Exercise 32

Plant Anatomy

Vegetative Structure of Vascular Plants

Learning Objectives

By the end of this exercise you should be able to:

1. Describe the functions of roots, stems, and leaves.
2. Distinguish between primary and secondary growth.
3. Describe the functional significance of the internal and external structure of roots, stems, and leaves.
4. Explain what causes growth rings in wood.

MULTI-MEDIA Please visit **www.mhhe.com/vodopich10e** to review multi-media resources tailored to this lab.

The structure of plants varies greatly among species; compare, for example, an oak tree with a cactus. However, these structural differences are typically quantitative rather than qualitative; that is, the differences among roots, stems, and leaves result not from tissues unique to one species or another, but rather from different arrangements and proportions of the same tissues. These differences among plants represent a variety of ways to achieve the same evolutionary "goals": survival and reproduction. This exercise will concentrate on the structure of roots, stems, and leaves of vascular plants.

ROOTS

During seed germination, a **radicle** or young **primary root** emerges from the seed and grows down. The primary root soon produces numerous **secondary roots** and forms a root system that absorbs water and minerals, anchors the plant, and stores food. Root systems have different morphologies. For example, a **taproot system** has a large main root and smaller secondary roots branching from it (e.g., carrot). In a **fibrous root system,** the primary and secondary roots are similar in size (e.g., roots of many grasses) (fig. 32.1). Examine the displays of taproot and fibrous root systems available in the lab.

Primary growth of roots and all primary tissues is formed by **apical meristems.** A meristem is a localized area of cellular division. Apical meristems occur at the tips of roots and stems. Primary growth (i.e., growth in length) produces herbaceous (nonwoody) tissue. **Secondary growth** refers to growth in girth resulting from nonapical meristems, some of which are discussed later in this exercise.

Question 1

a. How do taproot systems and fibrous root systems help plants survive and reproduce?

b. Would one type of root system provide more adaptive advantages in a particular environment such as a rain forest? A desert? Explain your answer.

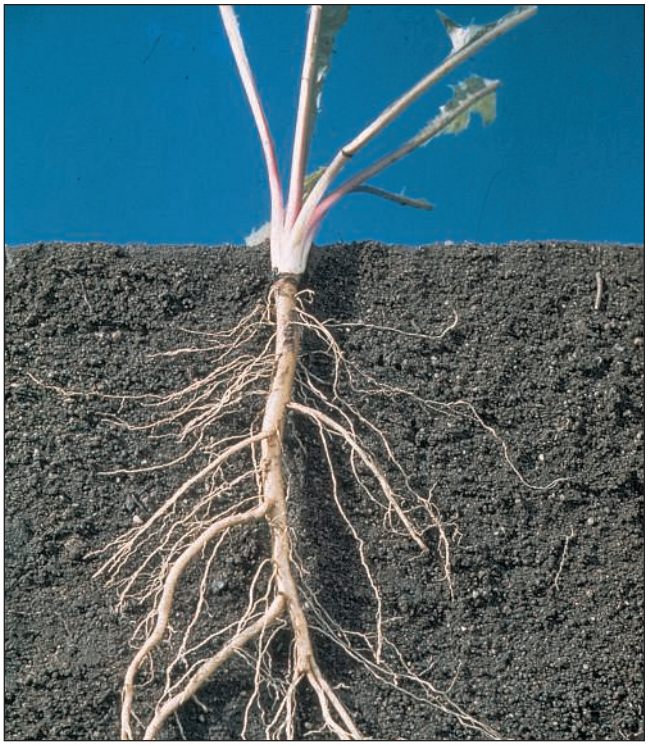
The Root Apex

Examine the root tips of two-day-old seedlings of radish (*Raphanus*) and corn (*Zea*) with your dissecting microscope. Refer to figure 32.2 and identify the **root cap, root apical meristem, zone of elongation,** and **zone of maturation.**

The cone of loosely arranged cells at the root cap perceives gravity and protects the root apical meristem. The root cap protects the root by secreting mucilage and sloughing cells as the root grows through the soil (fig. 32.3). The root apical meristem is behind the root cap and produces all of the new cells for primary growth. These cells elongate in the zone of elongation, which is 1–4 mm behind the root tip. This elongation produces primary growth.

Question 2

a. In the following space, sketch the root tips that you examined. In which area of a root tip are cells largest? In which area are they smallest?



(a)

(b)

Figure 32.1

Two common types of root systems of vascular plants. (*a*) The taproot system of dandelion (*Taraxacum*) consists of a prominent taproot and smaller lateral roots. (*b*) The fibrous root system of a grass consists of many similarly sized roots. Fibrous root systems form extensive networks in the soil and minimize soil erosion.

b. Aside from their size, do all cells in the root tip appear similar? Why is this significant?

Re-examine the two-day-old radish seedling with your dissecting microscope. Note the **root hairs** in the zone of maturation. Root hairs are outgrowths of epidermal cells and are short-lived. Root hairs increase the surface area of the root.

Question 3

a. Why do you think root hairs occur only in the zone of maturation? Why aren't they in the zone of maturation?

b. What is the function of root hairs?

Primary Tissues of the Root

The root apical meristem produces cells that differentiate into primary tissues of the root. The outer layer of cells is the **epidermis.** Just inside the epidermis is the **cortex,** whose cells contain numerous **amyloplasts,** which are starch-containing plastids. The inner layer of the cortex is the **endodermis,** which regulates water flow to the vascular tissue in the center of the root. Immediately inside the endodermis is the **pericycle,** which can become meristematic and produce **secondary roots** (figs. 32.4 and 32.5).

Procedure 32.1

Examine primary tissues of the root

1. Examine a prepared slide of a cross section of a buttercup (*Ranunculus,* a dicot) root (figs. 32.4 and 32.5). Sketch what you see. Label and state the function of each tissue that is present. (Note: Your instructor may have you examine a slide comparing cross sections of roots of monocots and dicots.)

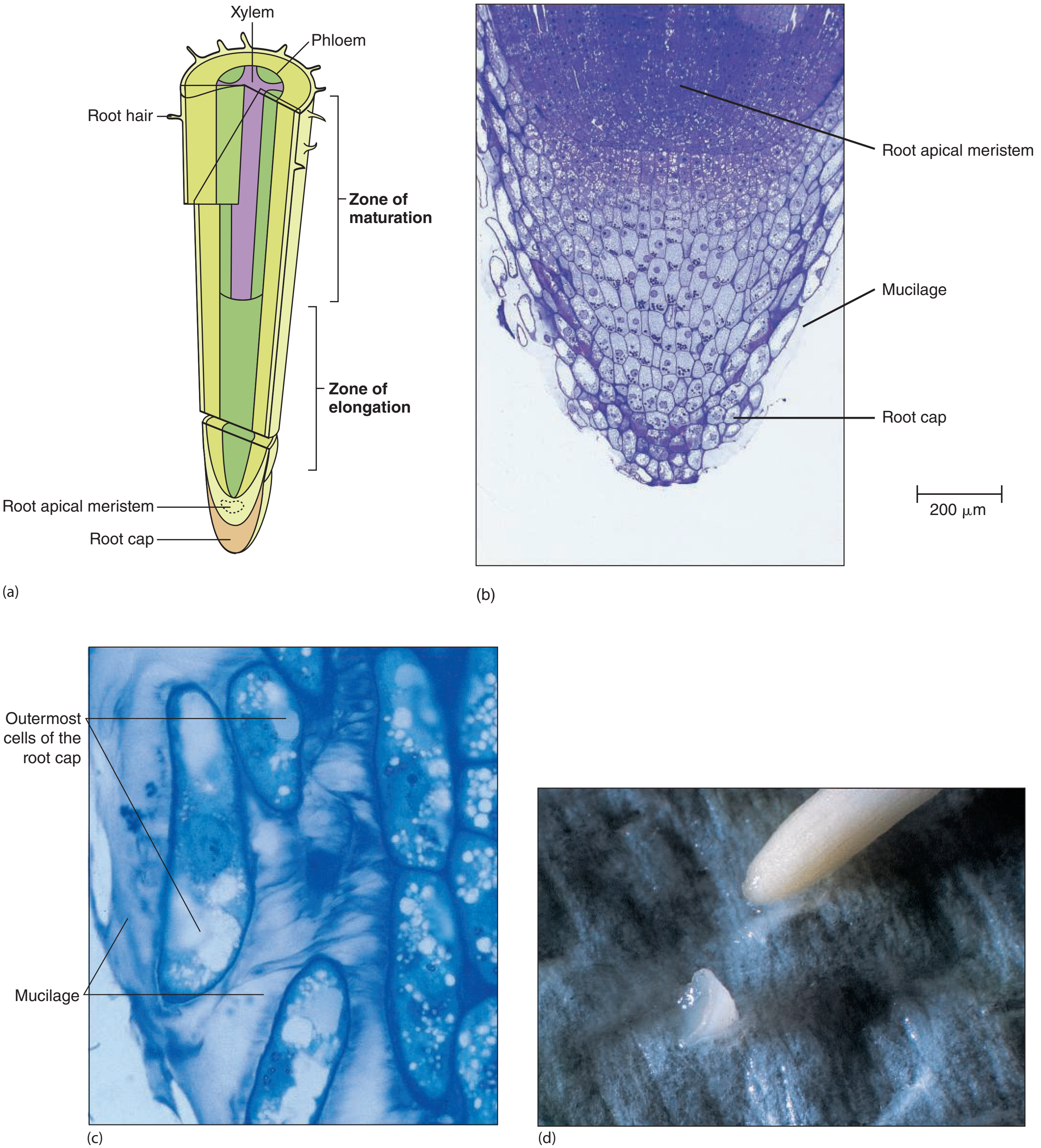


Figure 32.2

(*a*) Root tip showing root cap, root apical meristem, zone of elongation, and zone of maturation. (*b*) The root apical meristem is covered by a thimble-shaped root cap that protects the meristem as the root grows through the soil. (*c*) Mucilage produced by the root cap lubricates the root as it grows through the soil (see fig. 32.3). (*d*) In plants such as corn, the root cap can be removed from the rest of the root.

2. Examine a prepared slide labeled "lateral root origin." Locate the epidermis, cortex, pericycle, and newly formed secondary root. Sketch the lateral root and label its parts.

3. If time permits, also examine a prepared slide of a cross section of a corn (*Zea*, a monocot) root.

Question 4

a. Based on the presence of amyloplasts, what do you suppose is the primary function of the cortex?

b. Do secondary roots arise inside the primary root or on its surface?

c. How does the structure of a monocot root differ from that of a dicot?

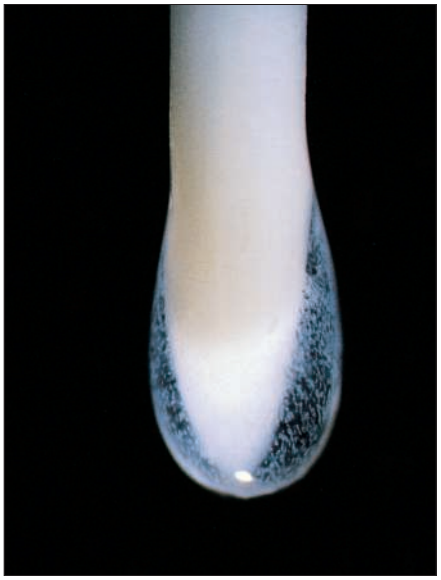


Figure 32.3

Tips of roots secrete large amounts of mucilage, a lubricant that helps the root force its way through the soil. The mucilage is secreted primarily by the root cap. Movement of the root through soil is also aided by the sloughing of root-cap cells. These sloughed cells are visible in the drop of mucilage on the tip of this root.

In the center of the buttercup root is the **vascular** (fluid-conducting) **cylinder** composed of **xylem** and **phloem** (fig. 32.5). Xylem transports water and minerals; phloem transports most organic compounds in the plant, including carbohydrates. Water-conducting cells in the xylem of angiosperms are called **tracheids** and **vessel elements** and are dead and hollow at maturity. Tracheids are long, spindle-shaped cells with thin areas called **pits** where the cell walls of adjacent cells overlap (fig. 32.6). Water moves through these pits from one cell to the next. Vessels are stacks of cylindrical cells with thin or completely open end-walls. Water moves through vessel elements in straight, open tubes. These tubes are usually stained red in slide preparations of buttercup roots.

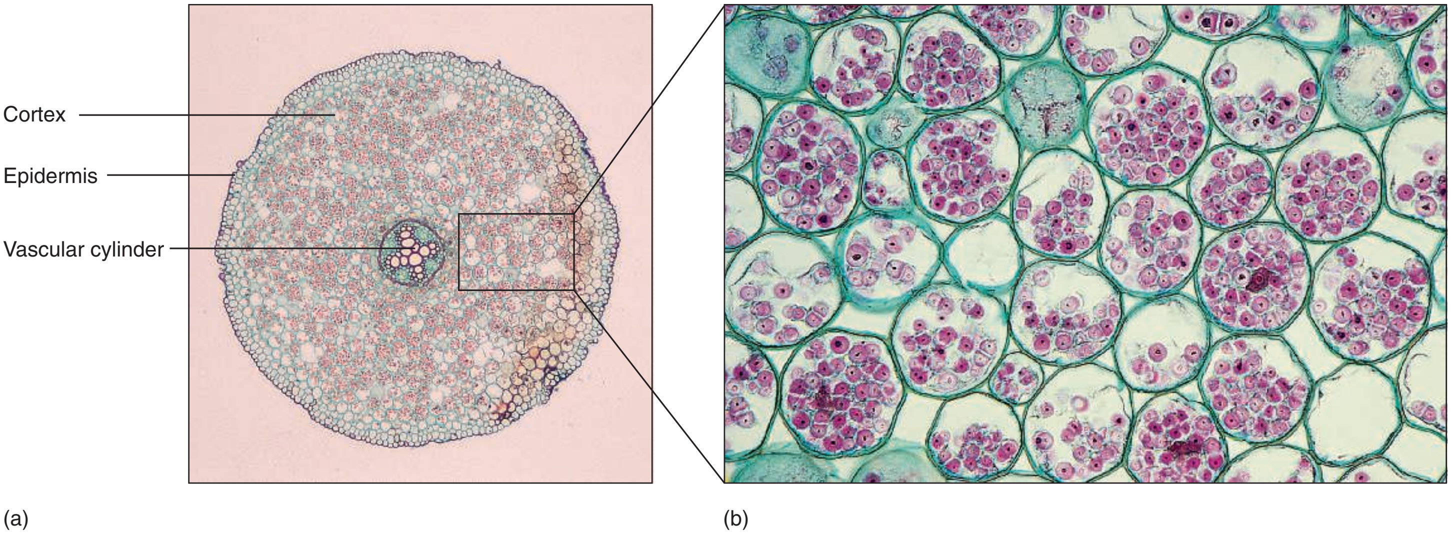


Figure 32.4

Transverse sections of a root of a buttercup (*Ranunculus*), a dicot. (*a*) Overall view of mature root. The vascular cylinder includes tissues specialized for long-distance transport of water and solutes, whereas the epidermis forms a protective outer layer of the root (16×). (*b*) Detail of cortex (250×). Each parenchyma cell in the cortex contains many amyloplasts, which store starch.

Conducting cells in phloem are called **sieve cells** and **sieve tube members** and are alive at maturity. Phloem cells are small, thin-walled, and arranged in bundles that alternate with the poles of xylem (fig. 32.5). Sieve tube members are usually stained green.

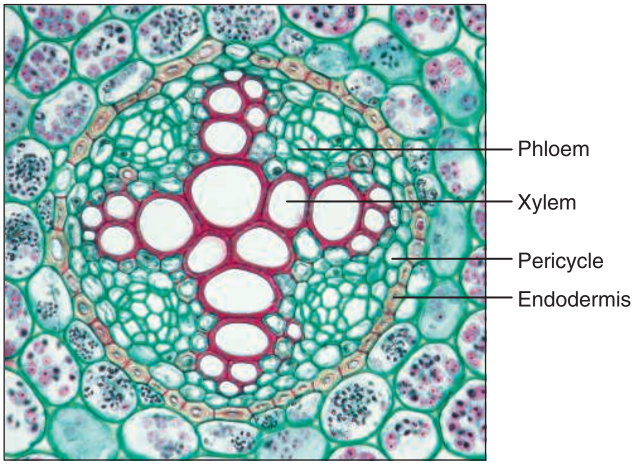


Figure 32.5

A cross section through the center of a root of a buttercup (*Ranunculus*), a dicot (125×). The phloem and xylem are vascular tissues of the vascular cylinder shown in figure 32.4*a*.

Procedure 32.2

Examine carrot root

1. Prepare two thin cross-sections of a carrot root.
2. Stain one slice with iodine (a stain for starch) and examine it with your microscope.
3. Stain the other section of carrot root with phloroglucinol. Phloroglucinol stains **lignin,** a molecule that strengthens xylary cell walls.

Phloroglucinol contains hydrochloric acid. Do not spill any on yourself or your belongings!

Question 5

a. Where is starch located in a carrot root?

b. What can you conclude from this observation?

STEMS

Stems are often conspicuous organs whose functions include support and the transport of water and solutes. Some stems (e.g., cacti) also photosynthesize and store food.

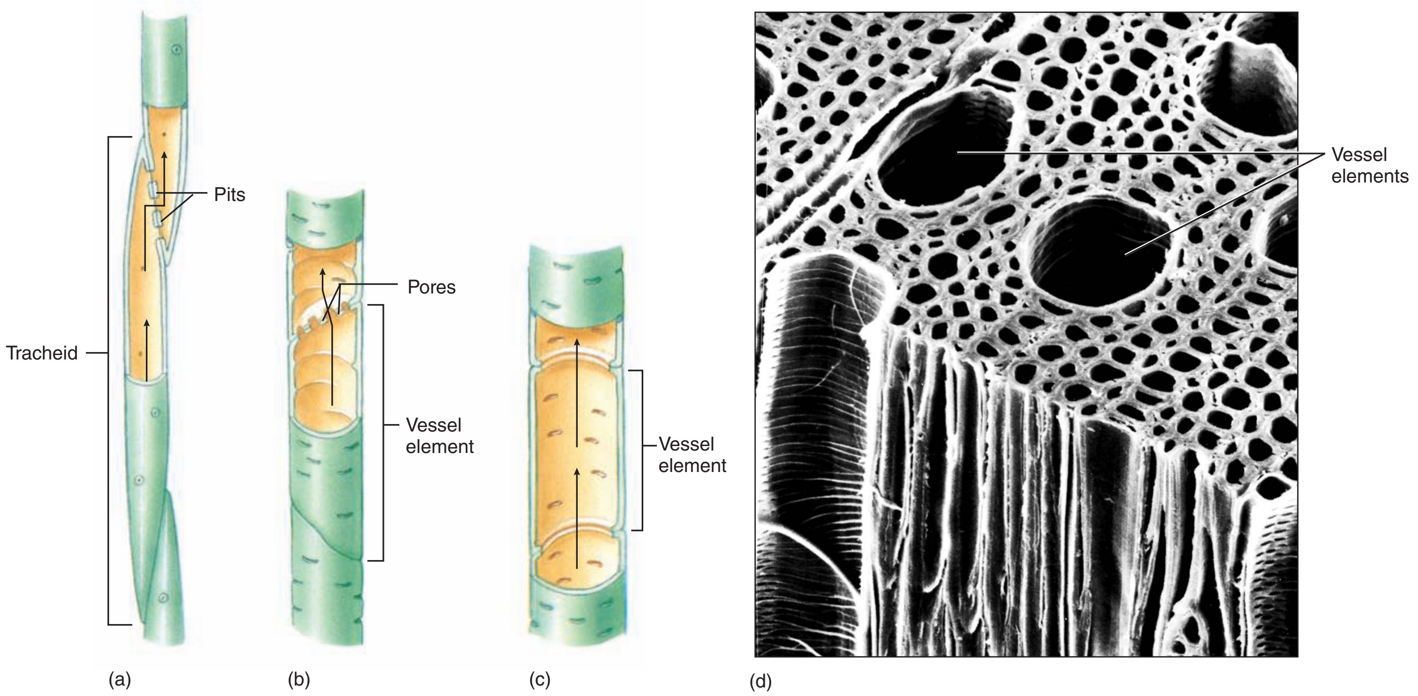


Figure 32.6

Comparison of vessel elements and tracheids. (*a*) In tracheids, water passes from cell to cell through pits, which are thin areas where cell walls overlap. (*b, c*) In vessel elements, water moves through pores, which may be simple or interrupted by bars. (*d*) The large openings shown in this scanning electron micrograph of the wood of a red maple (*Acer rubrum,* a dicot) are vessel elements (350×).

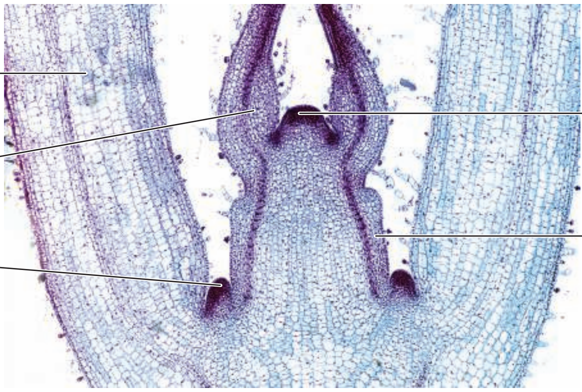


Figure 32.7
Shoot tip of *Coleus,* a dicot. The apical meristem is the site of rapid cell division and primary growth. Young leaves are produced at the tip of the shoot. Shoot tips, unlike root tips, are not covered by a cap.

The Shoot Apex

Examine a living *Coleus* plant and note the arrangement of leaves on the stem. Keeping this observation in mind, examine a prepared slide of a longitudinal section of a shoot tip of *Coleus* (fig. 32.7). The dome-shaped **shoot apical meristem** is not covered by a cap as was the root. The shoot apical meristem produces young leaves (**leaf primordia**) that attach to the stem at a **node.** An **axillary bud** between the young leaf and the stem forms a branch or flower.

Question 6

a. How does the absence of a cap at a shoot apex differ from the apical meristem of a root?

b. How would you explain this difference?

c. Are all cells in the shoot apex the same size? Why is this significant?

External Features of a Mature Woody Stem

Examine the features of a dormant twig (fig. 32.8). A **terminal bud** containing the apical meristem is at the stem tip and is surrounded by **bud scales. Leaf scars** from shed leaves occur at regularly spaced **nodes** along the length of the stem. The portions of stem between the nodes are called **internodes. Vascular bundle scars** may be visible within the leaf scars. Axillary buds protrude from the stem just distal to each leaf scar.

Search for clusters of **bud scale scars.** The distance between clusters or from a cluster to the terminal bud indicates the length of yearly growth.

Primary Tissues of Stems

An **epidermis** covers the stem. The epidermis is coated with a waxy, waterproof substance called **cutin.** Below the epidermis is the **cortex,** which stores food. The **pith** in the center of the stem also stores food. In sunflower stems, the cortex is not uniform. Rather, the three to four cell-layers of the cortex just below the epidermis are smaller, rectangular cells with unevenly thickened cell walls. These are **collenchyma** cells; they support elongating regions of the plant (fig. 32.10). In stems, xylem and phloem are arranged in bundles (fig. 32.10).

Procedure 32.3

Examine the primary tissues of stems

1. Examine a prepared slide of a cross section of a sunflower (*Helianthus*) stem (fig. 32.9).

2. On the slide you are examining, locate a vascular bundle. Sketch what you see.

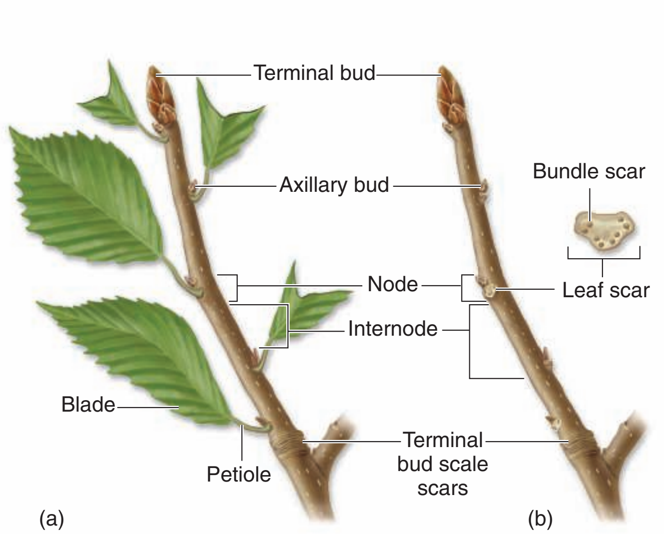


Figure 32.8
A woody twig. (*a*) In summer. (*b*) The twig in its dormant winter condition.

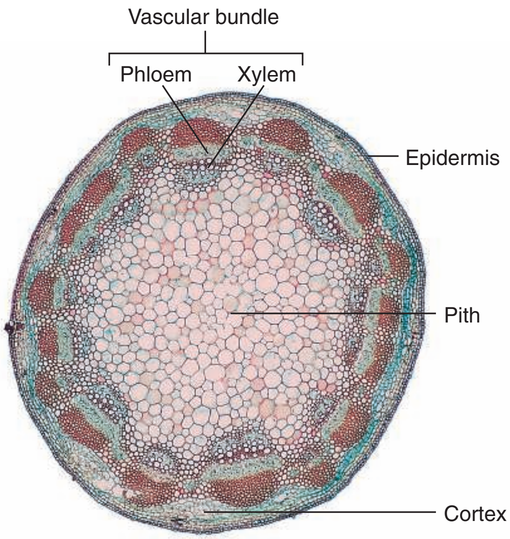


Figure 32.9
Cross-sectional view of a stem of sunflower (*Helianthus annus*), a dicot (10×). Note the ring of vascular bundles surrounding the pith. A high-magnification view of a vascular bundle from this stem is shown in figure 32.10.

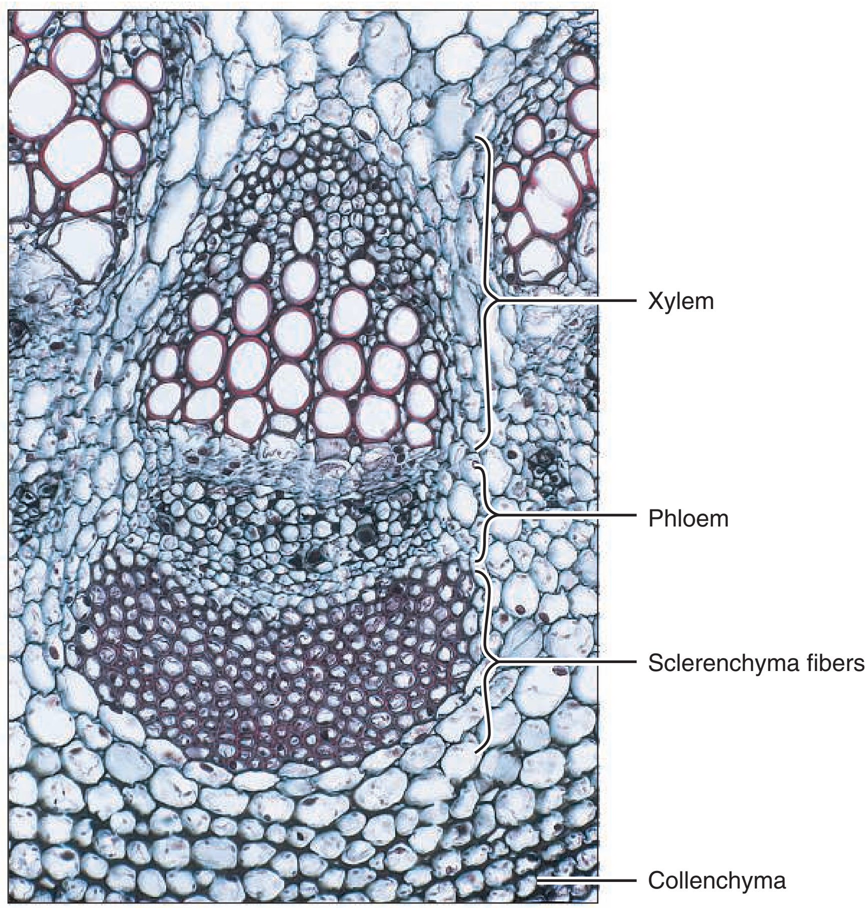


Figure 32.10
Cross section of a vascular bundle of a sunflower stem (485×). The sclerenchyma fibers support the stem and protect the vascular tissue. The walls of fibers are much thicker than those of adjacent cells.

Question 7

a. What is the significance of a coating of cutin on the epidermis?

b. How does the arrangement of xylem and phloem in stems differ from that in roots?

The darkly stained, thick-walled cells just outside the phloem in figure 32.10 are **sclerenchyma fibers,** which function in support. Sclerenchyma fibers from some plants are used to make linen, rope, and burlap.

The ring of vascular bundles in sunflower stems is typical of **dicots,** flowering plants with two **cotyledons** (seed leaves). Examine a prepared slide of a cross section of a corn stem (fig. 32.11). Corn is a **monocot** (a flowering plant with only one cotyledon). In the following space sketch a cross section of a sunflower stem and a corn stem. Note the distribution of the vascular bundles.

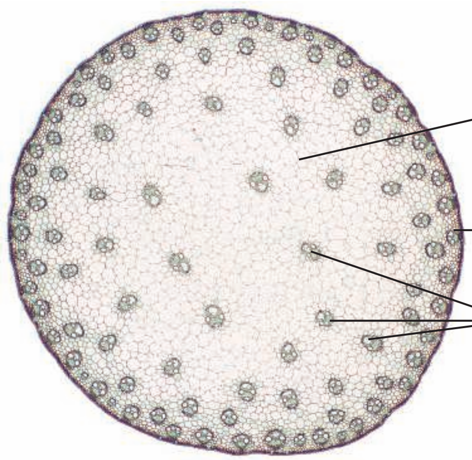


Figure 32.11

Cross section of a stem of corn (*Zea mays*), a monocot (5×). Unlike in dicots such as sunflower (fig. 32.9), bundles of vascular tissue in monocots occur throughout the ground tissue. The stem is surrounded by an epidermis.

Question 8

How does the arrangement of vascular bundles differ in stems of monocots as compared to dicots?

Secondary Growth of Stems

Between the xylem and phloem and each vascular bundle in dicot stems is a meristematic tissue called **vascular cambium.** The vascular cambium is a secondary meristem that produces secondary growth (i.e., growth in girth). The vascular cambium is cylindrical and produces secondary xylem to its inside and secondary phloem to its outside.

Question 9

How is secondary growth different from primary growth?

Procedure 32.4

Examine secondary growth in woody stems

1. Examine cross sections of 1-, 2-, and 3-year-old basswood (*Tilia*) stems. The vascular cambium is a narrow band of cells between the xylem and phloem (fig. 32.12).
2. Compare the structures of the three stems. The secondary xylem of older stems consists of concentric annual rings made of alternating layers of large and small cells. The large cells are formed in the spring, and the smaller cells are produced in summer.
3. In the following space draw cross-sections of 1-, 2-, and 3-year-old stems.

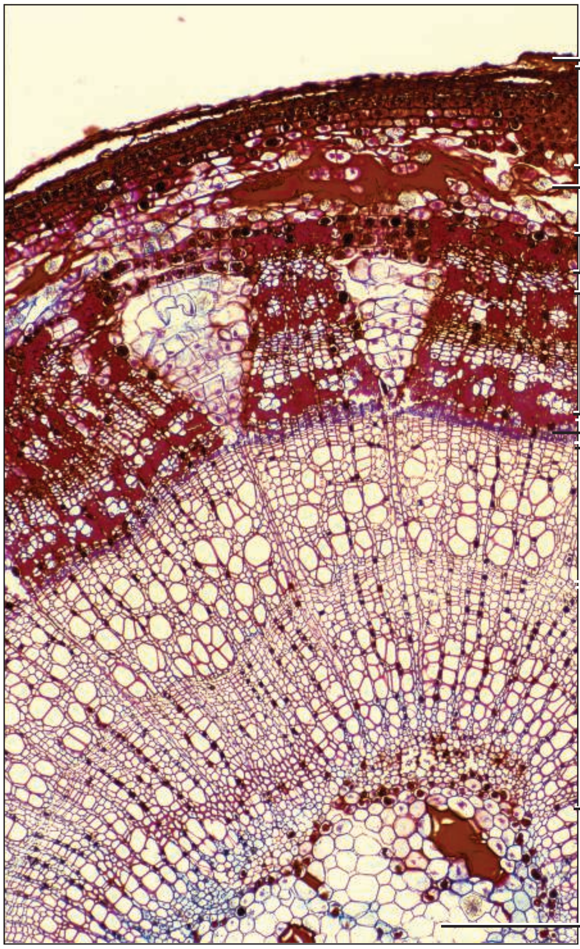


Figure 32.12

A cross section of a portion of a young linden (*Tilia*) stem showing secondary growth (400×). The vascular cambium produces secondary xylem (wood) to the inside and secondary phloem to the outside. Note the annual rings in the secondary xylem. A close-up of a growth ring from pine is shown in figure 32.13.

Question 10

a. How do you account for this seasonal production of different-sized cells?

b. What is the common name for secondary xylem?

c. What is "grain" in wood?

d. Aside from conducting water and minerals, what is another important function of secondary xylem?

4. Examine a prepared slide of a cross section of secondary xylem of pine (*Pinus*) (fig. 32.13). In cone-bearing plants such as pine, the conducting cells of xylem are all tracheids. The absence of vessel elements gives wood of these plants a relatively uniform appearance.

5. Now examine a prepared slide of a cross section of secondary xylem of oak (*Quercus*), a flowering plant (fig. 32.14). Sketch what you see.

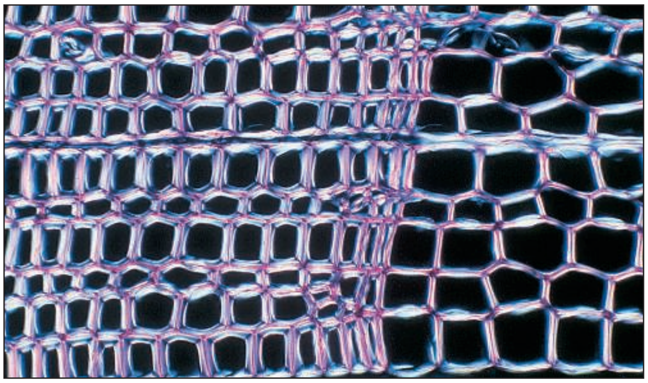


Figure 32.13

The wood of gymnosperms (such as this pine) consists almost exclusively of tracheids. These water-conducting cells are relatively small and help to support the plant. Although water moves slower through tracheids than through vessel elements, tracheids are less likely to be disabled by air bubbles that form in response to freezing and wind-induced bending of branches. The larger cells on the right side of this photo form during the wet days of spring and are called spring wood; the smaller cells at the left form during the drier days of summer and are called summer wood. The change in density between spring and summer wood produces a growth ring, which appears as "grain" in wood.

Question 11

a. What are the large cells in oak wood?

b. What is their function?

c. Which type of wood do you think transports more water per unit area, pine or oak? Why?

Bark

Bark includes all tissues outside of the vascular cambium, including the secondary phloem (fig. 32.12). When viewed in cross section, secondary phloem consists of pyramidal masses of thick- and thin-walled cells. The thin-walled cells are the conducting cells.

The increase in stem circumference resulting from activity of the vascular cambium eventually ruptures the epidermis. The ruptured epidermis is replaced by a tissue called the **periderm** that, like the epidermis, functions to minimize water loss. Periderm consists of cork cells produced by another secondary meristem called the **cork cambium.**

Locate the cork cambium in cross sections of 1-, 2-, and 3-year-old basswood stems. The cork cambium is a band of thin-walled cells located beneath the epidermis. The cork cambium produces cork cells to the outside and cork parenchyma to the inside. Cork cells stain red because of the presence of suberin, a water-impermeable lipid.

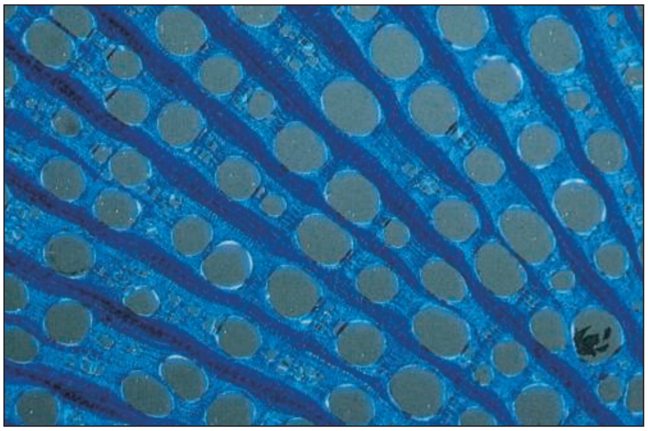


Figure 32.14

Unlike the xylem of gymnosperms, which contains only tracheids, the xylem of angiosperms also contains vessel elements. These vessel elements are much wider than tracheids and appear in this micrograph as large circles. Vessel elements are an adaptation for increased rates of water flow in angiosperms (see fig. 32.6*c*).

Question 12

Is the amount of cork similar in 1-, 2-, and 3-year-old stems? If not, how does it differ? Why is this important?

As the stem diameter continues to increase, the original periderm ruptures and new periderms form in the underlying tissues. Tissues outside the new periderm die and form encrusting layers of bark.

Gas exchange through peridermal tissues occurs through structures called **lenticels** (fig. 32.15). Examine a prepared slide of a lenticel and locate lenticels on a mature woody stem.

Question 13

How does a lenticel differ from the remainder of the periderm?

LEAVES

With few exceptions, most photosynthesis occurs in leaves, although some may occur in green stems. Leaves typically consist of a **blade** and a **petiole.** The petiole attaches the leaf blade to the stem. **Simple leaves** have one blade connected to the petiole, whereas **compound leaves** have several

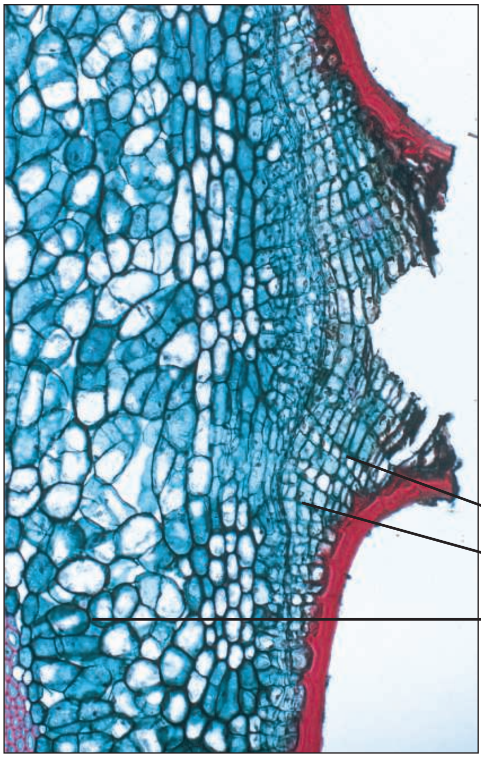


Figure 32.15
A lenticel in a cross-section of part of a young stem of elderberry (*Sambucus*). Gas exchange across the cork layer of the stem occurs through lenticels.

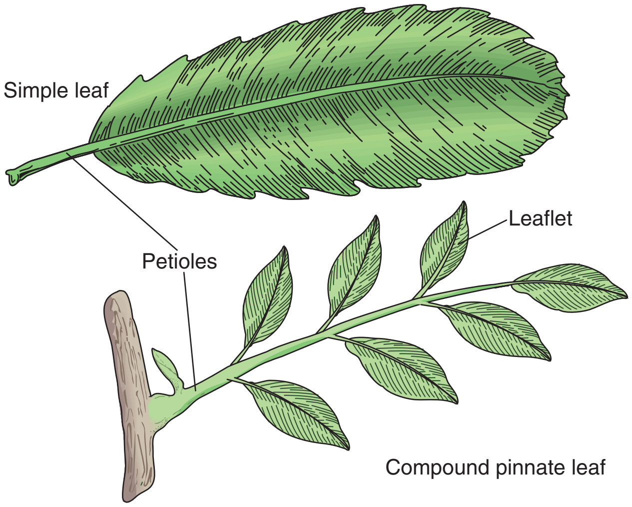


Figure 32.16
Simple and compound leaves.

leaflets sharing one petiole (fig. 32.16). **Palmate** leaflets of a compound leaf arise from a central area, as your fingers arise from your palm. **Pinnate** leaflets arise in rows along a central midline. Examine the simple and compound leaves on display, and sketch a representative of each type of leaf.

Leaves are also classified according to their **venation** (i.e., arrangement of veins) (fig. 32.17). **Parallel veins** extend the entire length of the leaf with little or no cross-linking. **Pinnately veined** leaves have one major vein (i.e., a midrib) from which other veins branch. **Palmately veined** leaves have several veins each having branches. Veins of vascular tissue in leaves are continuous with vascular bundles in stems.

Examine the leaves on display in the lab and determine their venation. Sketch a few of these leaves to show their venation. List the names of common leaves on demonstration and indicate whether each is simple, pinnately compound, or palmately compound. Also indicate whether venation in each leaf is parallel, pinnate, or palmate.

The arrangement of leaves on a stem is called **phyllotaxis** and characterizes individual plant species (fig. 32.18). **Opposite phyllotaxis** refers to two leaves per node located on opposite sides of the stem. **Alternate phyllotaxis** refers to one leaf per node, with leaves appearing first on one side of the stem and then on another. **Whorled phyllotaxis** refers to more than two leaves per node. Examine the plants on display in the lab to determine their phyllotaxis.

What Good Is Bark?

You've doubtless seen chips of bark used as garden mulch that is spread around plants. Because bark cells (secondary phloem and periderm) were once alive, they contain many nutrients that are released into the soil as the bark decays. However, sawdust (wood) has few nutrients in it and may result in nitrogen deficiency due to rapid decomposition. Consequently, sawdust is a poor mulch for plants.

Tree Girdling

You've probably heard of "tree girdling," which is the stripping of a ring of bark from a branch. (In the wild, porcupines also girdle trees.) Girdling removes secondary phloem from a tree, thereby leaving no pathway for photosynthate to move from the leaves to the roots. As a result, the shoot accumulates sugars and grows rapidly. The following spring it is impossible to send sugars from the roots to the girdled branch to renew growth. Thus, the branch or tree dies the year after it is girdled.

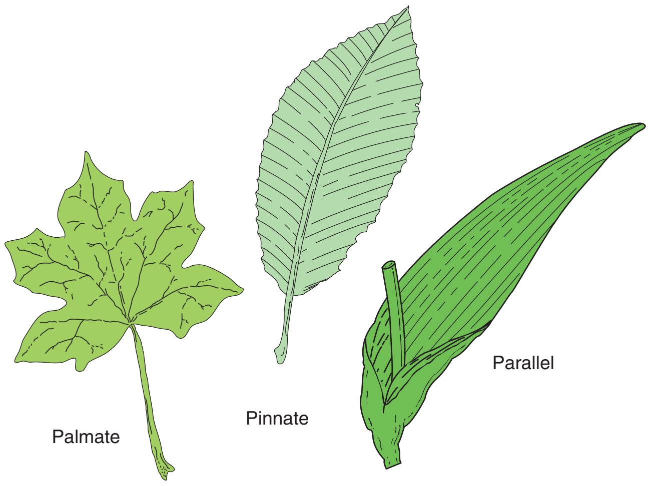


Figure 32.17
Palmate, pinnate, and parallel venation of leaves.

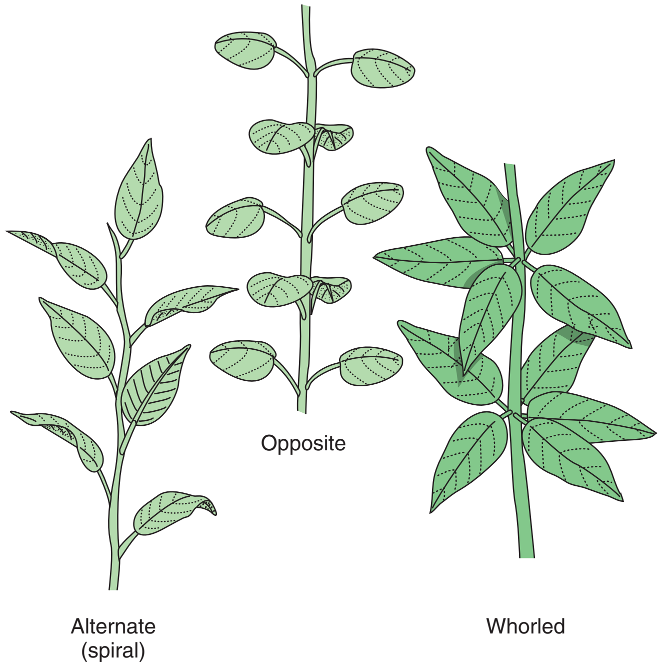


Figure 32.18
Patterns of leaf arrangement (phyllotaxis).

Internal Anatomy of a Leaf

Examine a cross section of a leaf of *Ligustrum* (privet) (figs. 32.19 and 13.9). The leaf is only 10–15 cells thick—pretty thin for a solar collector! The epidermis contains pores called **stomata,** each surrounded by two guard cells (you will study stomata again in the next exercise). Just below the upper epidermis are closely packed cells called **palisade mesophyll** cells; these cells contain about 50 chloroplasts per cell. Below the palisade layers are **spongy mesophyll** cells with numerous intercellular spaces. Examine and sketch a cross section of a corn leaf.

Question 14

a. What is the function of stomata?

b. Do epidermal cells of leaves have a cuticle? Why is this important?

c. What is the significance of chloroplasts being concentrated near the upper surface of the *Ligustrum* leaf?

d. What are the functions of air spaces near the lower surface of the leaf?

e. How is the internal anatomy of a corn leaf different from that of *Ligustrum*?

f. How is it similar?

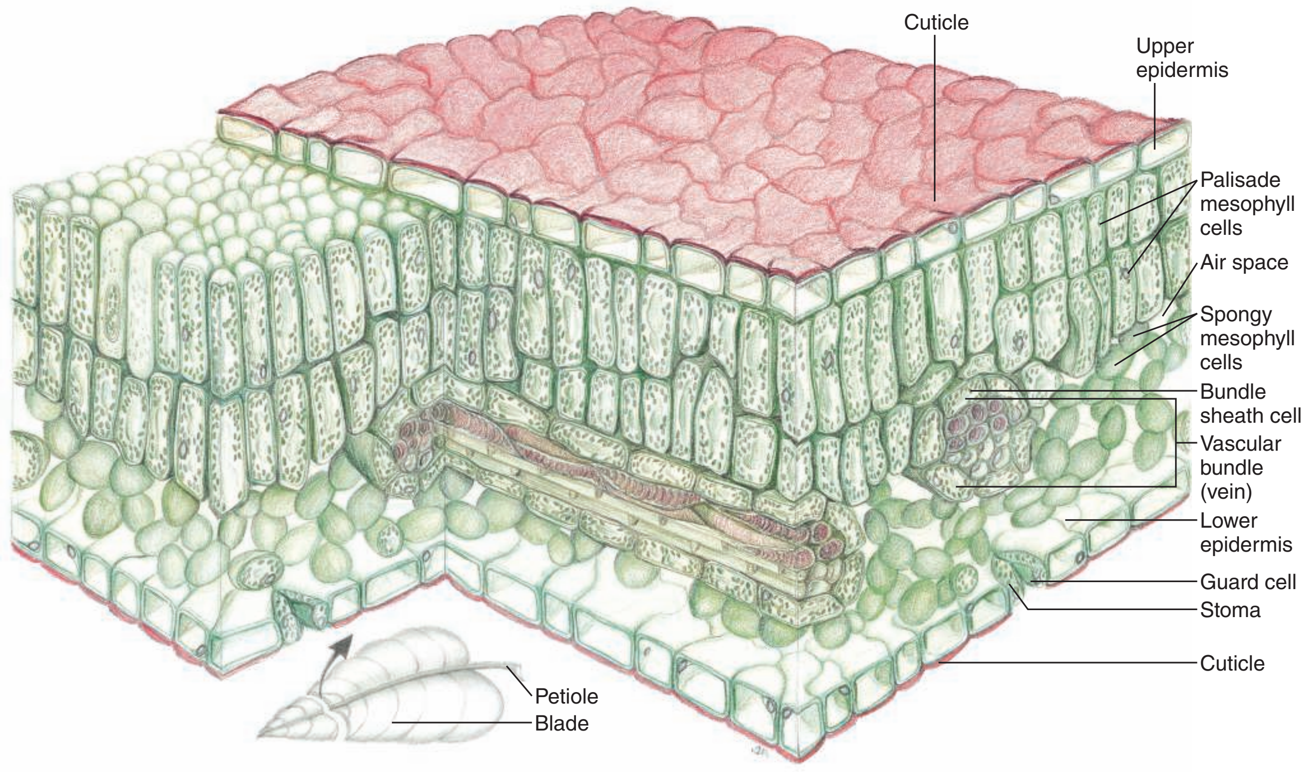


Figure 32.19

Ligustrum leaf, cross section. Most photosynthesis occurs in the densely packed palisade mesophyll cells, just beneath the upper epidermis of the leaf. Gas exchange occurs through stomata, usually most abundant on the lower side of the leaf. Water loss is minimized by the waxy cuticle that covers the leaf.

g. Based on the arrangement of vascular tissue, how could you distinguish the upper versus lower surfaces of a leaf?

h. If time permits, also examine prepared slides of leaves of corn (*Zea mays,* a monocot) and pine (*Pinus,* a gymnosperm). What differences are there in the structures of these leaves? How do these structural differences correlate with functional differences?

INVESTIGATION

How Plants Sense and Respond to Light and Gravity

Observation: The ability of plant roots to grow downward and shoots to grow upward is adaptive because it increases the plants' chances of encountering water (by the roots) and light (by the shoot).

Question: When the roots of a corn (*Zea mays*) seedling grow downward, is this a negative response to light or a positive response to gravity?

a. Establish a working lab group and obtain Investigation Worksheet 32 from your instructor.
b. Discuss with your group well-defined questions relevant to the preceding observation and question. Choose and record your group's best question for investigation.
c. Translate your question into a testable hypothesis and record it.
d. Outline on Worksheet 32 your experimental design and supplies needed to test your hypothesis. Ask your instructor to review your proposed investigation.
e. Conduct your procedures, record your data, answer your question, and make relevant comments.
f. Discuss with your instructor any revisions to your questions, hypotheses, or procedures. Repeat your work as needed.

Questions for Further Thought and Study

1. What is the function of xylem? Phloem? Vascular cambium? Epidermis?

2. What are the functions of stomata and lenticels? In what ways do these structures differ?

3. How is the internal anatomy of a stem different from that of a root?

4. How is primary growth different from secondary growth?

5. How is a leaf structurally adapted for its function?

6. Why does a stem typically contain more sclerenchyma and collenchyma than does a leaf?

7. An old friend tells you that 30 years ago she nailed a sign into a tree trunk at a height of 1 meter. She now says the sign is 25 meters up in the tree. Should you believe her? Why or why not?

8. Compare and contrast (*a*) monocot and dicot roots, and (*b*) monocot and dicot stems.

DOING BIOLOGY YOURSELF

Choose a couple of defined environments nearby, such as a vacant field or riverside. Survey the variety of leaf morphologies of the dominant plants. What can you conclude about the predominance of monocots versus dicots in each environment?

WRITING TO LEARN BIOLOGY

Why is leaf abscission especially important for temperate plants?

WRITING TO LEARN BIOLOGY

Would you expect to find annual rings in wood of a tropical dicot tree? Why or why not?