut shells and the grit of pear fruit.

Vascular Tissue

Vascular tissues are the conducting tissues in plants. You can readily see the vascular tissues in a leaf; they are the **veins**. The vascular tissues form a continuum throughout the plant, allowing the unrestricted movement of materials. There are two types: **xylem**, which conducts water and minerals from the roots upward, and **phloem**, which transports organic materials synthesized by the plant. Both xylem and phloem are complex tissues composed of several cell types.

Tracheids and **vessel elements** are the water-conducting cells in the xylem. Both cell types have secondary walls, and at maturity, these cells are dead and consist only of cell walls. Tracheids are long, thin cells with tapering ends and numerous pits in the walls; these cells also function in support. Vessel elements are usually shorter and wider and often have horizontal end walls with large openings. Like the tracheids, the side walls have numerous pits. Vessel elements are attached end to end to form a long, pipelike **vessel** (fig. 3.4a).

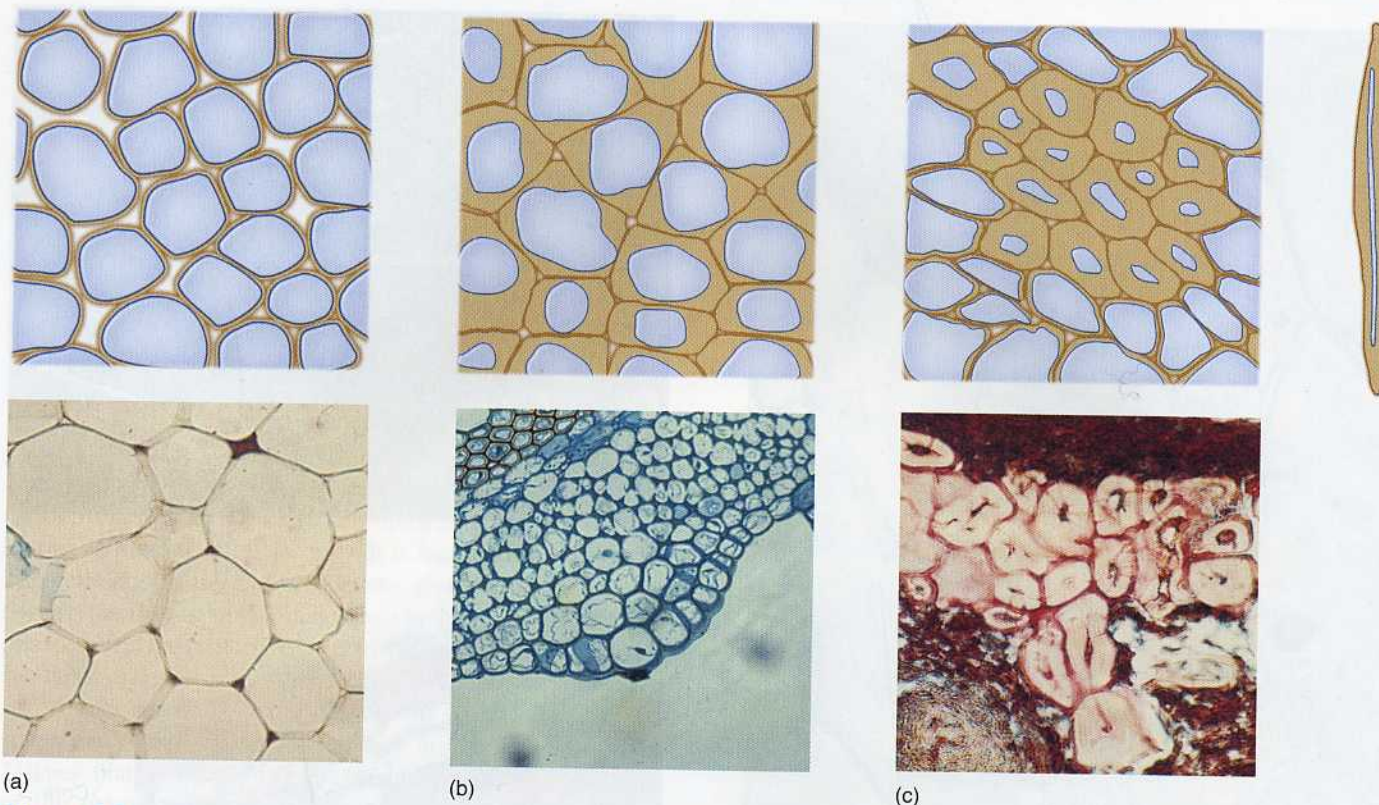


Figure 3.3 Ground tissues. (a) Parenchyma cells are the most abundant plant tissue type and have characteristically thin cell walls. (b) Collenchyma cells have primary cell walls that are thickest at the corners. (c) Sclerenchyma cells have very thick secondary cell walls and are nonliving.

Tracheids and vessel elements are found in angiosperms, but only tracheids occur in other plants with vascular tissue. Fibers are present in the xylem, where they provide additional support. Parenchyma cells, which also occur in the xylem, are the only living and metabolically active cells in this tissue.

Xylem can be either primary or secondary; primary xylem originates from the apical meristem whereas secondary xylem comes from the vascular cambium. In trees, secondary xylem is very extensive; it is what we call wood.

The cells involved in the transport of organic materials in the phloem are the **sieve tube members**. Unlike the conducting cells in the xylem, the sieve tube members are living cells with only primary walls. But they are unusual living cells because the nucleus and some organelles degenerate as the sieve tube member matures. The end walls of these cells have several to many large pores and are called **sieve plates**. They allow plasmodesmata, cytoplasmic connections, to occur between adjacent sieve tube members and provide channels for conduction. The column of connected sieve tube members is referred to as a **sieve tube** (fig. 3.4b).

Adjoining each sieve tube member is a **companion cell**, which is physiologically and developmentally related to its sieve tube member. The smaller companion cell has a large nucleus that controls the adjacent sieve tube member through the numerous plasmodesmata that connect the two cells. The companion cells are involved in the loading and unloading of organic materials for transport. As in the xylem, both fibers and parenchyma cells are found in the

phloem. Both primary and secondary phloem occur; again, the primary phloem is produced by the apical meristem and the secondary by the vascular cambium. Table 3.1 is a summary of these plant tissues.



Table 3.1
Plant Tissues

Tissue Type	Cell Types	Function
Dermal		
Epidermis	Epidermal cells	Protection
Periderm	Cork cells	Protection
Ground		
Parenchyma	Parenchyma cells	Storage, photosynthesis
Collenchyma	Collenchyma cells	Support
Sclerenchyma	Sclereids, fibers	Support, protection
Vascular		
Xylem	Tracheids, vessel elements, fibers, parenchyma	Water conduction, support
Phloem	Sieve tube members, companion cells, fibers, parenchyma	Food transport

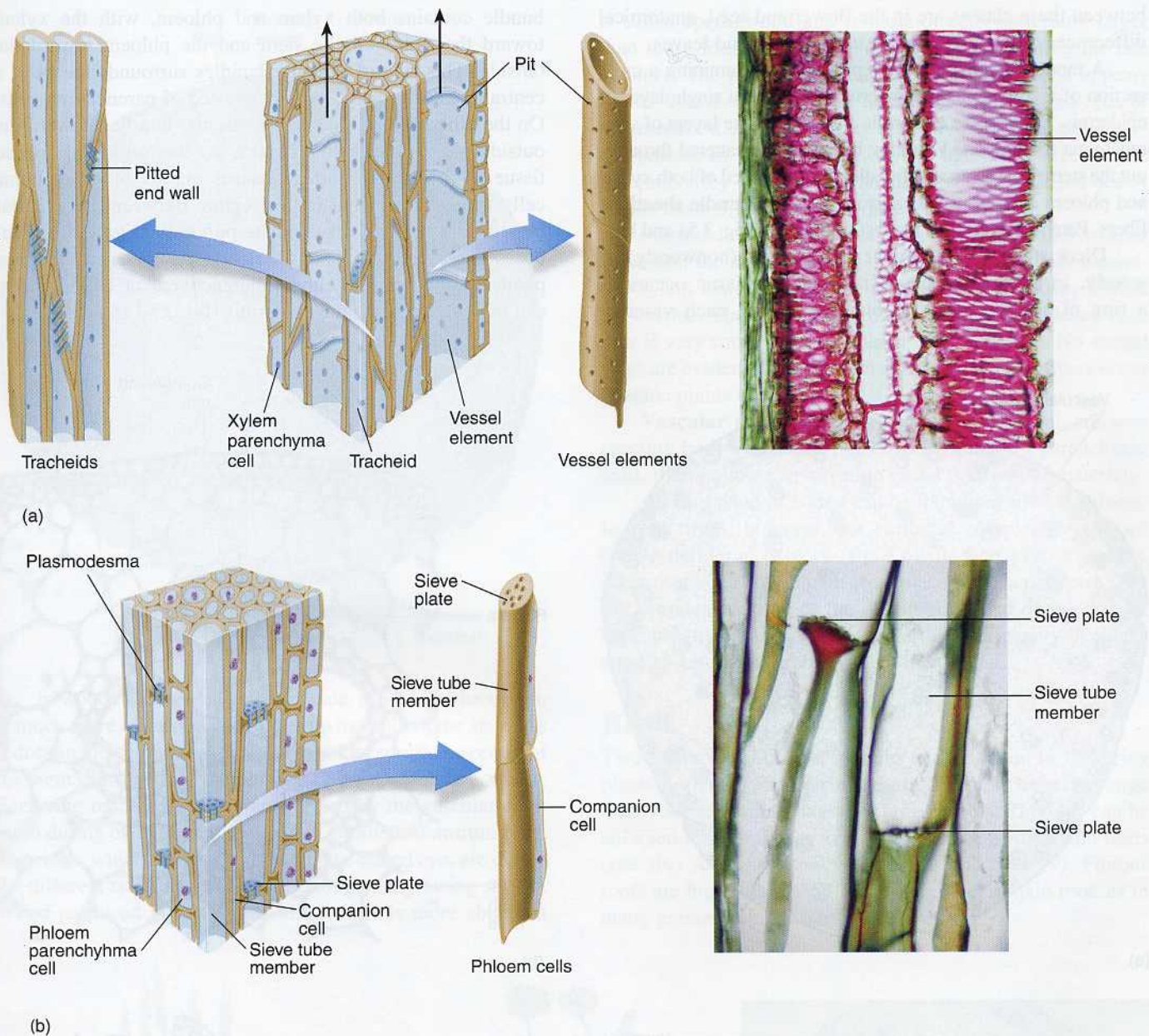


Figure 3.4 (a) Xylem. The conducting cells of xylem are tracheids and vessel elements. (b) Phloem. Sugars are loaded by companion tube members for transport.

Concept Quiz

Xylem and phloem are the vascular, or conducting, tissues in plants. Xylem conducts water and dissolved minerals whereas phloem conducts organic materials.

How do the conducting cells of xylem (vessel elements and tracheids) differ from the sieve tube members and companion cells in phloem?

PLANT ORGANS

The principal vegetative organs of flowering plants are stems, roots, and leaves. Roots anchor the plant and absorb water and nutrients from the soil; stems support the plant and transport both water and organic materials; and leaves are the main photosynthetic structures.

Stems

Recall that angiosperms are divided into two classes of plants, the dicots and the monocots. Although the major differences

between these classes are in the flower and seed, anatomical differences can also be seen in stems, roots, and leaves.

A monocot stem is best exemplified by examining a cross section of a corn stem. The outermost tissue is a single layer of epidermis. Beneath the epidermis are two to three layers of sclerenchyma for support. **Vascular bundles** are scattered throughout the stem. These vascular bundles are composed of both xylem and phloem and are usually surrounded by a **bundle sheath** of fibers. Parenchyma fills in the rest of the stem (fig. 3.5a and b).

Dicot stems can be either **herbaceous** (nonwoody) or **woody**. In herbaceous dicots the vascular tissue occurs as a ring of separate vascular bundles. Again, each vascular

bundle contains both xylem and phloem, with the xylem toward the center of the stem and the phloem toward the outside. This ring of vascular bundles surrounds the **pith**, a central area of ground tissue composed of parenchyma cells. On the other side of the ring of vascular bundles, toward the outside of the stem, is the **cortex**, another region of ground tissue. Although the cortex consists mainly of parenchyma cells, fibers often occur in this region. Between the vascular bundles, the ground tissue of the pith and cortex is continuous. The outermost layer of the stem is the epidermis. In some plants, support tissue, either sclerenchyma or collenchyma, can be found beneath the epidermis (fig. 3.5c and d).

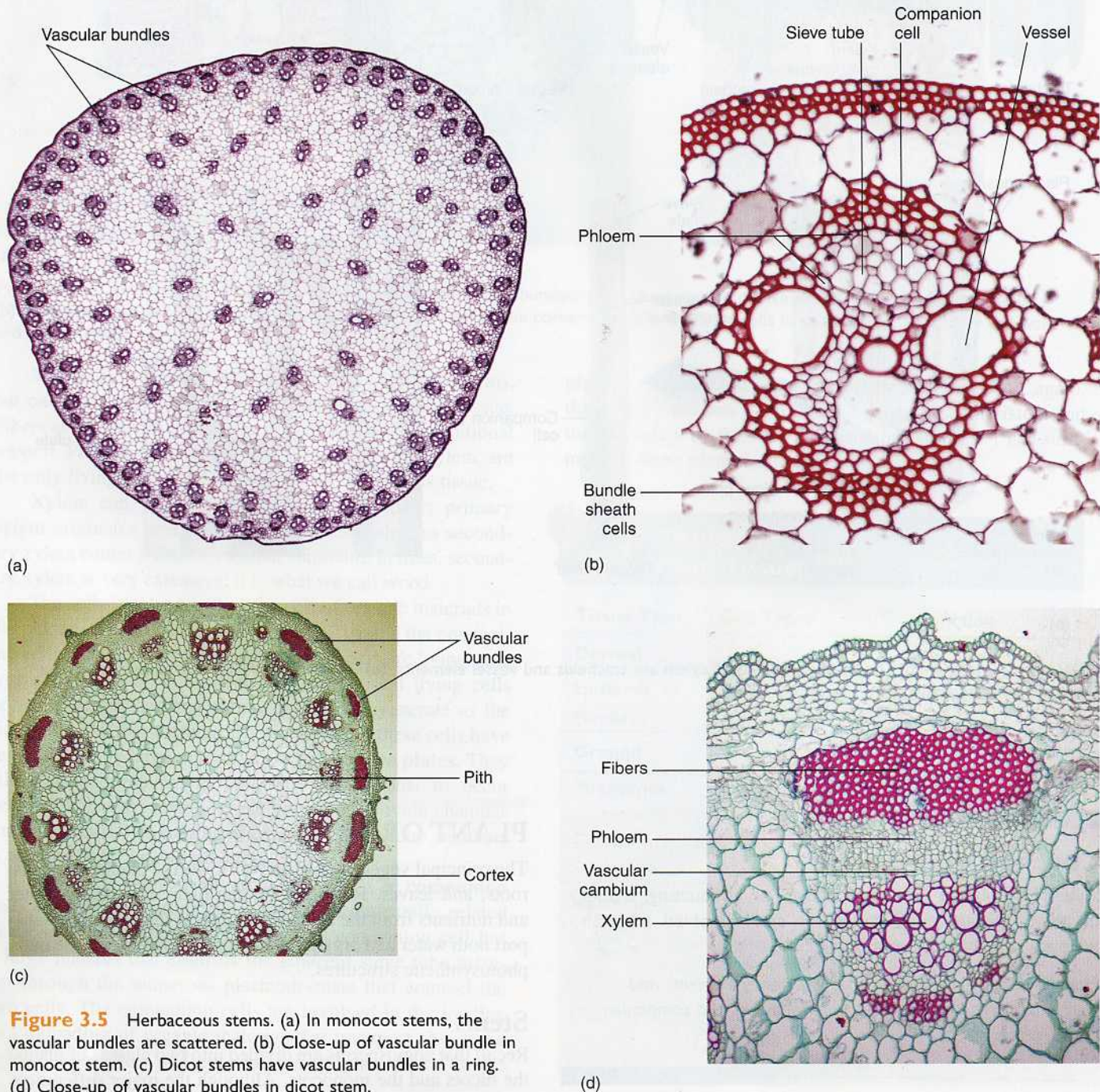
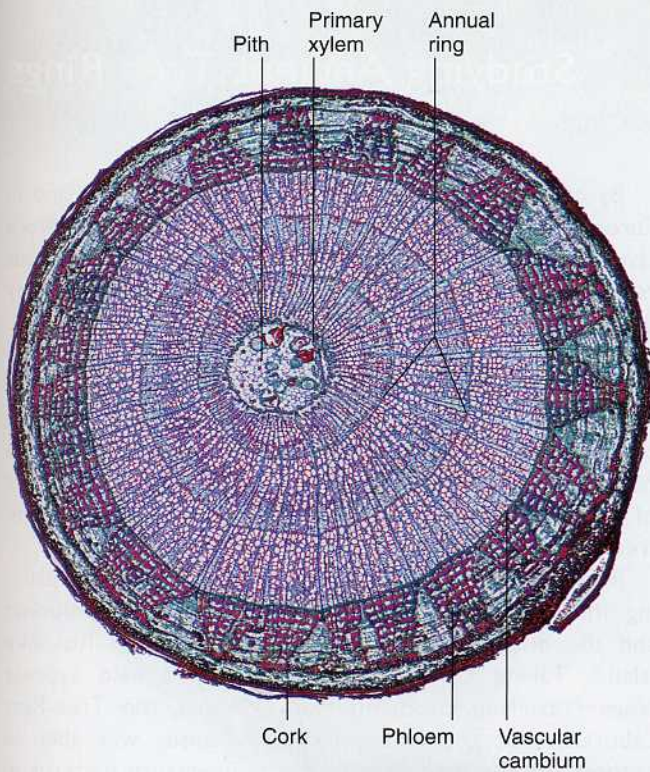


Figure 3.5 Herbaceous stems. (a) In monocot stems, the vascular bundles are scattered. (b) Close-up of vascular bundle in monocot stem. (c) Dicots have vascular bundles in a ring. (d) Close-up of vascular bundles in dicot stem.



In woody dicots the vascular tissue, especially the xylem, is much more extensive and makes up the bulk of the stem. As it does in the herbaceous dicots, the pith occupies the center of the stem. Surrounding the pith are rings of secondary xylem. Each ring represents the xylem formed by the vascular cambium during one growing season and is called an **annual ring**. The rings, which are easily visible to the naked eye, are due to the different sizes of cells formed through the growing season. Wood produced in the spring when water is more abundant

is called **springwood** and consists of cells noticeably larger than those found in **summerwood**, produced during the late summer. The portion of each ring with springwood appears lighter than the area with the smaller, densely packed cells of summerwood. Since each ring typically represents one growing season, in temperate regions the age of the tree can be determined by counting the annual rings (fig. 3.6 and see A Closer Look 3.1—Studying Ancient Tree Rings).

Surrounding the outermost ring of xylem is the vascular cambium, the meristematic tissue that produces both secondary xylem toward the inside and secondary phloem toward the outside. The amount of secondary phloem produced each year is very small when compared with the xylem. No annual rings are evident in the phloem although bands of fibers occur in some plants (fig. 3.6).

Vascular rays, resembling spokes of a wheel, are seen crossing both xylem and phloem. Composed of parenchyma cells, these rays are involved in radial transport of materials.

A small band of cortex can be found outside the phloem. In older trees, however, the cortex is completely replaced by the periderm, or cork (fig. 3.6). In fact, even the older, outermost layers of phloem are replaced by the periderm. The thickness and texture of the periderm depend on the type of tree, and the periderm varies from thin and papery in cherry or paper birch to extremely thick in cork oak.

Roots

Two major types of root systems can be found in flowering plants: **taproots** and **fibrous roots**. Taproots have one large main root with small lateral or branch roots. Taproots can be enlarged for storage, as evident in carrots, turnips, and beets (see also A Closer Look 4.2—Sugar and Slavery). Fibrous roots are highly branched and lack a central main root, as in many grasses (fig. 3.7).

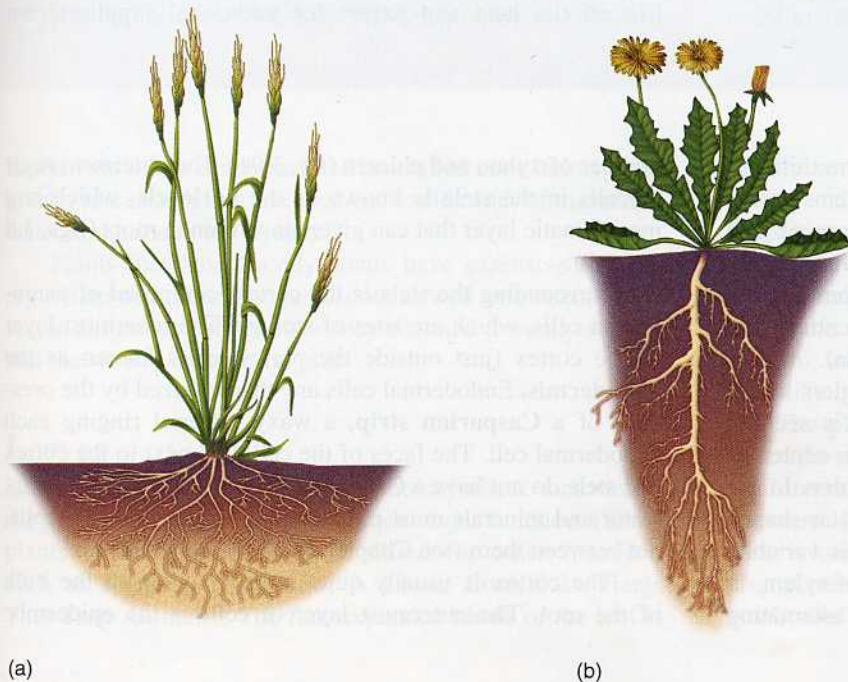


Figure 3.7 Root systems. (a) The fibrous root system of barley. (b) The taproot of a dandelion.



A CLOSER LOOK 3.1

Studying Ancient Tree Rings

The study of tree rings is known as **dendrochronology** and is of value to fields as diverse as astronomy, ecology, and anthropology. The science began in the early twentieth century by Andrew Douglass in Arizona. Douglass, an astronomer, frequently visited logging camps to study the annual ring patterns on tree stumps. The size of a ring can indicate climatic conditions that existed when the ring was formed (box fig. 3.1). A very narrow ring may indicate a year of low rainfall or drought whereas a wide ring may indicate abundant rainfall. Douglass wondered if the climatic changes brought about by the 11-year cycle of sunspots was evident in tree-ring patterns. Although Douglass did not find the answer to the sunspot question, he did see that tree-ring patterns from different areas throughout northern Arizona showed the same patterns of wide and narrow rings.

Douglass continued the study of tree rings for many years. By matching patterns from living trees, remains of fallen trees, and wood samples from Pueblo ruins, Douglass was able to date all the ancient pueblos throughout the Southwest. In 1937, Douglass founded the Laboratory of Tree Ring Research at the University of Arizona. Today, this laboratory is still a major world center for tree-ring study.

Conditions in Arizona are ideal for this type of study. Since rainfall is always limiting for tree growth, a small change in the weather will have a great effect on the width of the tree ring. Also, the arid climate prevents the decay of dead trees and wooden artifacts. In fact, in the Southwest, scientists have been able to construct a chronology of tree rings going back approximately 9,000 years.

By contrast, in other areas of the United States and in Europe, tree-ring analysis is more difficult because more favorable growing conditions that are relatively consistent result in more uniform tree rings. Also, when trees die they decay in the moister environment.

Another aspect of tree-ring research is **dendroclimatology**. By studying the annual rings of very old trees, scientists have been able to reconstruct major climatic changes of the past. Tree-ring specialists are trying to determine if droughts occur in a cyclic pattern. Others are looking at the effects of pollution, pests, forest fires, volcanoes, or earthquakes on tree rings.

Recently, tree-ring data have provided insight in explaining the high mortality of the first Jamestown colonists and the disappearance of the Lost Colony of Roanoke Island. Taking cores from 800-year old bald cypress trees (*Taxodium distichum*) from Virginia, the Tree-Ring Laboratory at the University of Arkansas was able to reconstruct the precipitation and temperature patterns in the region from A.D. 1185 to 1984. They discovered that the last sighting of the settlers at Roanoke Island off the North Carolina coast in August 1587 coincided with the beginning of an extreme drought (1587–1589), the driest period in 800 years. Similarly, the Jamestown colonists had the misfortune to begin their settlement in April 1607 during the driest 7-year period (1606–1612) in over 770 years. These studies suggest that the disappearance of the Lost Colony at Roanoke Island and the 80% mortality of colonists during the establishment of Jamestown were in part due to the drought. Both colonies had planned to live off the land and barter for additional supplies from

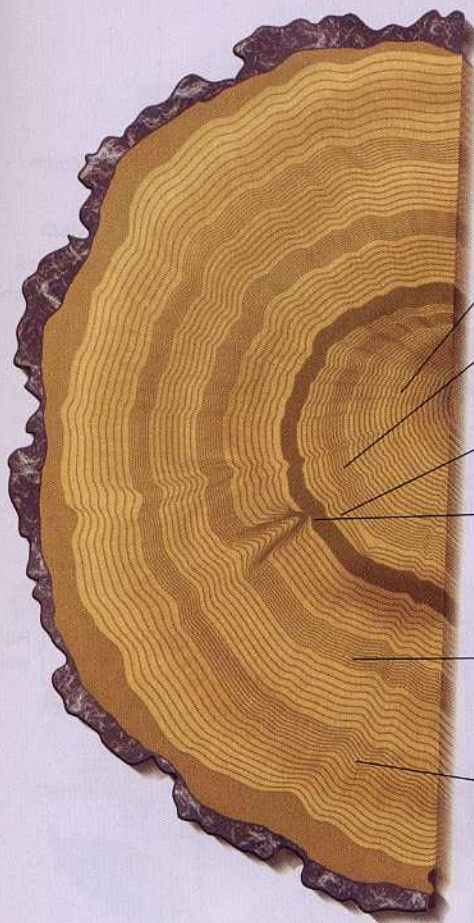
At the tips of all main roots or branch roots are thimble-shaped **root caps**, which protect the root meristems as the roots grow through the soil. The meristem (**zone of cell division**) accounts for primary growth in roots. Just behind the meristem, the newly formed cells elongate considerably (**zone of elongation**) before they begin to differentiate into the various tissues that constitute the root (fig. 3.8a).

A cross section of a dicot root in the region where cells have differentiated (**zone of maturation**) is seen in Figure 3.8b. The vascular tissue is found in the center of the root, making up the **stele**, or **vascular cylinder**. In the very center of the stele is the xylem, usually in a star-shaped configuration. The number of arms of this star is variable, with bundles of phloem found between the arms of xylem. In monocot roots, a pith is present that is encircled by alternating

bundles of xylem and phloem (fig. 3.9a). The outermost layer of cells in the stele is known as the **pericycle**, which is a meristematic layer that can give rise to branch roots (figs. 3.8 and 3.9).

Surrounding the stele is the cortex, composed of parenchyma cells, which are sites of storage. The innermost layer of the cortex (just outside the pericycle) is known as the **endodermis**. Endodermal cells are characterized by the presence of a **Casparian strip**, a waxy material ringing each endodermal cell. The faces of the cell wall next to the cortex and stele do not have a Casparian strip. Because of this strip, water and minerals must pass through the endodermal cells, not between them (see Chapter 4).

The cortex is usually quite large, making up the bulk of the root. The outermost layer of cells is the epidermis.



1914

When the tree was 6 years old, something pushed against it, making it lean. The rings are now wider on the lower side, as the tree builds "reaction wood" to help support it.

1924

The tree is growing straight again. But its neighbors are growing too, and their crowns and root systems take much of the water and sunshine the tree needs.

1927

The surrounding trees are harvested. The larger trees are removed and there are once again ample nourishment and sunlight. The tree can grow rapidly again.

1930

A fire sweeps through the forest. Fortunately, the tree is only scarred, and year by year more and more of the scar is covered over by newly formed wood.

1942

These narrow rings may have been caused by a prolonged dry spell. One or two dry summers would not have dried the ground enough to slow the tree's growth this much.

1957

Another series of narrow rings may have been caused by an insect such as the larva of the sawfly. It eats the leaves and leafbuds of many kinds of coniferous trees.

Box Figure 3.1 The pattern of annual rings is correlated with events in the life of this tree.
Source: St. Regis Paper Company, New York, NY, 1966.

indigenous peoples. This strategy failed as the lack of rainfall caused crops and livestock to die, affecting the food supply not only of the colonists but also of the native peoples. The extreme climatic conditions of 1587–1589 and of 1606–1612, determined by the deciphering of tree-ring

data, can explain the fate of the early colonists in Roanoke and Jamestown.

Overall we know that trees are living histories. Contained within the tissues of the tree is the history of the environment for the year in which a ring was formed.

Extensions of the epidermal cell are called **root hairs**; these greatly increase the surface area and are the sites of maximum water and mineral absorption.

Plants that have woody stems have extensive secondary xylem and annual rings in roots as well as in stems. One major difference between a woody root and a woody stem is that the woody root has no pith.

Leaves

Leaves have often been called the photosynthetic factories of the plant since photosynthesis is their major function. (Some plants have leaves that are modified for other functions such as trapping insects. See A Closer Look 3.2—Plants That Trap Animals.) The flat, expanded **blade** of the leaf is

ideally suited for the photosynthetic process. The **petiole**, or leaf stalk, connects the leaf blade to the stem and transports materials to and from the blade. Some leaves have no petiole; in those cases, the blade is attached directly to the stem. Small paired appendages called **stipules** may be present at the base of the leaf (fig. 3.10a). Stipules are varied in form: in some plants they are leaflike; in others they are thornlike.

The place where the petiole is attached to the stem is called the **node**. The areas of the stem between adjacent nodes are **internodes**. There are three patterns of leaf arrangement on stems. If only one leaf is present at a node, the arrangement is known as **alternate**. If two leaves occur at a node, the arrangement is **opposite**; with three or more, the arrangement is **whorled** (fig. 3.10b).

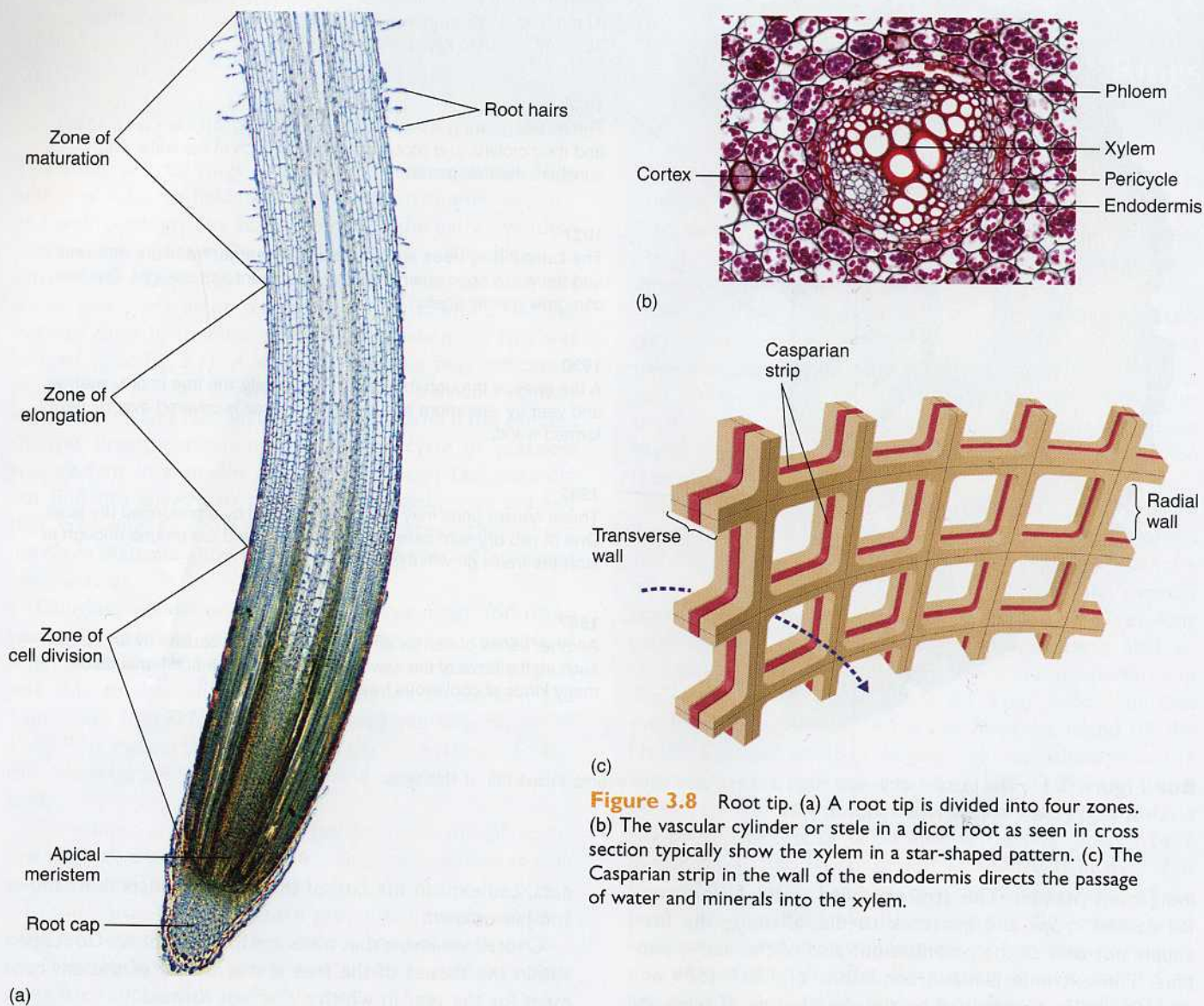


Figure 3.8 Root tip. (a) A root tip is divided into four zones. (b) The vascular cylinder or stele in a dicot root as seen in cross section typically show the xylem in a star-shaped pattern. (c) The Casparian strip in the wall of the endodermis directs the passage of water and minerals into the xylem.

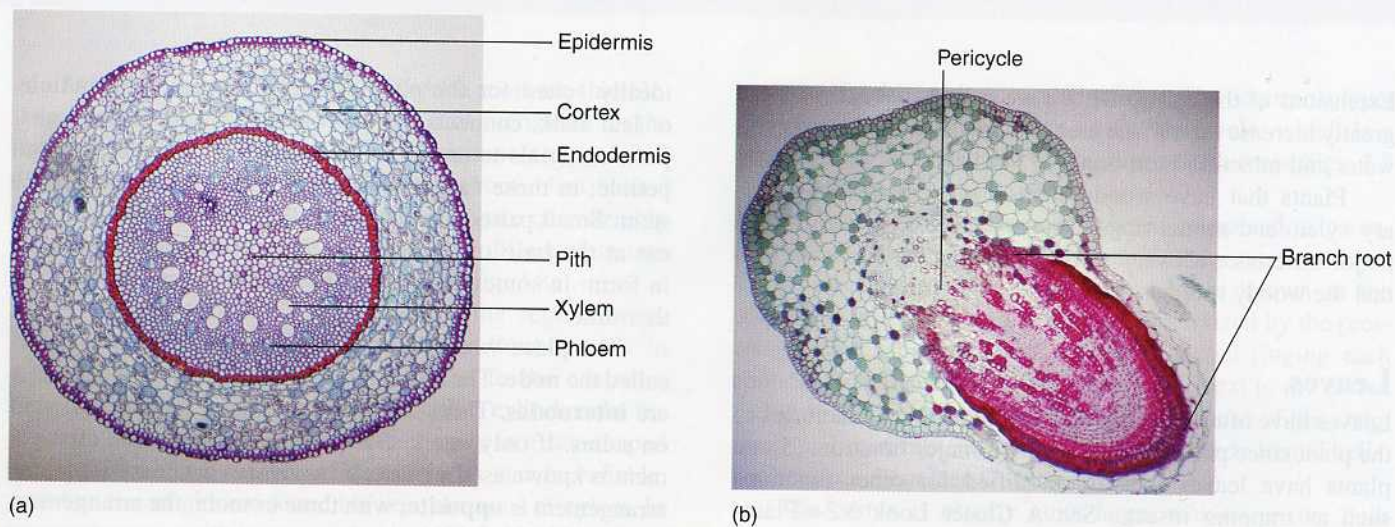


Figure 3.9 (a) The vascular cylinder of monocot roots typically contain a pith. (b) Branch roots originate from the pericycle.

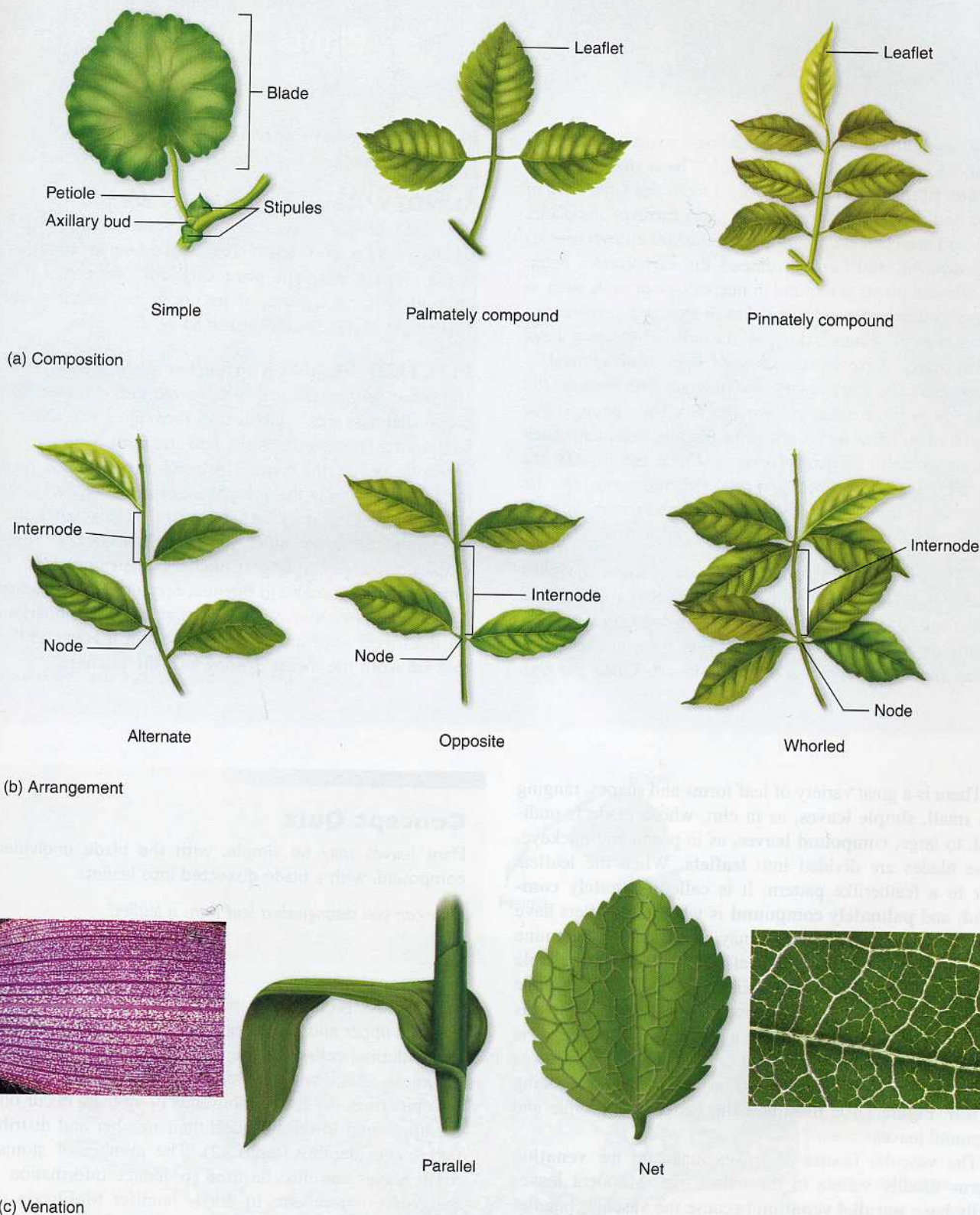


Figure 3.10 Leaf morphology. (a) Leaf composition. Leaves may be simple, consisting of a single undivided blade, or compound, in which the blade is subdivided into leaflets. (b) Leaf arrangement. Alternate, opposite, or whorled indicates the number of leaves coming off a node. (c) Leaf venation. The venation pattern is commonly parallel in monocot leaves and net in dicot leaves.



A CLOSER LOOK 3.2

Plants That Trap Animals

Usually, the natural order is for animals to eat plants, but with some plants, tables are turned. These are the **carnivorous plants**. Although Audrey II from the *Little Shop of Horrors* had a taste for human flesh, most carnivorous plants “snack” on insects. Out of more than 250,000 known species of angiosperms, 400 have developed the carnivorous habit. Most of these plants are found in nutrient-poor soils such as acid freshwater bogs, and it is believed that this carnivorous trait supplies nutrients lacking in the soil. The plants have been reported to grow with renewed vigor after a “meal.”

Since plants are stationary and animals are motile, the plants have evolved elaborate traps to lure their prey. These traps are all modified leaves that offer various incentives such as nectar or color to attract insects. Once the insects are ensnared, digestive enzymes are released, and soon only the empty shell of the insect remains. There are various types of traps; we will consider three of the best known.

VENUS FLYTRAP A native to the North Carolina coastal region, *Dionaea muscipula* has a trap that imprisons its victims (box fig. 3.2a). Each leaf is a two-sided trap with trigger hairs on each side. When the trigger hairs are touched, the trap snaps shut tightly around the insect. Once the trap

has closed, digestive enzymes begin their job. After a few days the trap opens, ready for another unsuspecting insect.

SUNDEW Sundews, *Drosera* spp., are small plants that use flypaper-like leaves to trap insects (box fig. 3.2b). Glandular hairs on the leaf surface produce an adhesive that is the “superglue of the plant kingdom.” An insect that has been lured to the plant for its nectar or by its coloration sticks tight and is soon digested away.

PITCHER PLANTS In pitcher plants, *Sarracenia* spp. and other genera, the leaf has evolved into a vase or pitcher shape that acts like a pitfall trap (box fig. 3.2c). Once lured to the pitcher, the insects slip into the pool of rainwater that has collected at the base. The pool also contains digestive juices that eat away the soft parts of the insect. At the end of a season, a pitcher may be filled with the indigestible shells of its many victims. *Nepenthes*, vines found throughout the Asian tropics, produce the largest pitchers. *Nepenthes rajah*, found only on two mountains in Borneo, produces pitchers that are a foot deep. Another *Nepenthes* species grows in large mats on the forest floor and appears to digest leaves and flowers that fall from the forest canopy into the pitchers.

There is a great variety of leaf forms and shapes, ranging from small, **simple leaves**, as in elm, whose blade is undivided, to large, **compound leaves**, as in pecan and buckeye, whose blades are divided into **leaflets**. When the leaflets occur in a featherlike pattern, it is called **pinnately compound**, and **palmately compound** is when the leaflets have a common attachment. Often, it may be difficult to determine whether you are looking at a leaf or a leaflet. One reliable indicator is the position of the axillary bud. The upper angle that forms between the top surface of a leaf and the stem is called the **axil**, and it is here that a **bud** (embryonic shoot) is located. Axillary buds are found only at the base of leaves (fig. 3.10a), so if you see an axillary bud you are looking at a leaf. Figure 3.10a illustrates the varieties of simple and compound leaves.

The vascular tissues of leaves make up the **venation** patterns usually visible to the naked eye. Monocot leaves usually have **parallel venation** because the vascular bundles are arranged in parallel lines running the length of the blade. In contrast, dicots have **net**, or **reticulate, venation**, in which the vascular tissue is highly branched, forming a network throughout the blade (fig. 3.10c). In late fall or winter you may encounter decaying leaves that have only the vascular tissue remaining as a lacy network.

Concept Quiz

Plant leaves may be simple, with the blade undivided, or compound, with a blade dissected into leaflets.

How can you distinguish a leaf from a leaflet?

A cross section of a blade reveals epidermis covering both the upper and lower leaf surfaces (fig. 3.11). Recall that the epidermal cells are covered by a waxy cuticle of variable thickness. Guard cells and stomata are distributed throughout the epidermis. Although thousands of stomata occur on both the upper and lower surfaces, their number and distribution varies considerably (table 3.2). The number of stomata in fossil leaves can also be used to deduce information about the paleoenvironment. In 2004, Jennifer McElwain of the Field Museum in Chicago, examined the density of stomata in leaves of the California black oak (*Quercus kelloggii*) at different altitudes, from near sea level to elevations of 2,500 meters (8,125 ft). She developed an equation that uses stomatal density to calculate the altitude at which the tree lives and was able to apply this to fossil leaves of the California



(a)



(b)



(c)

Box Figure 3.2 Carnivorous plants. (a) Venus flytrap has guard hairs to prevent prey from escaping. (b) Glandular hairs of the sundew produce a sticky glue. (c) Pitcher plants.

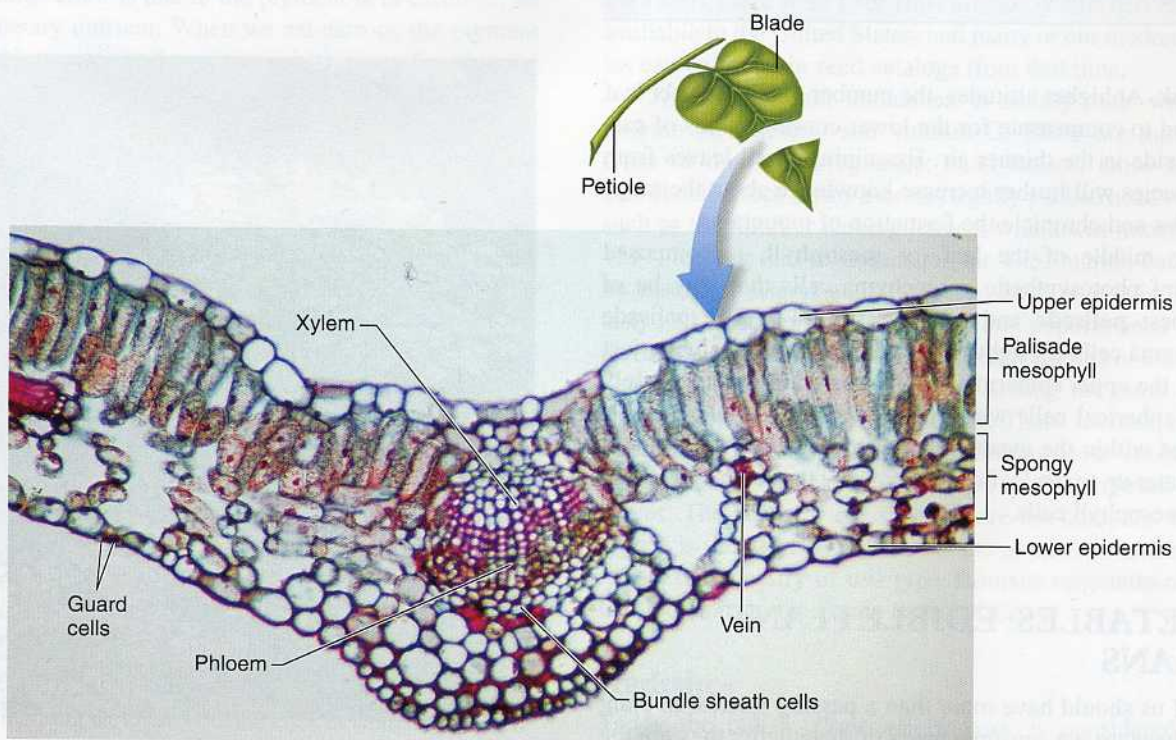


Figure 3.11 Leaf anatomy. Cross section of a leaf illustrates that palisade and spongy cells make up the mesophyll.



Table 3.2 Distribution of Stomata on Leaves of Various Species

Species	Average Number of Stomata per cm ²	
	Upper Epidermis	Lower Epidermis
Apple (<i>Malus pumila</i>)	0	29,400
Black oak (<i>Quercus velutina</i>)	0	58,000
Cabbage (<i>Brassica oleracea</i>)	14,100	22,600
Corn (<i>Zea mays</i>)	5,200	6,800
Geranium (<i>Pelargonium domesticum</i>)	1,900	5,900
Mulberry (<i>Morus alba</i>)	0	48,000
Pea (<i>Pisum sativum</i>)	10,100	21,600
Scarlet oak (<i>Quercus coccinea</i>)	0	103,800
Sunflower (<i>Helianthus annuus</i>)	8,500	15,600
Wheat (<i>Triticum aestivum</i>)	3,300	1,400

black oak. At higher altitudes, the number of stomata per leaf increased to compensate for the lower concentrations of carbon dioxide in the thinner air. Examining fossil leaves from other species will further increase knowledge about the range of species and chronicle the formation of mountains.

The middle of the leaf, or **mesophyll**, is composed mainly of photosynthetic parenchyma cells that may be of two types: **palisade** and **spongy** (fig. 3.11). The palisade parenchyma cells are tightly packed columnar cells lying just beneath the upper epidermis. Spongy parenchyma are loosely packed spherical cells with many large intercellular spaces. Scattered within the mesophyll are the vascular bundles that bring water up to the leaf and carry away the sugars produced by the mesophyll cells.

VEGETABLES: EDIBLE PLANT ORGANS

Most of us should have more than a passing interest in plant organs because we consume many of them daily; they are the vegetables in our diet. Technically, vegetables are edible parts

of the vegetative plant body: stems, roots, leaves, or even flower parts. This definition excludes fruits, which develop from the ovary of a flower and contain seeds. See A Closer Look 3.3—Supermarket Botany, to test your botanical powers of recognition. Interestingly, the legal definitions of fruits and vegetables differ from these botanical definitions. In 1893, the U.S. Supreme Court ruled that tomatoes and similar fruits are legally vegetables since fruits are generally thought of as sweet whereas vegetables are not (see Chapter 6). The debate continues, but we will give the botanical definition priority. Next, we will consider a few examples of some common vegetables, examining their history and folklore.

Carrots

Carrots (*Daucus carota*) are one of the most popular vegetables in the American diet; we each consume about 10 pounds of this root each year. Cutting through a carrot clearly shows the organization of the root, with the stele more deeply pigmented than the surrounding cortex.

Carrots are **biennial** plants; *biennial* means that it takes two years for the plant to complete its life cycle. During the first year, the plant stores a large amount of food in an enlarged taproot that we call the carrot. During the second summer, the plant uses the stored food in the taproot to produce a flowering stalk. Normally, we harvest carrots after the first growing season, but we can see the flowering stalk in the wild carrot, a beautiful summer weed also called Queen Anne's lace. Carrots were first introduced into North America by the early colonists, and Queen Anne's lace is the wild descendant of those first carrots (fig. 3.12).



Figure 3.12 Queen Anne's lace, the flowers of wild carrot.

A CLOSER LOOK 3.3

Supermarket Botany

A trip through the produce section in your neighborhood market is a chance to test your knowledge of plant structure (box fig. 3.3). To play “supermarket botany,” determine what plant organs are represented by the following vegetables:

1. Beet _____
2. Celery _____
3. Cabbage _____
4. Potato _____
5. Water chestnut _____
6. Onion _____
7. Rhubarb _____
8. Pumpkin _____
9. Rutabaga _____
10. Brussels sprouts _____



Box Figure 3.3 The produce section in a market offers a chance to study plant anatomy up close.

Today, we associate the color orange with carrots, but carrots were not always orange. Originally, carrots were purple and branched. It was not until the sixteenth century that a pale yellow variety appeared in western Europe. In the seventeenth century, Dutch plant breeders developed a deep orange carrot that is the ancestor of all orange carrots grown today.

The orange color is due to the pigment beta-carotene, an important dietary nutrient. When we eat carrots, the pigment is converted into vitamin A, a vitamin with many functions in the body. One important role of this vitamin is in night vision. The old wives’ tale may be true: eating carrots may help you see better in the dark. Although vitamin A is necessary for healthy skin, eating too many carrots can turn the skin yellow. This condition is known as carotenemia, a harmless condition that will disappear a few weeks after the person stops eating carrots. Recently, scientific research suggested an additional benefit to eating foods rich in vitamin A; they may lower the risk of developing cancers of the larynx, esophagus, and lung. Current research is also investigating the value of vitamin A as an antioxidant (see Chapter 10).

Carrots also contain sizable amounts of potassium, calcium, phosphorus, and sugar. Their high sugar content has made them the key ingredient in many desserts, such as the familiar carrot cake.

Lettuce

Contemporary Americans seem to have a love affair with lettuce (*Lactuca sativa*). It is the national favorite cold vegetable. This passion is something we share with the ancient Romans, who traditionally began their feasts with a salad of lettuce. The Romans

also believed that lettuce had medicinal values as a soporific (sleep inducer). Lettuce juice and lettuce teas were used for their sedative effects in colonial America; in fact, extracts from wild lettuce were used for this purpose until World War II.

Lettuce was first introduced into the New World by Columbus, who planted some in the West Indies in 1493. By the 1880s, there were over 100 cultivars (cultivated varieties) available in the United States, and many of our modern varieties can be found in seed catalogs from that time.

Nutritionally, the lettuce leaf is mainly water with some vitamin A, calcium, and vitamin C. There are three basic types of this leafy vegetable: head lettuce, loose-leaf, and cos. Head lettuce forms a dense, tightly packed head of leaves such as the familiar iceberg lettuce, which was introduced in 1894. Iceberg lettuce dominates the U.S. market because of its ease in transport and storage, even though it is the least tasty and least nutritious variety. Other popular head lettuces are Boston and Bibb. Many loose-leaf varieties of lettuce can be found in today’s supermarket. Among the most popular are redleaf, oakleaf, and green leaf. These lettuces are non-heading, with their ruffled leaves forming loose clusters. Cos varieties form an upright cylindrical head composed of long leaves. The heads of cos varieties are not compact; romaine lettuce is the most popular. Both the names *cos* and *romaine* reflect the ancestry of this type. Romans originally obtained the lettuce from the Greek Island of Cos.

Radishes

Today the radish, *Raphanus sativus*, is considered just a peppery garnish for salads, but in the past radishes were

Answers:

1. A taproot; almost all root vegetables are taproots.
2. A petiole although the petiole is greatly enlarged and you can see the remains of the blade.
3. Leaves, of course, but actually a whole stem with shortened internodes and tightly packed leaves.
4. An underground stem actually; even buds are present as the “eyes.” See Chapter 14.
5. Another underground stem; see Chapter 14.
6. Underground leaves and stem, but the stem is usually too tough to eat.
7. A petiole again; in this case, knowledge of plant anatomy may save your life, since all other parts of the plant are poisonous.
8. Botanically, it is not a vegetable at all, but a fruit; see Chapter 6.
9. A taproot again; the result of a medieval cross between cabbage and turnip.
10. These are actually axillary or lateral buds that look like miniature cabbages.

enormous, mild-tasting vegetables that were usually cooked. These cooking or winter radishes were valued because they could be easily stored in root cellars through the winter. Our present-day radishes, known as summer radishes, were first developed in the eighteenth century. Containing only potassium and some iron, the summer radish is not particularly nutritious, but it makes an attractive and tasty addition to salad greens.

Botanically, the radish is a composite vegetable consisting of both root and hypocotyl (the base of the stem). Like the carrot, the radish is a biennial that has developed this underground storage organ to fuel the second year's growth.

Although Americans favor the small red globose varieties, radishes come in all shapes, sizes, and colors. The Japanese daikon is scarcely recognizable as a radish. It is white, carrot-shaped, and approximately 46 cm (18 inches) long. This vegetable is a staple of Oriental cuisine; the Japanese have at least 100 different ways of cooking daikon.

An unusual use of radishes is seen in the festival “La Noche de Rabanos” (The Night of the Radishes), which is held each year on December 23 in Oaxaca City in southern Mexico. Radishes grown in the rocky soils of this region are often grotesquely misshapen and may resemble human or animal forms. In 1889, these bizarre vegetables were part of displays in an agricultural exhibit. This event developed into a yearly festival. Over the years, the displays became more and more elaborate. Today, the radishes are carved into detailed figures and arranged into dioramas that depict historical and religious themes such as the Mexican Revolution or the Nativity.

Asparagus

Asparagus is an aerial stem vegetable with a royal reputation. This monocot was a favorite of France's King Louis XIV. Native to southern Europe and the eastern Mediterranean region, asparagus was a popular vegetable of the ancient Greeks and Romans. The Puritans valued asparagus as a spring tonic and brought “sparagus” seeds with them to North America.

Asparagus is a perennial plant that, once established, can be harvested for many years. The species of commerce is *Asparagus officinalis* although several wild species have also been harvested for their stalks. Asparagus is dioecious,

having separate male and female plants; however, newer all-male varieties have been developed. These varieties are disease resistant, have greater longevity, and produce larger stems since no energy is diverted to seed production. The female plants produce small whitish-green flowers and, later, red to purple berries.

California leads the United States in the cultivation of asparagus, with most of the domestic market favoring the familiar green variety. A less common purple variety is gaining popularity, and a white variety is most often found in European cuisine. Mounding soil around the growing stem or covering the growing shoots under black plastic tunnels produces the white variety. The tender young stem tips, or spears, are cut by hand in the early spring (making asparagus one of the more expensive vegetables) while still under the surface. Both methods prevent sunlight from reaching the stems, inhibiting the production of chlorophyll, the green pigment seen in the normally photosynthetic asparagus stem. Fresh asparagus is highly perishable; the season lasts for only a few weeks.

If the asparagus stalk is not harvested but left to grow, the stem is said to “fern out” and takes on a delicate leafy



Figure 3.13 Cladophylls, leaflike stem branchlets, can be seen on some of the emerging asparagus shoots.

appearance (fig. 3.13). Several species of asparagus “ferns” are cultivated as house or garden plants or used in cut flower arrangements. The delicate leafy structures are not leaves at all but modified stems called **cladophylls** that mimic leaves in appearance and function.

Asparagus is rich in vitamins A, C, and folic acid, one of the B vitamins. A deficiency of folic acid raises the risk of heart disease and, during pregnancy, raises the risk of spina bifida and other neural tube birth defects (see Chapter 10).

For some people, eating asparagus has an unpleasant aftereffect. Sulfur compounds in the asparagus are voided in the urine, imparting an offensive odor. Why some people can detect these malodorous compounds and others cannot is a question that researchers are debating. Some researchers suggest that the foul-smelling compounds are produced through an interaction of the chemicals in asparagus with a particular type of personal biochemistry that is genetically determined. Other researchers believe that the compounds in asparagus taint everyone’s urine but only some people have the capacity to smell the odor-causing compounds.

In a few areas of the world, such as Australia, asparagus species are considered noxious weeds, crowding out native species (See A Closer Look 22.2—Killer Alga: Story of a Deadly Invader for more information on invasive species.) Some pets have been known to develop dermatitis from contact with asparagus and digestive upset from eating the berries.

Delving into the backgrounds of other common vegetables will reveal other interesting facts and folklore; there’s more to vegetables than just good nutrition.

CHAPTER SUMMARY

1. Meristems are regions of active cell division and are the source of cells for the various tissue types in the plant body. Growth at apical meristems is primary growth. Increase in the girth in woody plants is called secondary growth.
2. There are three basic tissue types in plants: dermal, ground, and vascular. Dermal tissues include the epidermis and periderm and cover the surface of a plant. Ground tissues include parenchyma, collenchyma, and sclerenchyma. Parenchyma is the most abundant and versatile plant tissue, functioning in storage and photosynthesis. Both collenchyma and sclerenchyma are tissues of support. There are two types of sclerenchyma: fibers and sclereids.
3. Vascular tissues are the conducting tissue in plants. Xylem conducts water and minerals from the soil upward; and phloem moves organic solutes throughout the plant body. Tracheids and vessel elements are the water-conducting cells of xylem. Sieve tube members, assisted by companion cells, conduct organic solutes through the phloem.
4. The vegetative organs of the plant body include roots, stems, and leaves. Roots anchor the plant and absorb

water and minerals from the soil. Two types of root systems are found: taproot and fibrous root. At the tip of any root there are four distinct regions or zones: root cap, zone of cell division, zone of cell elongation, and zone of maturation. Vascular tissue in a nonwoody root is organized into a stele; the pattern of xylem and phloem in the stele varies in monocot and dicot roots. The stele is surrounded by a cortex and an outer layer of epidermis. Extending from the epidermal cells are root hairs through which most of the water and minerals that enter a root are absorbed.

5. Stems support leaves to maximize light absorption and are part of the conduit for the transport of water, minerals, and organic solutes. Leaves are the main photosynthetic structures in most plants. Unlike roots, the vascular tissue in both stems and leaves is organized into vascular bundles. In stems of herbaceous dicots, the vascular bundles are arranged in a ring around a pith; in monocots, the vascular bundles are scattered. In woody dicots, the discrete vascular bundles are replaced by continuous rings of xylem that correspond to the xylem produced during a single growing season.
6. A leaf may have three parts: the blade, the petiole, and a pair of stipules. If the blade is undivided, the leaf is said to be simple; if the blade is divided into separate leaflets, the leaf is compound. According to the pattern of the leaflets, compound leaves may be pinnately or palmately compound. Leaf venation patterns are either parallel (most monocots) or net (most dicots). The entire leaf surface is covered by epidermis; the epidermis secretes a waxy layer, the cuticle. Guard cells are found in the leaf epidermis. They regulate the entry and exit of gases through the stomata. The mesophyll of the leaf is composed of two types of photosynthetic parenchyma cells: palisade and spongy cells.
7. An examination of the produce section of a supermarket reveals that many of our common vegetables can be identified as being one of the organs of a plant. Many vegetables have a value beyond the culinary as sources of medicine and folklore.

REVIEW QUESTIONS

1. What is the role of meristematic tissues?
2. Describe the organization of a typical herbaceous dicot or monocot stem.
3. Describe the anatomical differences between monocots and dicots.
4. What cell types and tissues are involved in support?
5. What are the functions of roots, stems, and leaves?
6. How can scientists date wood artifacts from archeological sites?
7. Describe the trapping mechanisms of some common carnivorous plants.

8. Investigate the origins and folklore of the following vegetables: cabbage, turnips, and beets.
9. How old is the woody stem pictured in Figure 3.6? Was it cut down in the spring or summer?
10. In A Closer Look 3.3—Supermarket Botany, you learned that the potato, mistaken by most to be a root, is actually an underground stem. What must be the anatomical features of the dicot potato tuber?

FURTHER READING

- Forterre, Yoel, Jan Skotheim, Jacques Dumais, and L. Mahadevan. 2005. How the Venus Flytrap Snaps. *Nature* 433(7024): 421–425.
- Hirasuna, Delphine. 1985. *Vegetables*. Chronicle Books, San Francisco.
- Mauseth, James D. 1988. *Plant Anatomy*. Benjamin Cummings Publishing, Menlo Park, CA.
- Mauseth, James D. 2003. *Botany: An Introduction to Plant Biology*, 3rd Edition. Jones and Bartlett, Sudbury, MA.
- Millus, Susan. 2002. The Wood Detective. *Science News* 162(12): 184–85.
- Moran, Jonathan. 2006. Life and Death in a Pitcher. *Natural History* 115(8): 56–62.
- Norris, Scott. 2000. Reading between the Lines. *BioScience* 50(5): 389–394.

- Pietropaolo, James, and Patricia Pietropaolo. 1986. *Carnivorous Plants of the World*. Timber Press, Portland, OR.
- Roberts, Jonathan. 2002. *The Origin of Fruit and Vegetables*. Universe Publishing, New York.
- Ross, Gary N. 1986. Night of the Radishes. *Natural History* 95(12): 59–64.
- Rupp, Rebecca. 1987. *Blue Corn and Square Tomatoes*. Garden Way Publishing, Pownal, VT.
- Schnell, Donald. 2002. *Carnivorous Plants of The United States and Canada*, 2nd Edition. Timber Press, Portland, OR.
- Shiga, David. 2004. Ancient Heights. *Science News* 165(25/26): 390.
- Simpson, Beryl B., and Molly Conner-Ogorzaly. 2001. *Economic Botany: Plants in Our World*, 3rd Edition. McGraw-Hill, New York.
- Trefil, James. 1985. Concentric Clues from Growth Rings Unlock the Past. *Smithsonian* 16(4): 47–54.

ONLINE LEARNING CENTER

Visit www.mhhe.com/levetin5e for online quizzing, web links to chapter-related material, and more!