Montezuma baldcypress trees, *Taxodium mucronatum*, line the banks of the Rio Cuchujaqui in the southern region of the Mexican state of Sonora. The tangled surface roots allow the trees to take advantage of surface water from floods. Some of the trees have taproots that reach very deep into the aquifer below to help them survive the dry seasons.
Plant Cells and Tissues

Plants have adapted to a range of environments over the course of their evolution. As plants grow, their cells become specialized for particular functions. The tissue patterns vary in each plant’s roots, stems, and leaves. They also vary depending on the plant’s stage of growth and taxonomic group. This chapter examines the structure and function of roots, stems, and leaves.

PLANT CELLS

All organisms are composed of cells. Recall that plant cells have unique structures, including a central vacuole, plastids, and a cell wall that surrounds the cell membrane. These common features are found in three basic types of plant cells—parenchyma, collenchyma, and sclerenchyma—which are shown in Figure 29-1. Small changes in the structure of these plant cells help make different functions possible. The three types of plant cells are arranged differently in roots, stems, and leaves.

Parenchyma (puh-REN-kuh-muh) cells are usually loosely packed cube-shaped or elongated cells with a large central vacuole and thin, flexible cell walls. Parenchyma cells are involved in metabolic functions, including photosynthesis, storage of water and nutrients, and healing. These cells usually form the bulk of nonwoody plants (plants with flexible, green stems). The fleshy parts of most fruit are made up mostly of parenchyma cells.

The cell walls of collenchyma (koh-LEN-kuh-muh) cells are thicker than those of parenchyma cells. Collenchyma cell walls are also irregular in shape. The thicker walls provide support for the plant.

VOCABULARY

parenchyma
collenchyma
sclerenchyma
epidermis
cuticle
tracheid
pit
vessel element
vessel
sieve tube member
sieve tube
sieve plate
companion cell
meristem
apical meristem
lateral meristem
vascular cambium
cork cambium

FIGURE 29-1
Plants are composed of three basic types of cells: (a) parenchyma, (b) collenchyma, and (c) sclerenchyma.
Collenchyma cells are usually grouped in strands. They are specialized for supporting regions of the plant that are still lengthening. Celery stalks contain a great amount of collenchyma cells.

**Sclerenchyma** (skluh-REN-kuh-muh) cells have thick, even, rigid cell walls. They support and strengthen the plant in areas where growth is no longer occurring. This type of cell is usually dead at maturity, providing a frame to support the plant. The hardness of the shells around nuts is due to the presence of sclerenchyma cells.

**PLANT TISSUE SYSTEMS**

Cells that work together to perform a specific function form a tissue. Tissues are arranged into systems in plants, including the dermal system, ground system, and vascular system, which are summarized in Table 29-1. These systems are further organized into the three major plant organs—the roots, stems, and leaves. The organization of each organ reflects adaptations to the environment.

**Dermal Tissue System**

The dermal tissue system forms the outside covering of plants. In young plants, it consists of the **epidermis** (EP-uh-DUHR-muh), the outer layer made of parenchyma cells. The outer epidermal wall is often covered by a waxy layer called the **cuticle**, which prevents water loss. Some epidermal cells of the roots develop hairlike extensions that increase water absorption. Openings in the leaf and stem epidermis are called **stomata**. Stomata regulate the passage of gases and moisture into and out of the plant. In woody stems and roots, the epidermis is replaced by dead cork cells.

<table>
<thead>
<tr>
<th><strong>TABLE 29-1</strong> Characteristics of Plant Tissue Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tissue system</strong></td>
</tr>
<tr>
<td>Dermal tissue system</td>
</tr>
<tr>
<td>Ground tissue system</td>
</tr>
<tr>
<td>Vascular tissue system</td>
</tr>
</tbody>
</table>

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Ground Tissue System

Dermal tissue surrounds the ground tissue system, which consists of all three types of plant cells. Ground tissue functions in storage, metabolism, and support. Parenchyma cells are the most common type of cell found in ground tissue. Nonwoody roots, stems, and leaves are made up primarily of ground tissue. Cactus stems have large amounts of parenchyma cells for storing water in dry environments. Plants that grow in waterlogged soil often have parenchyma with large air spaces that allow air to reach the roots. Nonwoody plants that must be flexible to withstand wind have large amounts of collenchyma cells. Sclerenchyma cells are found where hardness is an advantage, such as in the seed coats of hard seeds and in the spines of cactuses.

Vascular Tissue System

Ground tissue surrounds the vascular tissue system, which functions in transport and support. Recall that the term vascular tissue refers to both xylem and phloem. Xylem tissue conducts water and mineral nutrients primarily from roots upward in the plant. Xylem tissue also provides structural support for the plant. Phloem tissue conducts organic compounds and some mineral nutrients throughout the plant. Unlike xylem, phloem is alive at maturity.

In angiosperms, xylem has two major components—tracheids and vessel elements. Both are dead cells at maturity. Look at Figure 29-2a. A tracheid (TRAY-kee-id) is a long, thick-walled sclerenchyma cell with tapering ends. Water moves from one tracheid to another through pits, which are thin, porous areas of the cell wall. A vessel element, shown in Figure 29-2b, is a sclerenchyma cell that has either large holes in the top and bottom walls or no end walls at all. Vessel elements are stacked to form long tubes called vessels. Water moves more easily in vessels than in tracheids. The xylem of most seedless vascular plants and most gymnosperms contains only tracheids, which are considered a primitive type of xylem cell. The vessel elements in angiosperms probably evolved from tracheids. Xylem also contains parenchyma cells.

The conducting parenchyma cell of angiosperm phloem is called a sieve tube member. Look at Figure 29-2c. Sieve tube members are stacked to form long sieve tubes. Compounds move from cell to cell through end walls called sieve plates. Each sieve tube member lies next to a companion cell, a specialized parenchyma cell that assists in transport. Phloem also usually contains sclerenchyma cells called fibers. Commercially important hemp, flax, and jute fibers are phloem fibers.

Vascular tissue systems are adapted to different environmental conditions. For example, xylem forms the wood of trees, providing the plants with strength while conducting water and mineral nutrients. In aquatic plants, such as duckweed, xylem is not necessary for support or water transport and may be nearly absent from the mature plant.
**TABLE 29-2  Types of Meristems**

<table>
<thead>
<tr>
<th>Type</th>
<th>Location</th>
<th>Growth function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical meristem</td>
<td>tips of stems and roots</td>
<td>increase length at tips</td>
</tr>
<tr>
<td>Intercalary meristem</td>
<td>between the tip and base of stems and leaves</td>
<td>increase length between nodes</td>
</tr>
<tr>
<td>Lateral meristem</td>
<td>sides of stems and roots</td>
<td>increase diameter</td>
</tr>
</tbody>
</table>

**PLANT GROWTH**

Plant growth originates mainly in meristems (MER-i-STEMZ), regions where cells continuously divide. Look at Table 29-2. Most plants grow in length through apical (AP-i-kuhl) meristems located at the tips of stems and roots. Some monocots grow in length through intercalary (in-TUHR-kah-ler-ee) meristems located above the bases of leaves and stems. Intercalary meristems allow grass leaves to quickly regrow after being grazed or mowed.

Gymnosperms and most dicots also have lateral meristems, which allow stems and roots to increase in diameter. Lateral meristems are located near the outside of stems and roots. There are two types of lateral meristems. The vascular cambium, located between the xylem and phloem, produces additional vascular tissues. The cork cambium, located outside the phloem, produces cork. Cork cells replace the epidermis in woody stems and roots. Cork cells are dead cells that provide protection and prevent water loss.

You have probably noticed that trees grow taller and wider over time. Growth in length is called primary growth and is produced by apical and intercalary meristems. Growth in diameter is called secondary growth and is produced by the lateral meristems.

| 1. How do the structures of parenchyma cells, collenchyma cells, and sclerenchyma cells differ? |
| 2. Describe the structures of the three major plant tissue systems. |
| 3. What kind of meristems do monocots and dicots have in common? |

**CRITICAL THINKING**

5. **Making Comparisons** What vertebrate animal structures have cells that carry out functions similar to those of sclerenchyma?

6. **Applying Information** Describe some factors that may influence the transport of water through xylem tissue.

7. **Analyzing Information** Describe how the plant kingdom would be different if plant growth only occurred in lateral meristems.
Plants have three kinds of organs—roots, stems, and leaves. A plant’s root system includes the structures that typically grow underground. Roots are important because they anchor the plant in the soil. They also absorb and transport water and mineral nutrients. The storage of water and organic compounds is provided by roots.

**TYPES OF ROOTS**

When a seed sprouts, it produces a primary root. If this first root becomes the largest root, it is called a *taproot*, as illustrated in Figure 29-3a. Many plants, like carrots and certain trees, have taproots. Contrary to what you might think, even taproots rarely penetrate the ground more than a meter or two. A few species, such as cottonwoods, do have some roots that grow 50 m (164 ft) deep to tap into underground water supplies.

In some plants, the primary root does not become large. Instead, numerous small roots develop and branch to produce a *fibrous root system*, like that shown in Figure 29-3b. Many monocots, such as grasses, have fibrous root systems. Fibrous roots of monocots often develop from the base of the stem rather than from other roots.

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**VOCABULARY**

- taproot
- fibrous root system
- adventitious root
- root cap
- root hair
- cortex
- endodermis
- pericycle
- macronutrient
- micronutrient

---

![Image](https://www.scilinks.org/topic/Types_of_Roots/Keyword:HM61572)

**FIGURE 29-3**

Plants can have either a taproot or a fibrous root system. (a) Many dicots, including the radish, have a large central taproot with small lateral roots. (b) Most monocots, including grasses, have a highly branched fibrous root system.
Specialized roots that grow from uncommon places, such as stems and leaves, are called **adventitious roots**. Figure 29-4a shows the prop roots of corn, which help keep the plant’s stems upright. The aerial roots of an epiphytic orchid, shown in Figure 29-4b, obtain water and mineral nutrients from the air. Aerial roots on the stems of ivy and other vines enable them to climb walls and trees.

**ROOT STRUCTURES**

Root structures are adapted for several functions. Study Figure 29-5. Notice that the root tip is covered by a protective **root cap**, which covers the apical meristem. The root cap produces a slimy substance that functions like lubricating oil, allowing the root to move more easily through the soil as it grows. Cells that are crushed or knocked off the root cap as the root moves through the soil are replaced by new cells produced in the apical meristem, where cells are continuously dividing.

**Root hairs**, which are extensions of epidermal cells, increase the surface area of the root and thus increase the plant’s ability to absorb water and minerals from the soil. Root hairs are shown in Figure 29-5. Most roots form symbiotic relationships with fungi to form a **mycorrhiza**. The threadlike hyphae of a mycorrhiza also increase the surface area for absorption. The spreading, usually highly branched root system increases the amount of soil that the plant can “mine” for water and mineral nutrients and aids in anchoring the plant. The large amount of root parenchyma usually functions in storage and general metabolism. Roots are dependent on stems and leaves for their energy, so they must store starch to use as an energy source during periods of little or no photosynthesis, such as winter.
Primary Growth in Roots

Roots increase in length through cell division, elongation, and maturation in the apical meristem in the root tip (shown in Figure 29-5 on the previous page). Dermal tissue matures to form the epidermis, which is the outermost boundary of the root. Ground tissue in roots matures into two different, specialized regions: the cortex and the endodermis. The cortex is located just inside the epidermis, as you can see below in Figure 29-6. This largest region of the primary root is made of loosely packed parenchyma cells.

The innermost boundary of the cortex is the endodermis (én-doh-DUHR-mis), also shown in Figure 29-6. Endodermal cell walls contain a narrow band of a waterproof substance that stops the movement of water beyond the endodermal cells. To enter farther into the root than the endodermis, water and dissolved substances must pass through a selectively permeable membrane. Once past this membrane, dissolved substances can move from cell to cell via small channels in cell walls that interconnect the cytoplasm of adjoining cells, including those of the endodermis. The endodermis thus controls the flow of dissolved substances into the vascular tissue of the root. The endodermis also prevents dissolved substances from backing into the cortex.

Vascular tissue in roots matures into the innermost core of the root. In most dicots and gymnosperms, xylem makes up the central core of the root, as shown in Figure 29-6a. Dicot root xylem usually forms an X-shaped structure with pockets of phloem between the xylem lobes. In monocots, the center of the root usually contains a pith of parenchyma cells, as Figure 29-6b shows. Monocot root xylem occurs in many patches that circle the pith. Small areas of phloem occur between the xylem patches.
The vascular tissues of a primary root are surrounded by the pericycle, a tissue that produces lateral roots. The pericycle is also shown in Figure 29-6 on the previous page.

**FIGURE 29-7**
The vascular tissues of a primary root are surrounded by the pericycle, a tissue that produces lateral roots. The pericycle is also shown in Figure 29-6 on the previous page.

The outermost layer or layers of the central vascular tissues is termed the **pericycle** (PER-i-SIE-kuhl). Lateral roots are formed by the division of pericycle cells. The developing lateral root connects its vascular tissues and endodermis to those of the parent root. Figure 29-7 shows how a lateral root grows out through the parent root’s endodermis and cortex, finally emerging from the epidermis.

**Secondary Growth in Roots**

Dicot and gymnosperm roots often experience secondary growth. Secondary growth begins when a pericycle and other cells form a vascular cambium between primary xylem and primary phloem. The vascular cambium produces secondary xylem toward the inside of the root and secondary phloem toward the outside. The expansion of the vascular tissues in the center of the root crushes all the tissues external to the phloem, including the endodermis, cortex, and epidermis. A cork cambium develops in the pericycle, replacing the crushed cells with cork.

**ROOT FUNCTIONS**

Besides anchoring a plant in the soil, roots serve two other primary functions. First, they absorb water and a variety of minerals or mineral nutrients that are dissolved in water in the soil. Roots are selective about which minerals they absorb. Roots absorb some minerals and exclude others. Table 29-3 on the next page lists the 13 minerals that are essential for all plants. They are absorbed mainly as ions. Carbon, hydrogen, and oxygen are not listed because they are absorbed as water and carbon dioxide.

Plant cells use some minerals, such as nitrogen and potassium, in large amounts. These elements are called **macronutrients** and usually are required in amounts greater than 1,000 mg/kg of dry matter. Plant cells use other minerals, such as manganese, in smaller amounts. These are called **micronutrients** and usually are required in amounts less than 100 mg/kg of dry matter.

Adequate amounts of all 13 mineral nutrients in Table 29-3 are required for normal growth. Plants with deficiencies show characteristic symptoms and reduced growth. Severe mineral deficiencies can kill a plant. Excess amounts of some essential mineral nutrients also can be toxic to a plant.
What are the differences between a taproot, a fibrous root system, and an adventitious root?

Explain how root hairs increase the ability of a plant to absorb water from the soil the plant grows in.

State one function of a root cap.

What is the difference between primary growth and secondary growth in roots?

What are the major functions performed by the root systems of plants?

Why might a taproot be an advantage to some plants, whereas a fibrous root system might be an advantage to others?

How are the roots of most plants adapted to perform the major root functions?

Suggest an environmental condition in which the regulation of water movement by endodermal cells might help ensure a plant’s survival.
In contrast to roots, which are mainly adapted for absorption and anchoring, stems are usually adapted to support leaves. Whatever their sizes and shapes, stems also function in transporting materials and providing storage.

### TYPES OF STEMS

A typical stem grows upright and is either woody or nonwoody. The many different forms of stems seen in nature, including those shown in Figure 29-8, represent adaptations to the environment. Strawberry stolons grow along the soil surface and produce new plants. Stems such as the edible white potato tuber are modified for storing energy as starch. Cactuses have green fleshy stems that both store water and carry on all the plant’s photosynthesis. Stems of the black locust and the honeylocust develop sharp thorns that can protect the plant from animals.

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**FIGURE 29-8**

Stems provide a supporting framework for leaves. Some plants produce stems that are modified for other functions. (a) A strawberry plant has stolons, which are horizontal, above-ground stems that form new plants. (b) The potato plant has tubers, which are enlarged, short, underground stems used for storing starch. (c) A cactus is called a *succulent* because of its fleshy, water-storing stems.
STEM STRUCTURES

Stems have a more complex structure than roots, yet they are similar in many ways. Did you know that a sign nailed 2 m (about 7 ft) high on a tree will remain 2 m high, even though the tree may grow much taller? That is because most stems, like roots, grow in length only at their tips, where apical meristems produce new primary tissues. Stems, like roots, grow in circumference through lateral meristems.

Stems have several features that roots lack, as Figure 29-9 shows. Each leaf is attached to the stem at a location called a node. The spaces between nodes are called internodes. At the point of attachment of each leaf, the stem bears a lateral bud. A bud is capable of developing into a new shoot system (the above-ground part of a plant, consisting of stems and leaves). A bud contains an apical meristem and is enclosed by specialized leaves called bud scales. The tip of each stem usually has a terminal bud.

**Quick Lab**

**Observing Stems**

**Materials** winter twig, fresh stem with leaves, hand lens or dissecting microscope

**Procedure**

1. Observe the twig with the hand lens. Locate several buds, and identify the bud scales. Locate leaf scars. Identify a node and an internode. Draw and label the twig.
2. Observe the fresh stem with the hand lens. Locate and identify the stem, nodes, internodes, buds, and a leaf. Draw and label the fresh stem.

**Analysis** How are a node and an internode related? How are a bud and a node related? How are the two stems alike? How are they different?

**FIGURE 29-9**

Apical meristems, responsible for the primary elongation of the plant body, are found in the shoot system and root system. Each leaf is attached to the stem at a node. The space between nodes, called the internode, is much larger in the older part of the stem.
In some plants that live in cold winter environments, the terminal bud opens and the bud scales fall off when growth resumes in the spring. The bud scales leave scars on the stem surface. Trees and shrubs often are identified in winter by stem characteristics.

Root tips usually have a protective layer, the root cap. The stem apical meristem is protected by bud scales only when the stem is not growing. A surface bud forms very close to the stem tip with one or more buds at each node. In contrast, lateral roots originate farther back from the root tip and form deep inside the root at no particular location along the root axis.

**Primary Growth in Stems**

As in roots, apical meristems of stems give rise to the dermal, ground, and vascular tissues. Locate each of these tissues in Figure 29-10. The dermal tissue is represented by the epidermis, or the outer layer of the stem. Its main functions are to protect the plant and to reduce the loss of water to the atmosphere while still allowing gas exchange through stomata.

In gymnosperm and dicot stems, ground tissue usually forms a cortex and a pith. The cortex frequently contains flexible collenchyma cells. The pith is located in the center of the stem. The ground tissue of monocot stems is usually not clearly separated into pith and cortex.

Vascular tissue formed near the apical meristem occurs in bundles—long strands that are embedded in the cortex. Look at the vascular bundles in Figure 29-10. Each bundle contains xylem tissue and phloem tissue. Xylem is usually located toward the inside of the stem, while phloem is usually located toward the outside.

Compare the arrangement of vascular bundles in monocots and dicots. Monocot stem vascular bundles are usually scattered throughout the ground tissue. Stem vascular bundles of dicots and gymnosperms usually occur in a single ring. Most monocots have little or no secondary growth, and they retain the primary growth pattern their entire lives. However, in many dicots and gymnosperms, the primary tissues are eventually replaced by secondary tissues.

**Secondary Growth in Stems**

Stems increase in thickness due to the division of cells in the vascular cambium. The vascular cambium in dicot and gymnosperm stems first arises between the xylem and phloem in a vascular bundle. Eventually, the vascular cambium forms a boundary. The vascular cambium produces secondary xylem to the inside and secondary phloem to the outside. It usually produces much more secondary xylem than it does secondary phloem. Secondary xylem is called wood. Occasionally, the vascular cambium produces new cambium cells, which increase the stem’s diameter.
Older portions of the xylem eventually stop transporting water. They often become darker than the newer xylem due to the accumulation of resins and other organic compounds produced by the few live cells remaining in the xylem. This darker wood in the center of a tree is called heartwood, as shown in Figure 29-11a. The functional, often lighter-colored wood nearer the outside of the trunk is sapwood. In a large-diameter tree, the heartwood keeps getting wider while the sapwood remains about the same thickness.

The phloem produced near the outside of the stem is part of the bark. Bark is the protective outside covering of woody plants. It consists of cork, cork cambium, and phloem. The cork cambium produces cork near the outside. However, cork cells are dead at maturity and cannot elongate, so the cork ruptures as the stem continues to expand in diameter. This results in the bark pattern of some trees, such as oaks and maples, appearing rough or irregular in texture.

During spring, if water is plentiful, the vascular cambium can form new xylem with cells that are wide and thin walled. This wood is called springwood, as shown in Figure 29-11b. In summer, when water is limited, the vascular cambium produces summerwood, which has smaller cells with thicker walls. In a stem cross section, the abrupt change between small summerwood cells and the following year’s large springwood cells produces an annual ring. The circles that look like rings on a target in Figure 29-11a are the annual rings of the stem. Because one ring is usually formed each year, you can estimate the age of the stem by counting its annual rings. Annual rings also form in dicot and gymnosperm roots, but they are often less pronounced because the root environment is more uniform. Annual rings often do not occur in tropical trees because of their uniform year-round environment.
Stems function in the transportation of nutrients and water, the storage of nutrients, and the support of leaves. Sugars, some plant hormones, and other organic compounds are transported in the phloem. The movement of sugars occurs from where the sugars are made or have been stored, called a source. The place where they will be stored or used is called a sink. Botanists use the term translocation to refer to the movement of sugars through the plant. For example, most of the time, sugars move from the leaves to the roots, to the shoot apical meristems, and to the developing flowers or fruits. Sugars may be newly made in photosynthetic cells or may have been stored as starch in roots or other stems.

Movement of sugars in the phloem is explained by the pressure-flow hypothesis, which states that sugars are actively transported into sieve tubes. Look at Figure 29-12. As sugars enter the sieve tubes, water is also transported in by osmosis. Thus, a positive pressure builds up at the source end of the sieve tube. This is the pressure part of the pressure-flow hypothesis.

At the sink end of the sieve tube, this process is reversed. Sugars are actively transported out, water leaves the sieve tube by osmosis, and pressure is reduced at the sink. The difference in pressure causes water to flow from source to sink. This water is also carrying dissolved substances with it. Transport in the phloem can occur in different directions at different times.

**FIGURE 29-12**

1. Sugars from a source enter the sieve tubes of the phloem.
2. Water moves from the xylem to the phloem by osmosis.
3. The water creates pressure that moves the sugars down the phloem.
4. The sugars exit the phloem and enter the sink, where they will be used or stored.

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Transport of Water

The transport of water and mineral nutrients occurs in the xylem of all plant organs, but it occurs over the greatest distances in the stems of tall trees. During the day, water is constantly evaporating from the plant, mainly through leaf stomata. This water loss is called transpiration (TRAN-spuh-RAH-shuhn). The large amount of water lost from the plant is a result of the plant’s need to obtain carbon dioxide from the air through the stomata. Exactly how do huge trees, like redwoods, move water and mineral nutrients up their 100 m tall trunks?

According to the cohesion-tension theory, water is pulled up the stem xylem by the strong attraction of water molecules to each other, a property of water called cohesion. The movement also depends on the rigid xylem walls and the strong attraction of water molecules to the xylem wall, which is called adhesion. The thin, continuous columns of water extend from the leaves through the stems and into the roots. As water evaporates from the leaf, the water column is subject to great tension. However, the water column does not break because of cohesion, and it does not pull away from the xylem walls because of adhesion. The only other possibility is for it to be pulled upward. The pull at the top of the tree extends all the way to the bottom of the column. As water is pulled up the xylem, more water enters the roots from the soil.

Storing Water and Nutrients

With abundant parenchyma cells in the cortex, plant stems are adapted for storage in most species. In some species, storage is a major function. Cactus stems are specialized for storing water. The roots of a cactus are found close to the soil surface, enabling them to absorb rainwater quickly and transport it to the cactus’s fleshy stem. The edible white potato is an underground stem that is specialized for storing starch. The “eyes” of white potatoes are buds that have the ability to develop into new shoots.

1. Explain why a plant species might develop thorny stems in response to its environment.
2. Describe the similarities of the apical meristems of roots to the apical meristems of stems.
3. Compare primary growth in monocots with primary growth in dicots.
4. Describe how summerwood and springwood form annual rings.
5. Describe how water is transported through xylem tissue.

CRITICAL THINKING

6. Analyzing Information Some squirrels damage trees by stripping off portions of the bark. Why might a squirrel eat bark?
7. Evaluating Differences What adaptive advantages might the dead cells of the xylem tissue provide over transporting cells that are alive?
8. Inferring Relationships The transport cells of the phloem tissue are connected end to end, and sugars flow through them. What inferences can you make about the contents of these cells?
HYPOTHESIS: Chimpanzees Eat Some Plants for Medicinal Purposes

Researchers studying chimpanzees in Africa have noted that chimps have an unusual feeding habit when they are ill. Before eating the shoots of the plant Vernonia amygdalina, chimps carefully remove the outer bark and leaves to chew on the exposed pith, the spongy material found in some vascular plants. The chimps extract juice from the pith, which the researchers found odd because the juice is extremely bitter. Even though the plant is available year-round, chimps rarely eat it. Based on his observations and those of other scientists, Michael A. Huffman, a researcher at the Primate Research Institute in Japan, wanted to find out whether chimps are self-medicating by eating these plants.

METHODS: Observe Behavior, Collect Samples, and Test Plants

Huffman began by collecting chimpanzee fecal samples at Mahale, Tanzania. He also made detailed observations of as many individual chimps as possible. The fecal samples were from chimps seen eating V. amygdalina during times of apparent illness. Huffman collaborated with other scientists already studying chemicals found in V. amygdalina.

RESULTS: Chimps Recover; Fecal Samples Contain Parasites; Plant Analysis Reveals Antiparasitic Compounds

Huffman and his colleagues found that within 24 hours after eating V. amygdalina, chimps regain their appetites, have reduced numbers of parasites, and recover from constipation or diarrhea. Scientists working with Huffman showed that the pith of V. amygdalina contains several bioactive chemicals. Tests revealed that these chemicals are effective against many different parasites. For example, vernonioside B1 and vernoniol B1 were shown to suppress movement and egg laying in Schistosoma japonicum, a parasitic worm. Scientists also found that chemicals from the pith are effective against drug-resistant malarial parasites.

CONCLUSIONS: Chimpanzees Self-Medicate by Eating Plants with Beneficial Chemical Compounds

Interestingly, a more toxic compound, vernodalin, was found in the leaves. The pith of the plant instead contained large amounts of vernonioside B1. This same pattern was later verified in analyses of other V. amygdalina specimens collected at various locations in Mahale during different seasons. Huffman and his colleagues think that because chimps discard the bark and leaves and just eat the pith, the chimps have learned that certain parts of the plant are harmful and certain parts are beneficial.

Additional research has revealed that V. amygdalina has been part of Tanzanian folk medicine for years. The WaTongwe people of this area use V. amygdalina for stomachaches and parasitic infections. Other African tribes use V. amygdalina to treat ailments in their livestock, which suggests agricultural applications for other countries.

REVIEW

1. What observations led Huffman to propose his hypothesis?
2. Can chimpanzees learn from experience? Explain your reasoning.
3. Critical Thinking Why was it important for Huffman to work with other scientists?
Leaves

Most leaves are thin and flat, an adaptation that helps them capture sunlight for photosynthesis. Although this structure may be typical, it is certainly not universal. Like roots and stems, leaves are extremely variable. This variability represents adaptations to environmental conditions.

Types of Leaves

Look at the leaves in Figure 29-13a. The coiled structure is a tendril, a modified leaf found in many vines, such as peas and pumpkins. It wraps around objects and supports the climbing vine. In some species, like grape, tendrils are specialized stems.

An unusual leaf modification occurs in carnivorous plants such as the pitcher plant, shown in Figure 29-13b. In carnivorous plants, leaves function as food traps. These plants grow in soil that is poor in several mineral nutrients, especially nitrogen. The plant receives substantial amounts of mineral nutrients when it traps and digests insects and other small animals.

Leaves, or parts of leaves, are often modified into spines that protect the plant from being eaten by animals, as shown in Figure 29-13c. Because spines are small and nonphotosynthetic, they greatly reduce transpiration in desert species such as cactuses.
Leaves come in a wide variety of shapes and sizes and are an important feature used for plant identification. Leaves can be round, straplike, needlelike, or heart-shaped. The broad, flat portion of a leaf, called the **blade**, is the site of most photosynthesis. The blade is usually attached to the stem by a stalklike **petiole**. The maple leaf shown in Figure 29-14a is a **simple leaf**; it has a single blade. In **compound leaves**, such as the white clover in Figure 29-14b, the blade is divided into **leaflets**. In some species, the leaflets themselves are divided. The result is a **doubly compound leaf**, such as that of the honeylocust shown in Figure 29-14c.

Leaves consist of three tissue systems. The **dermal tissue system** is represented by the epidermis. In most leaves the epidermis is a single layer of cells coated with a nearly impermeable cuticle. Water, oxygen, and carbon dioxide enter and exit the leaf through **stomata** in the epidermis. Epidermal hairs are often present and usually function to protect the leaf from insects and intense light.

The number of stomata per unit area of leaf varies by species. For example, submerged leaves of aquatic plants have few or no stomata. Corn leaves have up to 10,000 stomata per square centimeter on both upper and lower surfaces. Scarlet oak has over 100,000 stomata per square centimeter on the lower leaf surface and none on the upper surface. Regardless of their exact distribution, stomata are needed to regulate gas exchange.

In most plants, photosynthesis occurs in the leaf **mesophyll** (MEZ-oh-FIL), a ground tissue composed of chloroplast-rich parenchyma cells. In most plants, the mesophyll is organized into two layers, which are shown in Figure 29-15 on the next page. The **palisade mesophyll** layer occurs directly beneath the upper epidermis and is the site of most photosynthesis. Palisade cells are columnar and appear to be packed tightly together in one or two layers. However, there are air spaces between the long side walls of palisade cells. Beneath the palisade layer is the **spongy mesophyll**. It usually consists of irregularly shaped cells surrounded by large air spaces, which allow oxygen, carbon dioxide, and water to diffuse into and out of the leaf.

The vascular tissue system of leaves consists of vascular bundles called **veins**. Veins are continuous with the vascular tissue of the stem and the petiole, and they lie embedded in the mesophyll. Veins branch repeatedly so that each cell is usually less than 1 mm (0.04 in.) from a vein.

**Venation** is the arrangement of veins in a leaf. Leaves of most monocots, such as grasses, have **parallel venation**, meaning that several main veins are roughly parallel to each other. The main veins are connected by small, inconspicuous veins. Leaves of most dicots, such as sycamores, have **net venation**, meaning that the main vein or veins repeatedly branch to form a conspicuous network of smaller veins.
LEAF FUNCTIONS

Leaves are the primary site of photosynthesis in most plants. Mesophyll cells in leaves use light energy, carbon dioxide, and water to make sugars. Light energy also is used by mesophyll cells to synthesize amino acids and a variety of other organic molecules. Sugars made in a leaf can be used by the leaf as an energy source or as building blocks for cells. They also may be transported to other parts of the plant, where they are either stored or used for energy or building blocks.

A major limitation to plant photosynthesis is insufficient water due to transpiration. For example, up to 98 percent of the water that is absorbed by a corn plant’s roots is lost through transpiration. However, transpiration may benefit the plant by cooling it and by speeding the transport of mineral nutrients through the xylem.

Modifications for Capturing Light

Leaves absorb light, which, in turn, provides the energy for photosynthesis. The leaves of some plant species have adapted to their environment to maximize light interception. On the same tree, leaves that develop in full sun are thicker, have a smaller area per leaf, and have more chloroplasts per unit area. Shade-leaf chloroplasts are arranged so that shading of one chloroplast by another is minimized, while sun-leaf chloroplasts are not.

In dry environments, plants often receive more light than they can use. Structures have evolved in these plants that reduce the amount of light absorbed. For example, many desert plants have evolved dense coatings of hairs that reduce light absorption. The cut window plant shown in Figure 29-16 protects itself from its dry environment by growing underground. Only its leaf tips protrude above the soil to gather light for photosynthesis.
CHAPTER 29

Gas Exchange

Plants must balance their need to open their stomata to receive carbon dioxide and release oxygen with their need to close their stomata to prevent water loss through transpiration. A stoma is bordered by two kidney-shaped guard cells. Guard cells, shown in Figure 29-15 on the previous page, are modified cells on the leaf epidermis that regulate gas and water exchange. Figure 29-17 shows how the stomata are arranged differently in monocots and dicots.

The stomata of most plants open during the day and close at night. The opening and closing of a stoma is regulated by the amount of water in its guard cells. When epidermal cells of leaves pump potassium ions (K⁺) into guard cells, water moves into the guard cells by osmosis. This influx of water makes the guard cells swell, which causes them to bow apart and form a pore. During darkness, potassium ions are pumped out of the guard cells. Water then leaves the guard cells by osmosis. This causes the guard cells to shrink slightly and the pore to close.

Stomata also close if water is scarce. The closing of stomata greatly reduces further water loss and may help the plant survive until the next rain. However, stomata closure virtually shuts down photosynthesis by cutting off the supply of carbon dioxide.

SECTION 4 REVIEW

1. Describe three adaptations found in different types of leaves.
2. What is the difference between a simple leaf, a compound leaf, and a doubly compound leaf?
3. Describe the basic function of each of the three leaf tissues.
4. Explain the function of the guard cells in regulating the opening and closing of stomata on a leaf’s surface.

CRITICAL THINKING

5. Evaluating Information Why might it be an advantage for a plant to have most of its stomata on the underside of a horizontal leaf?
6. Inferring Relationships Why do plants grown in greenhouses in winter rarely grow as fast as the same type of plant grown outside in the summer, even if the temperatures are the same?
7. Predicting Results Suppose a plant had a mutation that produced defective potassium ion pumps. What might happen to this plant?
### SECTION 1  Plant Cells and Tissues

- Parenchyma, collenchyma, and sclerenchyma are basic plant cell types.
- The three types of plant tissue systems are dermal, ground, and vascular.

#### Vocabulary
- parenchyma (p. 583)
- collenchyma (p. 583)
- sclerenchyma (p. 584)
- epidermis (p. 584)
- cuticle (p. 584)
- tracheid (p. 585)
- pit (p. 585)
- vessel element (p. 585)
- vessel (p. 585)
- sieve tube member (p. 585)
- sieve tube (p. 585)
- sieve plate (p. 585)
- companion cell (p. 585)
- meristem (p. 586)
- apical meristem (p. 586)
- lateral meristem (p. 586)
- vascular cambium (p. 586)
- cork cambium (p. 586)

### SECTION 2  Roots

- A taproot is a large primary root. A fibrous root system has many small branching roots. Adventitious roots are specialized roots that grow from uncommon places.
- Roots are made up of root caps, apical meristems, and root hairs.

#### Vocabulary
- taproot (p. 587)
- fibrous root system (p. 587)
- adventitious root (p. 588)
- root cap (p. 588)
- root hair (p. 588)
- cortex (p. 589)
- endodermis (p. 589)
- pericycle (p. 590)
- macronutrient (p. 590)
- micronutrient (p. 590)

### SECTION 3  Stems

- Stem shape and growth are adaptations to the environment.
- Both nonwoody and woody stems contain xylem and phloem.

#### Vocabulary
- node (p. 593)
- internode (p. 593)
- bud (p. 593)
- bud scale (p. 593)
- pith (p. 594)
- wood (p. 594)
- heartwood (p. 595)
- sapwood (p. 595)
- bark (p. 595)
- springwood (p. 595)
- summerwood (p. 595)
- annual ring (p. 595)
- source (p. 596)
- sink (p. 596)
- translocation (p. 596)
- pressure-flow hypothesis (p. 596)
- transpiration (p. 597)
- cohesion-tension theory (p. 597)

### SECTION 4  Leaves

- The variability in leaf structures represents adaptations to environmental conditions. Leaves may be simple, compound, or doubly compound.
- Photosynthesis occurs mostly in the mesophyll.
- Some leaves are modified to maximize light interception. Gas exchange is controlled by stomata.

#### Vocabulary
- tendril (p. 599)
- blade (p. 600)
- petiole (p. 600)
- simple leaf (p. 600)
- compound leaf (p. 600)
- leaflet (p. 600)
- mesophyll (p. 600)
- palisade mesophyll (p. 600)
- spongy mesophyll (p. 600)
- vein (p. 600)
- venation (p. 600)
- net venation (p. 600)
- guard cell (p. 602)
CHAPTER REVIEW

USING VOCABULARY

1. For each pair of terms, explain the relationship between the terms.
   a. taproot and fibrous root
   b. sieve tube member and vessel element
   c. transpiration and translocation
2. Use the following terms in the same sentence:
   parenchyma, collenchyma, and sclerenchyma.
3. For each pair of terms, explain how the meanings of the terms differ.
   a. apical meristem and lateral meristem
   b. simple leaf and compound leaf
   c. root hair and root cap
4. Word Roots and Origins The word mesophyll is derived from the Latin meso, which means “middle,” and the Greek phyllon, which means “leaf.” Using this information, explain why the term mesophyll is a good name for the part of the leaf that the term describes.

UNDERSTANDING KEY CONCEPTS

5. Compare the structure and function of parenchyma, collenchyma, and sclerenchyma cells.
6. Compare the functions of the three plant tissue systems.
7. Differentiate the type of growth that occurs in each of the three kinds of meristems.
8. Explain the difference between primary growth and secondary growth.
9. Name two types of adventitious roots.
10. Sequence the structures of a root that a water molecule would pass through as it enters and then moves through a plant.
11. Relate what causes a plant stem or root to grow in diameter.
12. Name two familiar examples of carbohydrate storage in roots.
15. Explain how annual rings form in a woody plant.
16. Differentiate between the mechanisms of water and sugar transport in a plant.
17. Explain why all leaves do not look alike.
18. Describe the structure of a doubly compound leaf.
19. Name the type of plant tissue that makes up the mesophyll.
20. Identify a leaf adaptation for maximizing light interception.

CONCEPT MAPPING

Use the following terms to create a concept map that illustrates the structures and functions of one type of plant tissue: phloem, vessel, sieve tube member, tracheid, vascular tissue, vessel element, carbohydrates, and xylem.

CRITICAL THINKING

22. Applying Information When transplanting a plant, it is important to not remove any more soil than necessary from around the root system. From your knowledge of the function of roots and root hairs, why do you think this is so important?
23. Analyzing Data Suppose you examine a tree stump and notice that the annual rings are thinner and closer together 50 rings in from the edge. What would you conclude about the climate in the area 50 years ago?
24. Applying Information Why would an agricultural practice that eliminated transpirational water loss be disadvantageous for plants?
25. Evaluating Differences Would you expect water absorption in a plant to be greater in parts of roots that have undergone secondary growth or in parts that have not? Explain your reasoning.
26. Interpreting Graphics What causes a knot in a board, like the one shown in the photo below?
1. Which of the following are the main function of collenchyma and sclerenchyma?
   A. storage
   B. support
   C. transport
   D. photosynthesis

2. Most monocots do not have which of the following?
   F. xylem
   G. phloem
   H. primary growth
   J. secondary growth

3. Which of the following structures is found in stems but not in roots?
   A. node
   B. cortex
   C. epidermis
   D. vascular tissue

4. The movement of water through a plant is driven by the loss of water vapor from which structure?
   F. buds
   G. nodes
   H. leaves
   J. root hairs

5. What is the structure marked with an X?
   A. xylem
   B. cortex
   C. phloem
   D. endodermis

6. Mesophyll : photosynthesis :: sapwood :
   F. storage
   G. sugar transport
   H. water transport
   J. production of new cells

7. What type of leaf is shown?
   A. tendril
   B. simple
   C. compound
   D. doubly compound

**SHORT RESPONSE**

The primary function of leaves is to carry out photosynthesis.

Explain how a leaf’s structure is an adaptation that allows intake of carbon dioxide with minimal water loss.

**EXTENDED RESPONSE**

A stem contains tissues that transport water along with dissolved minerals and sugars.

Part A Identify the cells that transport water, and describe how water moves through a plant.

Part B Identify the cells that transport sugar, and describe how sugars move through a plant.
Observing Roots, Stems, and Leaves

OBJECTIVES

■ Observe the tissues and structures that make up roots, stems, and leaves.
■ Explain how roots, stems, and leaves are adapted for the functions they perform.

PROCESS SKILLS

■ observing
■ identifying
■ relating structure and function

MATERIALS

■ prepared slides of the following tissues:
  ■ *Allium* root tip longitudinal section
  ■ *Syringa* leaf cross section
  ■ *Ranunculus* root cross section
  ■ *Ranunculus* stem cross section
  ■ *Zea mays* stem cross section
■ compound light microscope

Background

1. Which plant tissues are responsible for the absorption of water and mineral nutrients?
2. How is sugar, which is produced in the leaf, moved to other parts of the plant?
3. How are woody and nonwoody stems different, and how are they alike?
4. What tissues are continuous in the root, stem, and leaf?
5. How does the leaf conserve water?

PART A Roots

1. **CAUTION** Glass slides may break and cut you. Observe the prepared slide of the *Allium* root tip under low power. Locate the root cap and the root tip meristematic cells. You may look at the photograph in the chapter for help. Note the long root hairs in the area above the root tip.
2. In your lab report, draw the root tip that you observe, and label the root cap, meristem, and root hairs in your drawings.

3. Change slides to the root cross section of the dicot *Ranunculus*. This slide should look similar to the photograph above. The inner core is the vascular tissue, which is surrounded by the endodermis. This area is involved in the transport of water, mineral nutrients, and organic compounds. Look for the X-shaped xylem and the smaller phloem cells surrounding the xylem.

4. In your lab report, draw what you see, and identify the xylem tissue and the phloem tissue in your drawing.

5. Locate the cortex, where starch is stored, which surrounds the vascular cylinder. Outside the cortex, find the epidermal cells and their root hairs. Draw a one-quarter section of the root tissues. Label all the tissues in your lab report.

PART B Stems

6. Observe a prepared slide of the stem of *Zea mays*, a monocot, and find the epidermis and the photosynthetic layer. It should look like the top photograph on the next page. In the center, look for the vascular bundles made up of xylem and phloem. Draw a diagram showing the location of the vascular bundles and the epidermis layer as they appear when viewed under low power.

7. Switch to high power, and observe a vascular bundle. Draw the vascular bundle, and label the tissues.

8. Observe a cross section of *Ranunculus*, a nonwoody dicot stem. Compare your slide with the photograph
11. Identify the stomata on the lower epidermis of the lilac leaf. Find the guard cells that open and close a particular stoma. Locate an open stoma and a closed stoma. Draw and label diagrams of the stomata and the guard cells in your lab report.

12. Look at the center part of the cross section. Note the spongy texture of the mesophyll layer. Locate a vein containing xylem and phloem. Now identify the palisade layer, the upper epidermis, and finally the clear, continuous, noncellular layer on top. This layer is called the cuticle. Draw and label a diagram of your observations in your lab report.

13. Clean up your materials before leaving the lab.

Analysis and Conclusions
1. In the dicot root that you observed, where are phloem and xylem located?
2. Where are the xylem and phloem found in the nonwoody stem that you observed?
3. How are the vascular bundles different in the monocot and dicot stems that you observed?
4. How are the root cap cells different from the root tip meristematic cells?
5. What is the function of the root hairs?
6. How do the arrangements of xylem and phloem differ in roots, stems, and leaves?
7. What is the function of a stoma?
8. What is the function of the air space in the mesophyll of the leaf?
9. Which leaf structures help to conserve water?
10. Which tissues of the leaf are continuous with the stem and root tissues? How is this functional?
11. Look at the various tissues found in your drawings of roots, stems, and leaves. Classify each tissue as either dermal tissue, ground tissue, or vascular tissue.

Further Inquiry
The parts of a flower are actually modified stems and leaves. Design—but do not carry out—a procedure for dissecting a flower. Include a diagram of the parts of the flower to be viewed. Use references from the library to determine which kinds of flowers are best for dissection.