23.1 Specialized Tissues in Plants

SC.912.L.14.7 Relate the structure of each of the major plant organs and tissues to physiological processes. Also covered: SC.912.N.1.1, SC.912.L.14.2

Key Questions

What are the three princi-
pal organs of seed plants?

What are the primary func-
ions of the main tissue systems
f seed plants?

How do meristems differ
m other plant tissues?

abulary

ermis • lignin •
l element •
tube element •
nion cell • parenchyma •
hyma • sclerenchyma •
m • apical meristem

Notes

Map As you read, make
t map to organize the
on in this lesson.

RY
UE

THINK ABOUT IT Have you ever wondered if plants were really alive? Compared to animals, plants don't seem to do much. If you look deep inside a living plant, this first impression of inactivity disappears. Instead, you will find a busy and complex organism. Plants move materials, grow, repair themselves, and constantly respond to the environment. They may act at a pace that seems slow to us, but their cells and tissues work together in remarkably effective ways.

Seed Plant Structure

What are the three principal organs of seed plants?

The cells of a seed plant are organized into different tissues, organs, and systems. **The three principal organs of seed plants are roots, stems, and leaves.** The organs are linked together by systems that run the length of the plant. These systems produce, store, and transport nutrients, and provide physical support and protection.

Roots Roots anchor plants in the ground, holding soil in place and preventing erosion. Root systems often work with soil bacteria and fungi in mutualistic relationships that help the roots absorb water and dissolved nutrients. Roots transport these materials to the rest of the plant, store food, and hold plants upright against forces such as wind and rain.

Stems Plant stems provide a support system for the plant body, a transport system that carries nutrients, and a defensive system that protects the plant against predators and disease. Stems also produce leaves and reproductive organs such as flowers. Whatever the size of a stem, its support system must be strong enough to hold up leaves and branches. The stem's transport system contains tissues that lift water from the roots up to the leaves and carry the products of photosynthesis from the leaves back down to the roots.

Leaves Leaves are the plant's main photosynthetic organs. The broad, flat surfaces of many leaves increase the amount of sunlight plants absorb. Leaves also expose a great deal of tissue to the dryness of the air and, therefore, have adaptations that protect against water loss. Adjustable pores in leaves help conserve water while letting oxygen and carbon dioxide enter and exit the leaf.

In Your Notebook

Plant Tissue Systems

What are the primary functions of the main tissue systems of seed plants?

Within the roots, stems, and leaves of plants are specialized tissue systems, shown in **Figure 23–1.** Plants have three main tissue systems: dermal, vascular, and ground. Dermal tissue covers a plant almost like skin covers you. Vascular tissue forms a system of pipelike cells that help support the plant and serve as its "bloodstream," transporting water and nutrients. Ground tissue produces and stores food. Next, you will see how the cells in these systems compare to one another.

Dermal Tissue Dermal tissue in young plants consists of a single layer of cells called the **epidermis** (ep uh DUR mis). The outer surfaces of epidermal cells are often covered with a thick waxy layer called the cuticle, which protects against water loss. Some epidermal cells have tiny projections known as trichomes (TRY kohmz). Trichomes help protect the leaf and may give the leaf a fuzzy appearance. **Dermal tissue is the protective outer covering of a plant.**

In older plants, dermal tissue may be many cell layers deep and may be covered with bark. In roots, dermal tissue includes root hair cells that help absorb water.

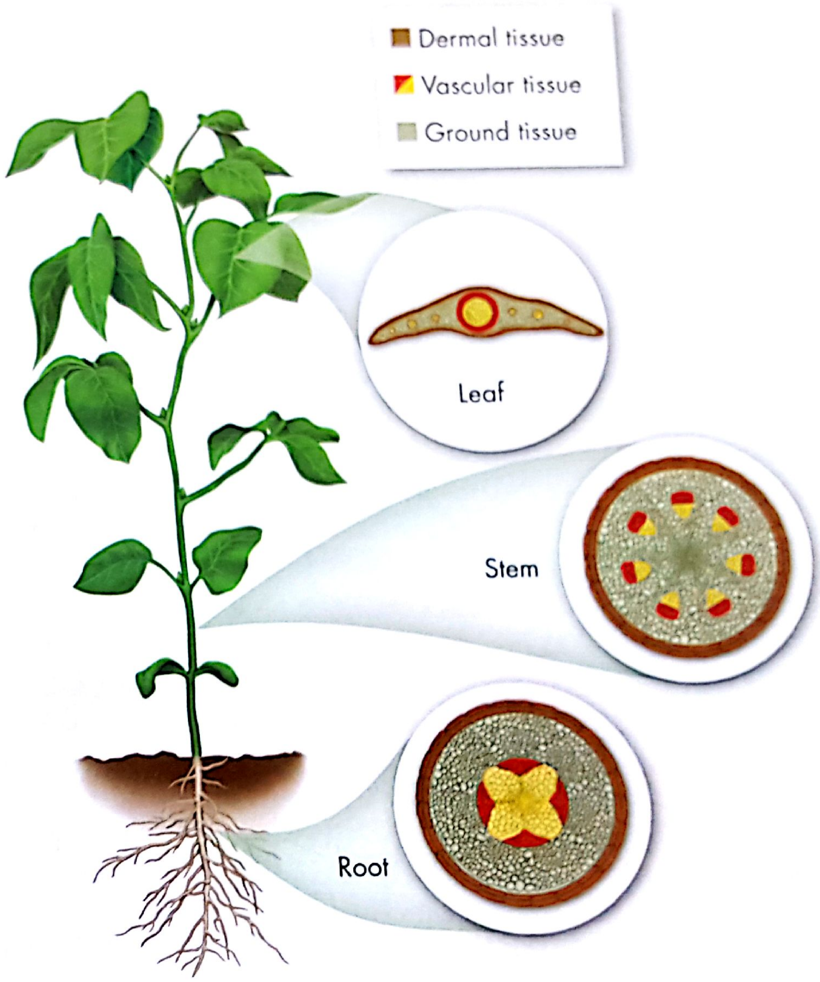
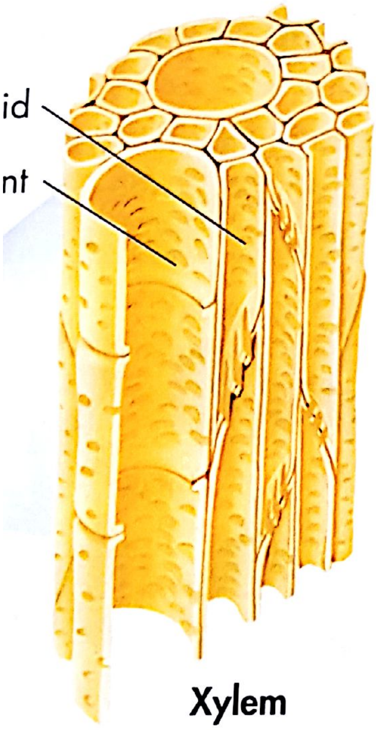


FIGURE 23–1 Principal Organs of Plants These cross sections of the principal organs of seed plants show that all three organs contain dermal tissue, vascular tissue, and ground tissue. **Interpret Visuals** ***Which tissue type is found in the center of a root?***

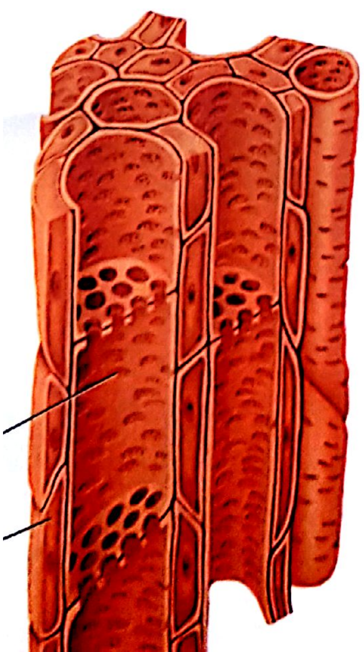
Vascular Tissue The two kinds of vascular tissue are xylem, a water-conducting tissue, and phloem, a tissue that carries dissolved food. As you can see in **Figure 23–2**, both xylem and phloem consist of long, slender cells that connect almost like sections of pipe. **Vascular tissue supports the plant body and transports water and nutrients throughout the plant.**

▶ ***Xylem: Tracheids*** All seed plants have xylem cells called tracheids. Recall from Chapter 22 that tracheids are long and narrow, with tough cell walls that help to support the plant. As they mature, tracheids die, leaving only their cell walls. These cell walls contain **lignin,** a complex molecule that resists water and gives wood much of its strength. Openings in the walls connect neighboring cells and allow water to flow from cell to cell. Thinner regions of the wall, known as pits, allow water to diffuse from tracheids into surrounding ground tissue. These adaptations allow tracheids to carry water throughout the plant and distribute it to tissues where it is needed.



Xylem

▶ ***Xylem: Vessel Elements*** In addition to tracheids, angiosperms possess a second form of xylem tissue known as a **vessel element.** Vessel elements are wider than tracheids and are arranged end to end on top of one another like a stack of tin cans. After they mature and die, cell walls at both ends are left with slitlike openings through which water can move freely. In some vessel elements, the end walls disappear altogether, producing a continuous tube.



▶ ***Phloem: Sieve Tube Elements*** Unlike xylem cells, phloem cells are alive at maturity. The main phloem cells are **sieve tube elements,** which are arranged end to end, forming sieve tubes. The end walls of sieve tube elements have many small holes through which nutrients move from cell to cell in a watery stream. As sieve tube elements mature, they lose their nuclei and most other organelles. The remaining organelles hug the inside of the cell wall and are kept alive by companion cells.

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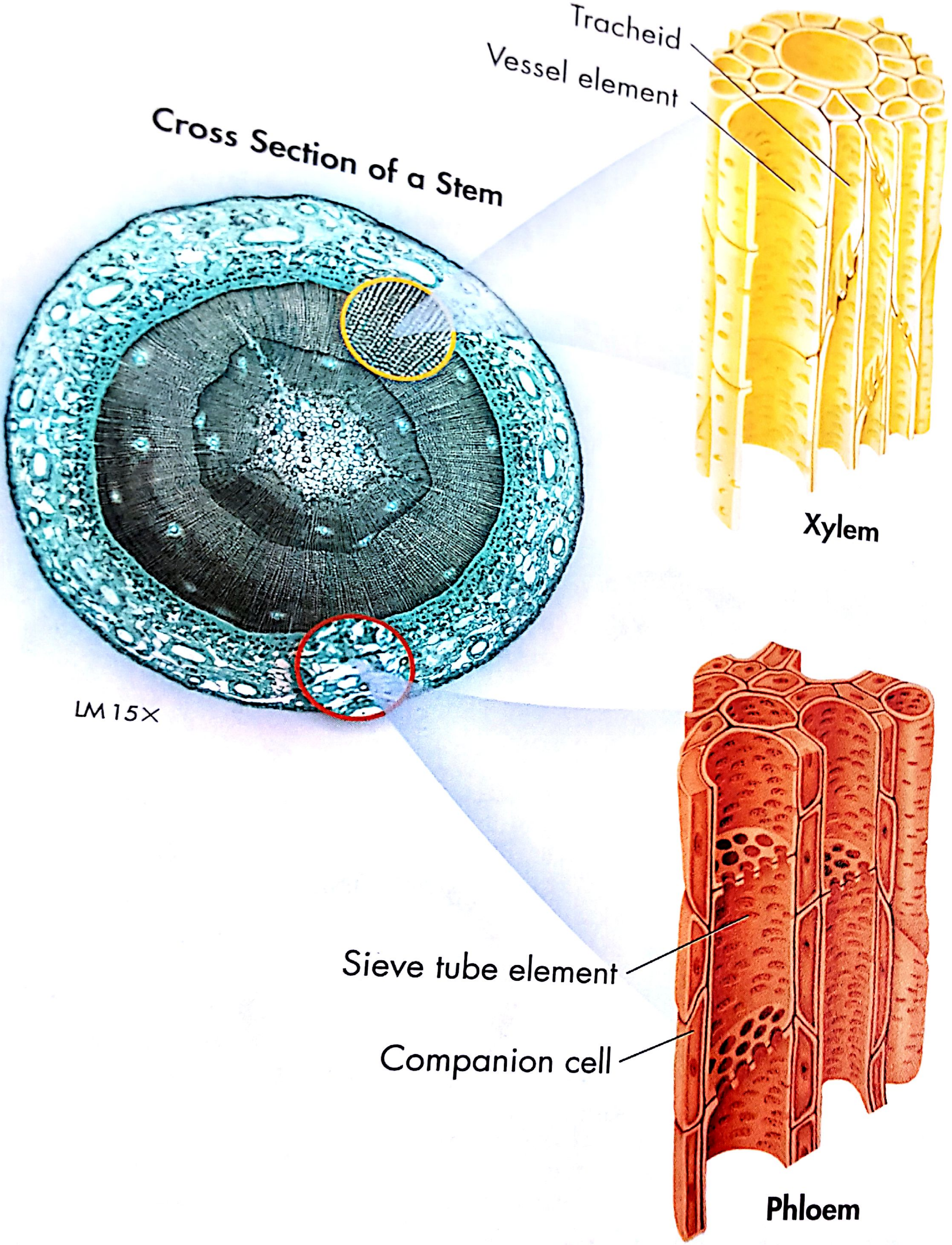
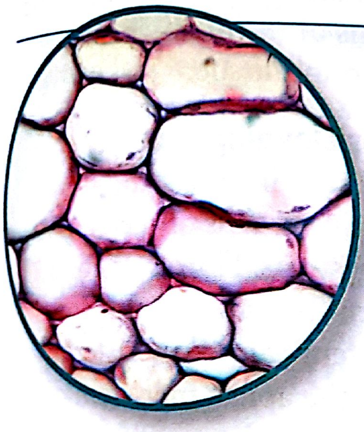
▶ ***Phloem: Companion Cells*** The cells that surround sieve tube elements are called **companion cells.** Companion cells keep their nuclei and other organelles through their lifetime. Companion cells support the phloem cells and aid in the movement of substances in and out of the phloem.

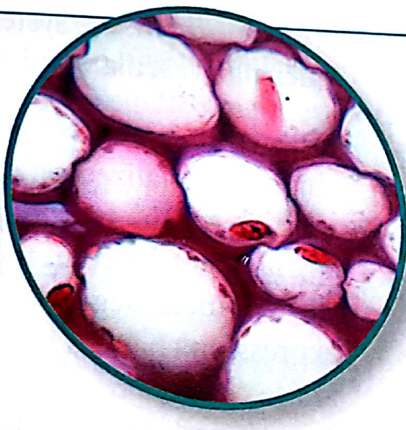


Cross Section of a Stem
LM 15×
Tracheid
Vessel element
Xylem
Sieve tube element
Companion cell
Phloem

Ground Tissue Plant tissue called ground tissue is neither dermal nor vascular. **Ground tissue produces and stores sugars, and contributes to physical support of the plant.** Ground tissue is an important part of food at the dinner table, too. The edible portions of plants like potatoes, squash, and asparagus are mostly ground tissue. Most ground tissue consists of **parenchyma** (puh RENG kih muh). Parenchyma cells have a thin cell wall and a large central vacuole surrounded by a thin layer of cytoplasm. In leaves, these cells contain many chloroplasts and are the site of most of a plant's photosynthesis.



Parenchyma
Thin cell walls



Collenchyma
Thicker cell walls

Sclerenchyma
Thickest cell walls

Ground tissue may also contain two types of cells with thicker cell walls. **Collenchyma** (kuh LENG kih muh) cells have strong, flexible cell walls that help support plant organs. Chains of such cells make up the familiar "strings" of a stalk of celery. **Sclerenchyma** (sklih RENG kih muh) cells have extremely thick, rigid cell walls that make ground tissue such as seed coats tough and strong. Sclerenchyma fibers are used to make rope from hemp, and when you last used a nutcracker to open a walnut, you broke through some really tough sclerenchyma!

In Your Notebook *Make a three-column chart in which to summarize information about the three main tissue systems of plants.*

FIGURE 23-
Ground Tis
show how t
tissue found
in thickness

Plant Growth and Meristems

How do meristems differ from other plant tissues?

When most animals reach adulthood, they stop growing. Not so with most plants. Even the oldest trees produce new leaves and new reproductive organs every year, almost as if they remained "forever young." How do they do it? The secrets of plant growth are found in **meristems,** tissues that, in a sense, really do stay young. **Meristems are regions of unspecialized cells in which mitosis produces new cells that are ready for differentiation.** Meristems are found in places where plants grow rapidly, such as the tips of stems and roots. The undifferentiated cells they produce are very much like the stem cells of animals.

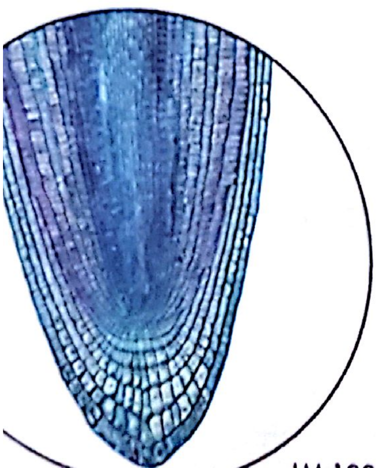
Apical Meristems Because the tip of a stem or root is known as its apex, meristems in these rapidly growing regions are called **apical meristems.** Unspecialized cells produced in apical meristems divide rapidly as stems and roots increase in length. **Figure 23–4** shows examples of stem and root apical meristems.

At first, the new cells that are pushed out of meristems look very much alike: They are unspecialized and have thin cell walls. Gradually, they develop into mature cells with specialized structures and functions. This process is called differentiation. As the cells differentiate, they produce each of the tissue systems of the plant, including dermal, vascular, and ground tissue.

Meristems and Flower Development The highly specialized cells found in cones and flowers (which are the reproductive organs of seed plants), are also produced in meristems. Flower or cone development begins when the pattern of gene expression changes in a stem's apical meristem. These changes transform the apical meristem of a flowering plant into a floral meristem. Floral meristems produce the tissues of flowers, which include the plant's reproductive organs as well as the colorful petals that surround them.

LM 60X

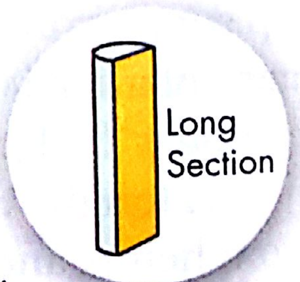
Stem apical meristem

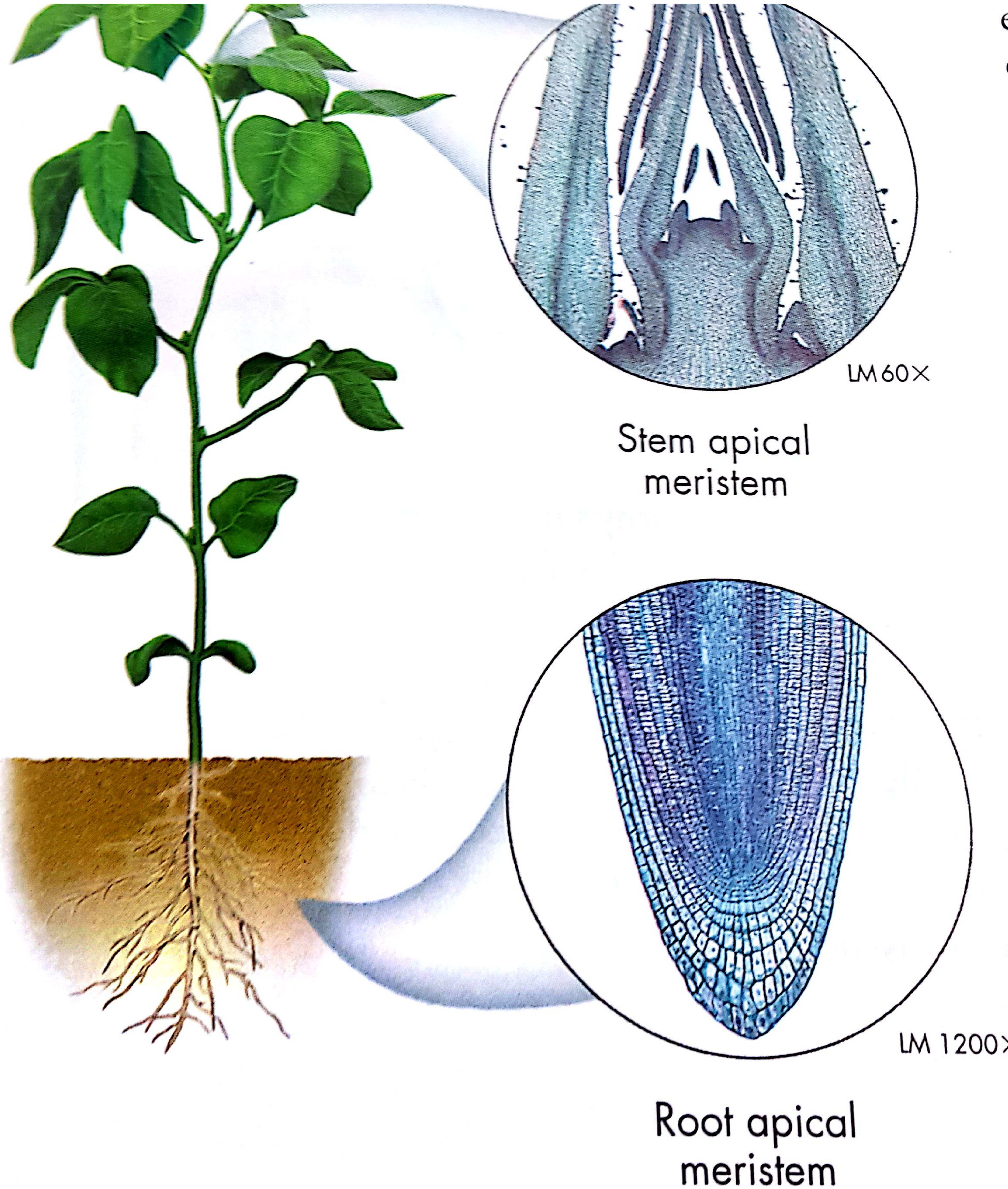


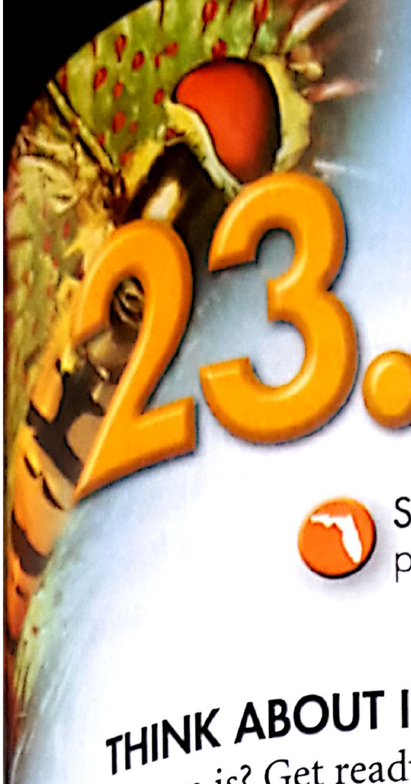
LM 1200X

Root apical meristem

FIGURE 23–4 Apical Meristems Apical meristems are found in the growing tips of stems and roots. Within these meristems, unspecialized cells are produced by mitosis.




LM 60×
Stem apical meristem
LM 1200×
Root apical meristem



23.2 Roots

SC.912.L.14.7 Relate the structure of each of the major plant physiological processes. Also covered: SC.912.L.14.2

THINK ABOUT IT Can you guess how large a typical plant's root system is? Get ready for a surprise if you think that roots are small and insignificant. In a 1937 study of a single rye plant, botanist Howard Dittmer showed that the length of all the branches in the rye plant's root system was an astonishing 623 kilometers (387 miles). The surface area of these roots was more than 600 square meters—130 times greater than the combined areas of its stems and leaves!

Root Structure and Growth

What are the main tissues in a mature root?

As soon as a seed begins to sprout, it puts out its first root to draw water and nutrients from the soil. Other roots soon branch out from this first root, adding length and surface area to the root system. Rapid cell growth pushes the tips of the growing roots into the soil. The new roots provide raw materials for the developing stems and leaves before they emerge from the soil.

Types of Root Systems The two main types of root systems are taproot systems and fibrous root systems, shown in **Figure 23–5.** Taproot systems are found mainly in dicots. Fibrous root systems are found mainly in monocots. Recall from Chapter 22 that monocots and dicots are two categories of flowering plants.

▸ ***Taproot System*** In some plants, the primary root grows long and thick and gives rise to smaller branch roots. The large primary root is called a taproot. Taproots of oak and hickory trees grow so long that they can reach water several meters down. Carrots, dandelions, and beets have short, thick taproots that store sugars and starches.

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▶ ***Fibrous Root System*** In other plants, such as grasses, the system begins with one primary root. But it is soon replaced by many equally sized branch roots that grow separately from the base of the stem. These fibrous roots branch to such an extent that no single root grows larger than the rest. The extensive fibrous root systems produced by many plants help prevent topsoil from being washed away by heavy rain.

FIGURE 23–5 A
Dandelions have
have a fibrous ro

Anatomy of a Root Roots contain cells from the three tissue systems—dermal, vascular, and ground tissue, as shown in Figure 23–6. **A mature root has an outside layer, called the epidermis, and also contains vascular tissue and a large area of ground tissue.** The root system plays a key role in water and mineral transport. The cells and tissues of a root are specialized to carry out these functions.

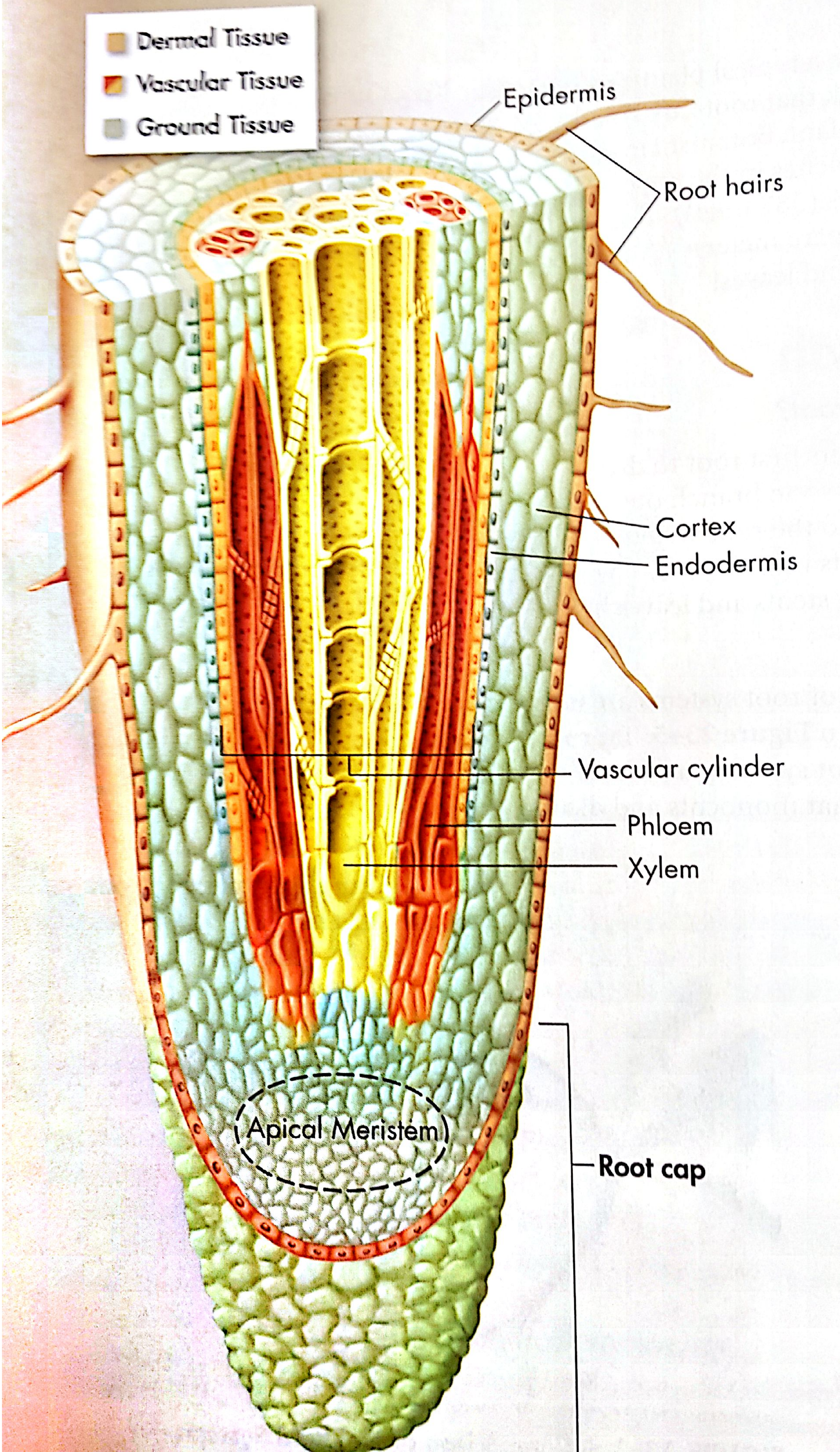
▶ ***Dermal Tissue: Epidermis*** The root's epidermis performs the dual functions of protection and absorption. Its surface is covered with thin cellular projections called **root hairs.** These hairs penetrate the spaces between soil particles and produce a large surface area that allows water and minerals to enter.

▶ ***Ground Tissue*** Just inside the epidermis is a region of ground tissue called the **cortex.** Water and minerals move through the cortex from the epidermis toward the center of the root. The cortex also stores the products of photosynthesis, such as starch.

A layer of ground tissue known as the **endodermis** completely encloses the vascular cylinder. The endodermis, as you will see, plays an essential role in the movement of water and minerals into the center of the root.

▶ ***Vascular Tissue*** At the center of the root, the xylem and phloem together make up a region called the **vascular cylinder.** Dicot roots like the one shown at left have a central column of xylem cells.

▶ ***Apical Meristem*** Roots grow in length when apical meristems produce new cells near the root tips. The root tip is covered by a tough **root cap** that protects the fragile meristem as the root tip forces its way through the soil. As the root grows, the root cap secretes a slippery substance that eases the progress of the root through the soil. Cells at the very tip of the root cap are constantly being scraped away, and new root cap cells are continually added by the meristem.


Dermal Tissue
Vascular Tissue
Ground Tissue
Epidermis
Root hairs
Cortex
Endodermis
Vascular cylinder
Phloem
Xylem
Apical Meristem
Root cap

Root Functions

What are the different functions of roots?

How does a root go about the job of absorbing water and minerals from the soil? Although it might seem to, water does not just "soak" into the root from soil. It takes energy on the part of the plant to absorb water. **Roots support a plant, anchor it in the ground, store food, and absorb water and dissolved nutrients from the soil.**

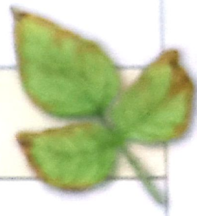
Uptake of Plant Nutrients An understanding of soil helps explain how plant roots function. Soil is a complex mixture of sand, silt, clay, air, and bits of decaying animal and plant tissue. Soil in different places contains varying amounts of these ingredients. Sandy soil, for example, is made of large particles that retain few nutrients, whereas the finely textured silt and clay soils of the Midwest and southeastern United States are high in nutrients. The ingredients define the soil and determine, to a large extent, the kinds of plants that can grow in it.

To grow, flower, and produce seeds, plants require a variety of inorganic nutrients in addition to carbon dioxide and water. The nutrients needed in largest amounts are nitrogen, phosphorus, potassium, magnesium, sulfur, and calcium. The functions of these essential nutrients within a plant are described in **Figure 23–7.**

In addition to large amounts of these nutrients, small amounts of other nutrients, called trace elements, are just as important. These trace elements include iron, zinc, molybdenum, boron, copper, manganese, and chlorine. As important as they are, excessive amounts of any of these nutrients in soil can also be poisonous to plants.

Essential Plant Nutrients

Essential Plant Nutrients

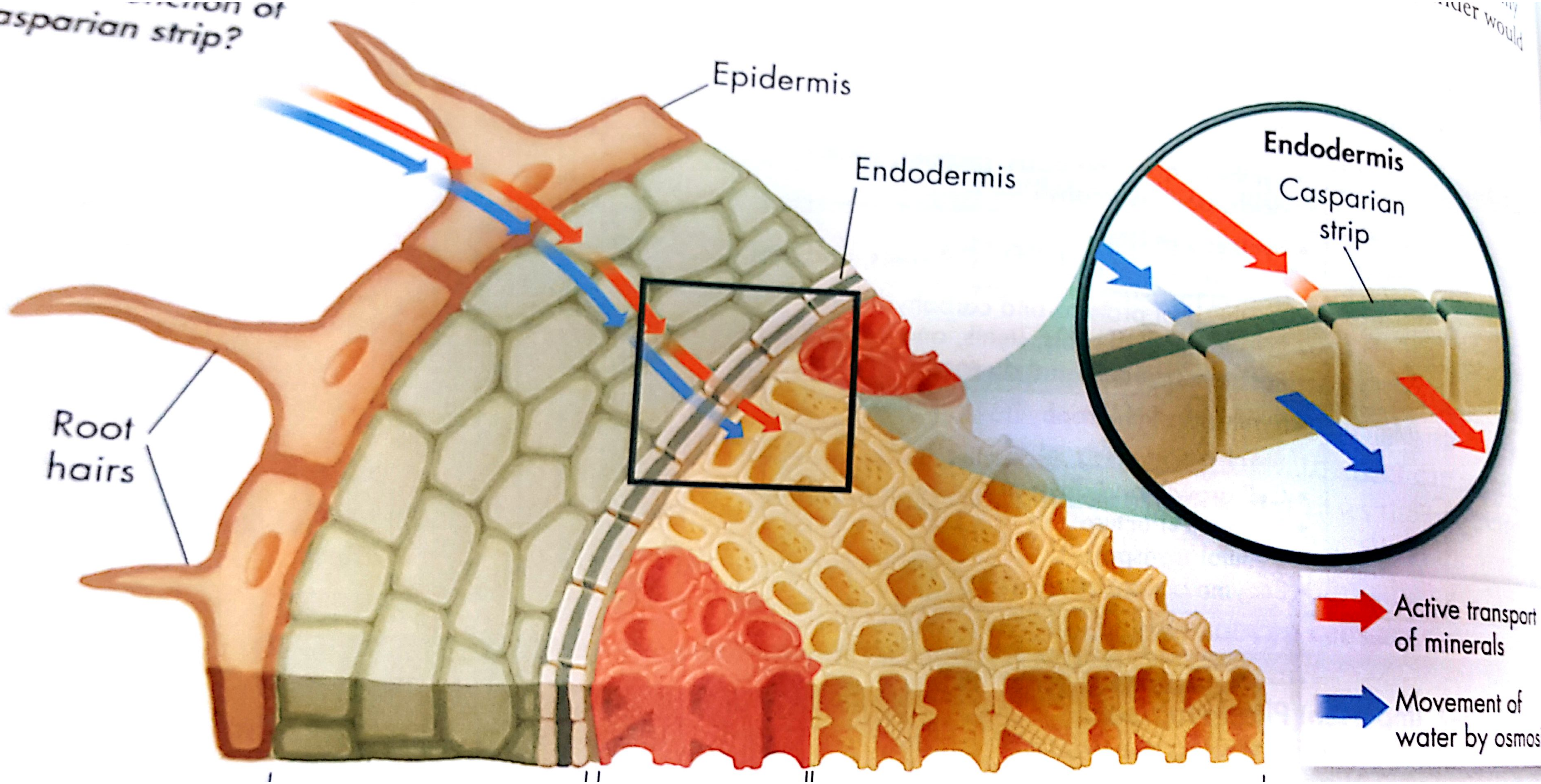
Nutrient (Chemical Symbol)	Some Roles in Plant	Result of Deficiency
Nitrogen (N)	• Proper leaf growth and color • Synthesis of amino acids, proteins, nucleic acids, and chlorophyll	• Stunted plant growth • Pale yellow leaves ▶ 
Phosphorus (P)	• Synthesis of DNA • Development of roots, stems, flowers, and seeds	• Poor flowering • Stunted growth
Potassium (K)	• Synthesis of proteins and carbohydrates • Development of roots, stems, and flowers • Resistance to cold and disease	• Weak stems • Stunted roots • Edges of leaves turn brown ▶ 
Magnesium (Mg)	• Synthesis of chlorophyll	• Thin stems • Mottled, pale leaves
Calcium (Ca)	• Cell growth and division • Cell wall structure • Cellular transport • Enzyme action	• Stunted growth • Curled leaves ▶ 

Active Transport of Dissolved Nutrients The cell membranes of root hairs and other cells in the root epidermis contain active transport proteins. As you know, active transport is a process that uses the energy of ATP to move ions and other materials across membranes. Active transport brings the mineral ions of dissolved nutrients from the soil into the plant. The high concentration of mineral ions in the plant cells causes water molecules to move into the plant by osmosis.

Water Movement by Osmosis You may recall that osmosis is the movement of water across a membrane toward an area where the concentration of dissolved material is higher. By using active transport to **accumulate** mineral ions from the soil, cells of the root epidermis create conditions under which osmosis causes water to "follow" those ions and flow into the root. Note that the root does not actually pump water. But by pumping mineral ions into its own cells, the end result is almost the same—the water moves from the epidermis through the cortex into the vascular cylinder, as shown in **Figure 23–8.**

Movement Into the Vascular Cylinder Next, the water and dissolved minerals pass the inner boundary of the cortex and move toward the vascular cylinder. The cylinder itself is enclosed by a layer of cortex cells known as the endodermis. The cells of the endodermis are each shaped a bit like a brick. Where these cells meet, their cell walls form a special waterproof zone called a **Casparian strip.** Most of the time, water can diffuse through cell walls, but not here. The strip is almost like a layer of waterproof cement between the bricks in a wall. Imagine many of these bricks placed edge to edge to build a cylinder, with this waterproof cement surrounding each of the bricks. The only way that water and dissolved nutrients could enter that cylinder would be through the bricks themselves.

me Casparian strip?



The waxy Casparian strip forces water and minerals to move through the cell membranes of endodermis cells rather than in between the cells. This enables the endodermis to filter and control the water and dissolved nutrients that enter the vascular cylinder. More importantly, the Casparian strip ensures that valuable nutrients will not leak back out. As a result, there is a one-way passage of water and nutrients into the vascular cylinder.

Root Pressure Why do plants "need" a system that ensures the one-way movement of water and minerals? That system is how the plant generates enough pressure to move water out of the soil and up into the body of the plant. As minerals are pumped into the vascular cylinder, more and more water follows by osmosis, producing a strong pressure. If the pressure were not contained, roots would expand as they filled with water.

Instead, contained within the Casparian strip, the water has just one place to go—up. Root pressure, produced within the cylinder by active transport, forces water through the vascular cylinder and into the xylem. As more water moves from the cortex into the vascular cylinder, more water in the xylem is forced upward through the root into the stem. In **Figure 23–9,** you can see a demonstration of root pressure in a carrot root.

Root pressure is the starting point for the movement of water through the vascular system of the entire plant. But it is just the beginning. Once you have learned about stems and leaves, you will see how water and other materials are transported within an entire plant.

3.3 Stems

SC.912.L.14.7 Relate the structure of each of the major plant organs and tissues to physiological processes. Also covered: SC.912.N.1.1, SC.912.N.1.6, SC.912.L.14.2, LA.910.2.2.3, MA.912.S.3.2

tions
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tems?
primary growth
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THINK ABOUT IT While visiting the salad bar for lunch, you notice an intriguing range of offerings. After making your basic salad, you decide to add some sliced water chestnuts and bamboo shoots on top. Then you serve yourself some asparagus and potato salad on the side. These good things are all from plants, of course, but can you think of something else that ties them together? They all come from the same part of the plant. Do you have any idea which part?

Stem Structure and Function

What are three main functions of stems?

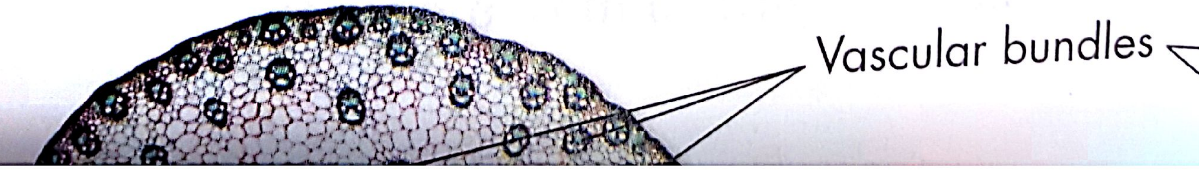
What do water chestnuts, bamboo shoots, asparagus, and potatoes all have in common? They are all types of stems. Stems vary in size, shape, and method of development. Some grow entirely underground; others reach high into the air. **Aboveground stems have several important functions: Stems produce leaves, branches, and flowers; stems hold leaves up to the sun; and stems transport substances throughout the plant.**

Stems make up an essential part of the water and mineral transport systems of the plant. Xylem and phloem form continuous tubes from the roots through the stems to the leaves. These vascular tissues link all parts of the plant, allowing water, nutrients, and other compounds to be carried throughout the plant. In many plants, stems also function in storage and aid in the process of photosynthesis.

Anatomy of a Stem Stems contain the plant's three tissue systems: dermal, vascular, and ground tissue. Stems are surrounded by a layer of epidermal cells that have thick cell walls and a waxy protective coating. Growing stems contain distinct **nodes,** where leaves are attached, as shown in **Figure 23–11.** Small buds are found where leaves attach to the nodes. **Buds** contain apical meristems that can produce new stems and leaves. In larger plants, stems develop woody tissue that helps support leaves and flowers.

Vascular Bundle Patterns The arrangement of tissues in a stem differs among seed plants. In monocots, clusters of xylem and phloem tissue, called **vascular bundles,** are scattered throughout the stem. In most dicots and gymnosperms, vascular bundles are arranged in a cylinder, or ring. For a comparison of monocot and dicot stems, look at **Figure 23–12.**

FIGURE 23–12 Comparing Monocots and Dicots These cross sections through a monocot and dicot stem show their similarities and differences. **Observe** ***How does the arrangement of the vascular bundles differ?***



Monocot Stems The cross section of a young monocot stem shows all three tissue systems clearly. The stem has a distinct epidermis, which encloses ground tissue and a series of vascular bundles. In monocots, vascular bundles are scattered throughout the ground tissue. The ground tissue is fairly uniform, consisting mainly of parenchyma cells.

Dicot Stems Young dicot stems have vascular bundles, too, but they are generally arranged in an organized, ringlike pattern. The parenchyma cells inside the ring of vascular tissue are known as **pith,** while those outside form the cortex of the stem. These relatively simple tissue patterns become more complex as the plant grows larger and the stem increases in diameter.

Growth of Stems

How do primary growth and secondary growth occur in stems?

Plants grow in ways that are very different from how animals grow. Cows have four legs, ants have six, and spiders have eight, but roses and tomatoes don't have a set number of leaves or branches. Unlike animals, the growth of most plants isn't precisely determined. However, plant growth is still carefully controlled and regulated. Depending upon the species, plant growth follows general patterns that produce the characteristic size and shape of the adult plant.

Primary Growth The growth of new cells produced by the apical meristems of roots and stems adds length to the plant. This pattern of growth, occurring at the ends of a plant, is called **primary growth.** The increase in length in a plant due to primary growth from year to year is shown in **Figure 23–13.** **Primary growth of stems is the result of elongation of cells produced in the apical meristem. It takes place in all seed plants.**

Secondary Growth As a plant grows larger, the older stems and roots have more mass to support and more fluid to move through their vascular tissues. As a result, they must increase in thickness as well as in length. This increase in the thickness of stems and roots is known as **secondary growth.** Secondary growth is very common among dicots and nonflowering seed plants such as pines, but it is rare in monocots. This limits the girth of most monocots.

Unlike monocots, most dicots have meristems within their stems and roots that can produce true secondary growth. This enables many dicots to grow to great heights because the increase in width supports the extra weight. In addition to showing primary growth, **Figure 23–13** illustrates the pattern of secondary growth in a dicot stem.

In conifers and dicots, secondary growth takes place in meristems called the vascular cambium and cork cambium. The **vascular cambium** produces vascular tissues and increases the thickness of stems over time. The **cork cambium** produces the outer covering of stems. Similar types of cambium tissue enable roots to grow. The addition of new tissue in these cambium layers increases the thickness of stems and roots.

Growth From the Vascular Cambium In a young dicot stem, bundles of xylem and phloem are arranged in a ring. Once secondary growth begins, the vascular cambium appears as a thin, cylindrical layer of cells between clusters of vascular tissue. This new meristem forms between the xylem and phloem of each vascular bundle. Divisions in the vascular cambium give rise to new layers of xylem and phloem. As a result, the stem becomes wider. Each year, the cambium continues to produce new layers of vascular tissue, causing the stem to become thicker and thicker.

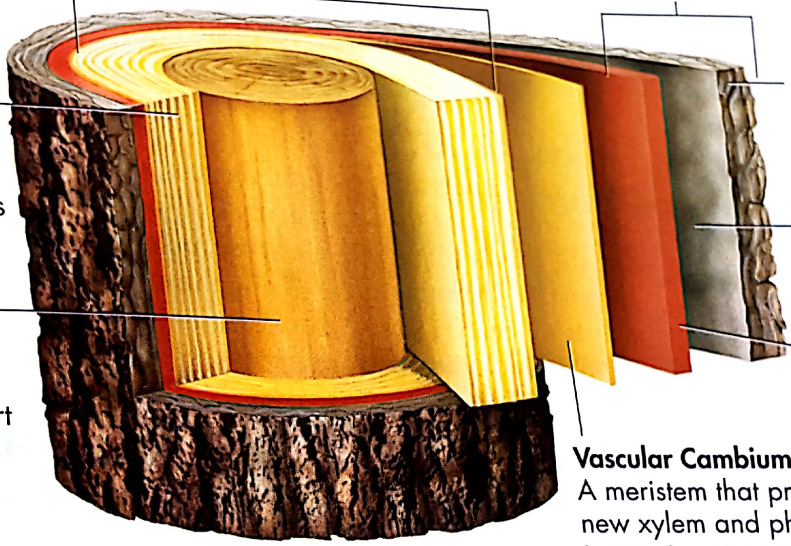
In Your Notebook *List in sequence all the tissues found in a mature woody stem. Start from the center and move outward.*

Formation of Wood Most of what we call "wood" is actually layers of secondary xylem produced by the vascular cambium. These cells build up year after year, layer on layer. As woody stems grow thicker, the older xylem near the center of the stem no longer conducts water and instead becomes what is known as **heartwood.** Heartwood usually darkens with age because it accumulates colored deposits. Heartwood is surrounded by **sapwood,** which is active in fluid transport and is, therefore, usually lighter in color.

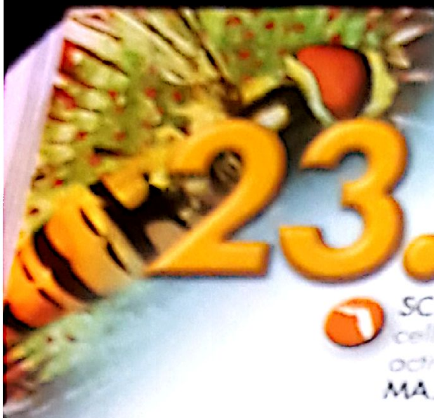
Tree Rings In most of the temperate zone, tree growth is seasonal. When growth begins in the spring, the vascular cambium begins to grow rapidly, producing large, light-colored xylem cells with thin cell walls. The result is a light-colored layer of early wood. As the growing season continues, the cells grow less and have thicker cell walls, forming a layer of darker late wood. This alternation of dark and light wood produces what we commonly call tree rings.

Each ring has light wood at one edge and dark wood at the other, making a sharp boundary between rings. Usually, a ring corresponds to a year of growth. By counting the rings in a cross section of a tree, you can estimate its age. The size of the rings may even provide information about weather conditions, such as wet or dry years. Thick rings indicate that weather conditions were favorable for tree growth, whereas thin rings indicate less-favorable conditions.

FIGURE 23–14 Formation of Wood and Bark This diagram shows the layers of wood and bark in a mature tree that has undergone several years of secondary growth. **Classify** ***Which two tissues are meristems?***



Formation of Bark In a mature stem, all of the tissues found outside the vascular cambium make up the **bark,** as shown in **Figure 23–14.** These tissues include phloem, the cork cambium, and cork. As a tree expands in width, the phloem layer must grow as well. This expansion may cause the oldest tissues to split and fragment as the expanding stem stretches them. The cork cambium surrounds the cortex and produces a thick, protective layer of waterproof cork that prevents the loss of water from the stem. As the stem increases in size, outer layers of dead bark often crack and flake off the tree.



23.4 Leaves

SC.912.L.14.2 Relate structure to function for the components of plant and animal cells. Explain the role of cell membranes as a highly selective barrier (passive and active transport). Also covered: SC.912.N.1.1, SC.912.L.14.7, LA.910.2.2.3, MA.912.S.3.2

Key Questions

How is the structure of a leaf adapted to make photosynthesis more efficient?

What role do stomata play in maintaining homeostasis?

Vocabulary

blade • petiole • mesophyll • palisade mesophyll • spongy mesophyll • stoma • transpiration • guard cell

Taking Notes

Preview Visuals Before you ead the lesson, look at igure 23–15. Locate the three ain tissue systems and infer ich tissue system makes up leaf veins.

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THINK ABOUT IT We hear a lot these days about "green industry," such as biofuels and material recycling, but did you know that the most important manufacturing sites on Earth are already green? They are the leaves of plants. In a sense, plant leaves are the world's most important manufacturers. Using the energy captured in their leaves, plants make the sugars, starches, and oils that feed virtually all land animals, including us.

Leaf Structure and Function

How is the structure of a leaf adapted to make photosynthesis more efficient?

Recall from Chapter 8 that photosynthesis uses carbon dioxide and water to produce sugars and oxygen. Leaves, therefore, must have a way of obtaining carbon dioxide and water as well as distributing end products. **The structure of a leaf is optimized to absorb light and carry out photosynthesis.**

Anatomy of a Leaf To collect sunlight, most leaves have a thin, flattened part called a **blade.** The flat shape of a leaf blade maximizes the amount of light it can absorb. The blade is attached to the stem by a thin stalk called a **petiole** (PET ee ohl). Like roots and stems, leaves have an outer covering of dermal tissue and inner regions of ground and vascular tissues, as shown in **Figure 23–15.**

▶ ***Dermal Tissue*** Leaves are covered on their top and bottom surfaces by epidermis. Leaf epidermis is made of a layer of tough, irregularly shaped cells with thick outer walls that resist tearing. The epidermis of nearly all leaves is also covered by a waxy cuticle. The cuticle is a waterproof barrier that protects tissues and limits the loss of water through evaporation.

▶ ***Vascular Tissue*** The vascular tissues of leaves are connected directly to the vascular tissues of stems, making them part of the plant's fluid transport system. Xylem and phloem tissues are bundled in leaf veins that run from the stem throughout the leaf.

▶ ***Ground Tissue*** The area between leaf veins is filled with a specialized ground tissue known as **mesophyll** (MES uh fil), where photosynthesis occurs. The sugars produced in mesophyll move to leaf veins, where they enter phloem sieve tubes for transport to the rest of the plant.

Photosynthesis The mesophyll tissue in most leaves is highly specialized for photosynthesis. Beneath the upper epidermis is a layer of cells called the **palisade mesophyll,** containing closely packed cells that absorb light that enters the leaf. Beneath the palisade layer is a loose tissue called the **spongy mesophyll,** which has many air spaces between its cells. These air spaces connect with the exterior through **stomata** (singular: stoma). Stomata are small openings in the epidermis that allow carbon dioxide, water, and oxygen to diffuse into and out of the leaf.

Transpiration The walls of mesophyll cells are kept moist so that gases can enter and leave the cells easily. The trade-off to this feature is that water evaporates from these surfaces and is lost to the atmosphere. **Transpiration** is the loss of water through leaves. This lost water may be replaced by water drawn into the leaf through xylem vessels in the vascular tissue. Transpiration helps to cool leaves on hot days, but it may also threaten the leaf's survival if water is scarce.

In Your Notebook Make a two-column table in which you list

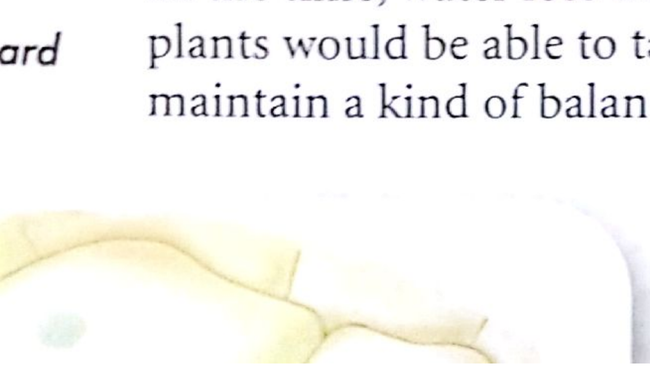
Gas Exchange and Homeostasis

What role do stomata play in maintaining homeostasis?

You might not think of plants as "breathing" the same way that animals do, but plants need to exchange gases with the atmosphere, too. Plants, in fact, can even be suffocated by lack of oxygen, something that often happens during extensive flooding. A plant's control of gas exchange is actually one of the most important elements of homeostasis for these remarkable organisms.

Gas Exchange Leaves take in carbon dioxide and give off oxygen during photosynthesis. When plant cells use the food they make, the cells respire, taking in oxygen and giving off carbon dioxide (just as animals do). Plant leaves allow gas exchange between air spaces in the spongy mesophyll and the exterior by opening their stomata.

Homeostasis It might seem that stomata should be open all the time, allowing gas exchange to take place and photosynthesis to occur at top speed. However, this is not what happens! If stomata were kept open all the time, water loss due to transpiration would be so great that few plants would be able to take in enough water to survive. So, plants maintain a kind of balance. **Plants maintain homeostasis by keeping their stomata open just enough to allow photosynthesis to take place but not so much that they lose an excessive amount of water.**



amount of water.

Guard cells in the epidermis of each leaf are the key to this balancing act. **Guard cells** are highly specialized cells that surround the stomata and control their opening and closing. Guard cells regulate the movement of gases, especially water vapor and carbon dioxide, into and out of leaf tissues.

The stomata open and close in response to changes in water pressure within the guard cells, as shown in **Figure 23–16.** When water is abundant, it flows into the leaf, raising water pressure in the guard cells, which then open the stomata. The thin outer walls of the cells are forced into a curved shape, which pulls the thick inner walls of the guard cells away from one another, opening the stoma. Carbon dioxide can then enter through the stoma, and water is lost by transpiration.

When water is scarce, the opposite occurs. Water pressure within the guard cells decreases, the inner walls pull together, and the stoma closes. This reduces further water loss by limiting transpiration.

In general, stomata are open during the daytime, when photosynthesis is active, and closed at night, when open stomata would only lead to water loss. However, stomata may be closed even in bright sunlight under hot, dry conditions in which water conservation is a matter of life and death. Guard cells respond to conditions in the environment, such as wind and temperature, helping to maintain homeostasis within a leaf.

Transpiration and Wilting Osmotic pressure keeps a plant's leaves and stems rigid, or stiff. High transpiration rates can lead to wilting. Wilting results from the loss of water—and therefore pressure—in a plant's cells. Without this internal pressure to support them, the plant's cell walls bend inward, and the plant's leaves and stems wilt. When a leaf wilts, its stomata close. As a result, transpiration slows down significantly. Thus, wilting helps a plant to conserve water.

FIGURE 23–17 Wilting A plant may wilt when water is scarce.

In Your Notebook *Make a list of molecules that are exchanged through the stomata. Which ones primarily enter the leaf? Which ones primarily exit the leaf?*

23.5 Transport in Plants

SC.912.L.14.7 Relate the structure of each of the major plant organs and tissues to physiological processes. Also covered: SC.912.N.1.1, SC.912.L.14.2

THINK ABOUT IT Look at a tall tree. Maybe there's one outside your school that's 15 meters high or even taller. Think about how much work it would be to haul water up to the top of that tree. Now think of a giant redwood, a hundred meters high. How does water get to the top?

Key Questions

- What are the major forces that transport water in a plant?
- What drives the movement of fluid through phloem tissue in a plant?

Vocabulary

adhesion • capillary action • pressure-flow hypothesis

Taking Notes

Compare/Contrast Table As you read, create a table in which you compare and contrast the functions of xylem and phloem.

Water Transport

What are the major forces that transport water in a plant?

Recall that active transport and root pressure cause water to move from soil into plant roots. The pressure created by water entering the tissues of a root can push water upward in a plant stem. However, this pressure does not exert nearly enough force to lift water up into trees. Other forces are much more important.

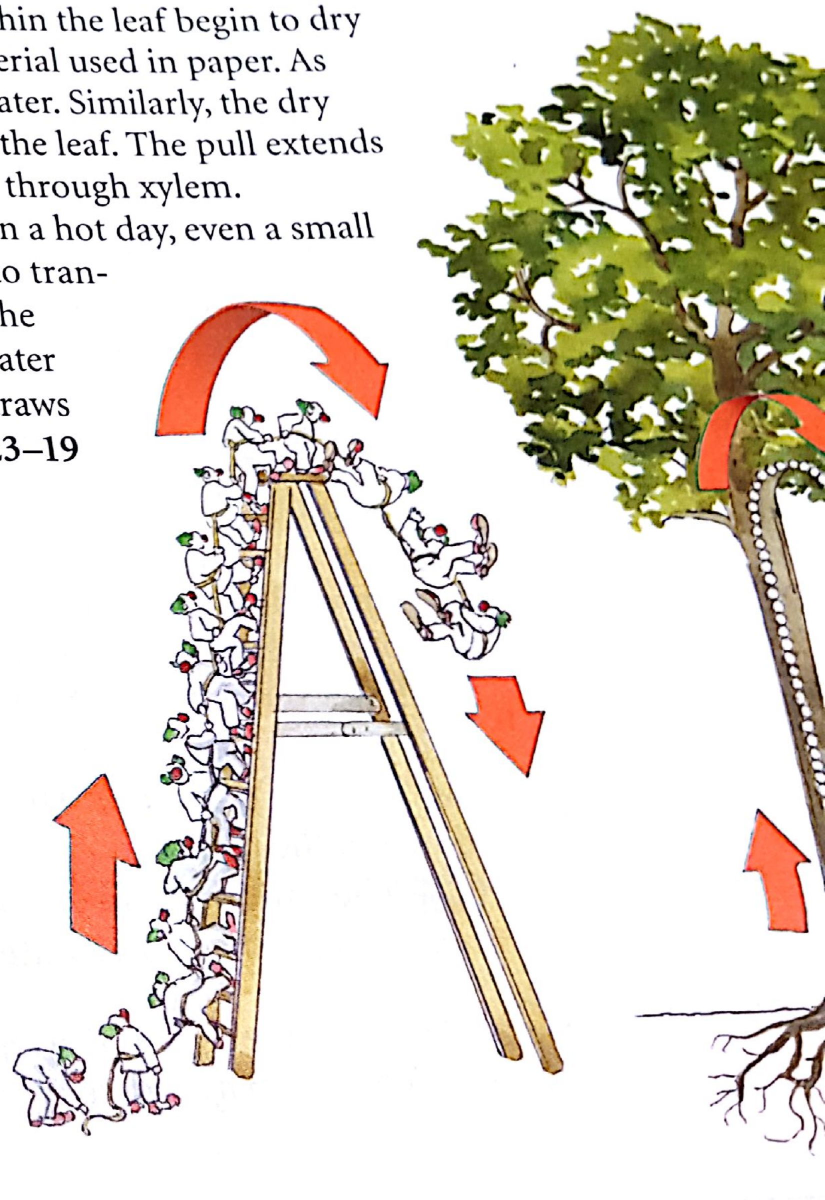
Transpiration The major force in water transport is provided by the evaporation of water from leaves during transpiration. As water evaporates through open stomata, the cell walls within the leaf begin to dry out. Cell walls contain cellulose, the same material used in paper. As you know, dry paper towels strongly attract water. Similarly, the dry cell walls draw water from cells deeper inside the leaf. The pull extends into vascular tissue so that water is pulled up through xylem.

How important is transpirational pull? On a hot day, even a small tree may lose as much as 100 liters of water to transpiration. The hotter and drier the air, and the windier the day, the greater the amount of water lost. As a result of this water loss, the plant draws up even more water from the roots. **Figure 23–19** shows an analogy for transpirational pull.

VISUAL ANALOGY

TRANSPIRATIONAL PULL

FIGURE 23–19 Imagine a chain of circus clowns who are tied together and climbing a tall ladder. When the first clown reaches the top, he falls off, pulling the clowns behind him up and over the top. Similarly, the chain of water molecules in a plant extends from the leaves down to the roots. As molecules exit leaves through transpiration, they pull up the molecules behind them.



How Cell Walls Pull Water Upward To pull water upward, plants take advantage of some of water's most interesting physical properties. Water molecules are attracted to one another by a force called cohesion. Recall from Chapter 2 that cohesion is the attraction of molecules of the same substance to each other. Water cohesion is especially strong because of the tendency of water molecules to form hydrogen bonds with each other. Water molecules can also form hydrogen bonds with other substances. This results from a force called **adhesion,** which is attraction between unlike molecules.

If you were to place empty glass tubes of various diameters into a dish of water, you would see both cohesion and adhesion at work. The tendency of water to rise in a thin tube is called **capillary action.** Water is attracted to the walls of the tube, and water molecules are attracted to one another. The thinner the tube, the higher the water will rise inside it, as shown in **Figure 23–20.**

Putting It All Together What does capillary action have to do with water movement through xylem? Recall that xylem tissue is composed of tracheids and vessel elements that form many hollow, connected tubes. These tubes are lined with cellulose cell walls, to which water adheres very strongly. So, when transpiration removes some water from the exposed walls, strong adhesion forces pull in water from the wet interior of the leaf. That pull is so powerful that it extends even down to the tips of roots and, through them, to the water in the soil. **The combination of transpiration and capillary action are the major forces that move water through the xylem tissues of a plant.**

Nutrient Transport

What drives the movement of fluid through phloem tissue in a plant?

How do sugars move in the phloem? The leading explanation of phloem transport is known as the **pressure-flow hypothesis,** shown in **Figure 23–21.** As you know, unlike the cells that form xylem, the sieve tube cells in phloem remain alive. 1 Active transport moves sugars into the sieve tube from surrounding tissues. 2 Water then follows by osmosis, creating pressure in the tube at the source of the sugars. 3 If another region of the plant has a need for sugars, they are actively pumped out of the tube and into the surrounding tissues. Osmosis then causes water to leave the tube, reducing pressure in the tube at such places. The result is a pressure-driven flow of nutrient-rich fluid from the sources of sugars (source cells) to the places in the plants where sugars are used or stored (sink cells). **Changes in nutrient concentration drive the movement of fluid through phloem tissue in directions that meet the nutritional needs of the plant.**

The pressure-flow system gives plants enormous flexibility in responding to changing seasons. During the growing season, sugars from the leaves are directed into ripening fruits or into roots for storage. As the growing season ends, the plant drops its fruits and stores nutrients in the roots. As spring approaches, chemical signals stimulate phloem cells in the roots to pump sugars back into phloem sap. Then the pressure-flow system raises these sugars into stems and leaves to support rapid growth.