CHAPTER 23

Plant Structure and Function

23.1 Roots, Stems, and Leaves

23.2 Plant Hormones and Tropisms

23.3 Plants and People

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HS-LS1-1, HS-LS1-2, HS-LS1-3, HS-LS1-5, HS-LS2-7, HS-ETS1-1, HS-ETS1-2

CASE STUDY

How can we save the crops we depend upon?

You might not realize it after a trip to your local supermarket, but nearly 50,000 species of plants are edible, at least in part. Despite this, only a small number of species appear regularly on most dinner tables. In fact, experts estimate that 60 percent of the food energy in the human diet comes from just three crops: wheat, corn, and rice.

Our dependency on such a small number of crops could pose huge problems if any of the crops fail. Raising a single crop in a large field is called monoculture. A monoculture can cause the soil to lose nutrients from year to year. It also encourages the spread of diseases and insect pests.

For example, consider the history of one of the world's favorite foods: the banana. Like other food plants, bananas have many different strains and varieties. By the 1950s, however, commercial plantations were raising only one variety of banana, the *Gros Michel*. Everyone agreed that the *Gros Michel* produced the largest and tastiest fruit, and it proved very profitable. Unfortunately, the *Gros Michel* was doomed by a tiny enemy, a soil fungus of the genus *Fusarium*. The fungus infected the roots of the *Gros Michel*, and then spread up the vascular system. The fungal infection was called Panama disease, and it ruined one banana plantation after another. By 1965, the *Gros Michel* was all but extinct.

The banana industry found another variety, the *Cavendish* banana, that was resistant to Panama disease. The *Cavendish* is the variety that most of us eat today. The bad news, however, is that new strains of the *Fusarium* fungus have evolved to infect the *Cavendish*. In southeast Asia, the fungus already has destroyed tens of thousands of acres of banana plantations. Experts are worried that the fungus could spread to the plantations in Africa and South America. Currently, there is no reasonable treatment for Panama disease. Once the fungus arrives, it cannot be stopped.

Similar problems are troubling citrus trees. Citrus fruits include oranges, lemons, and grapefruit. A disease called citrus greening has ruined millions of acres of citrus crops in the United States and elsewhere. The disease is caused by bacteria that are spread by very tiny insects, each no larger than the head of a pin. The disease is named for the green, ruined fruit that it causes. The fruits are bitter and not edible. Other diseases that threaten citrus crops include citrus canker, citrus black spot, and sweet orange scab. All are infections of bacteria and fungi, and all can spread quickly through an orchard. None can be treated after a tree is infected.

Managing diseases is just one of the challenges of agriculture, the systematic raising of plants. How did agriculture begin, and how has it changed over time? What challenges face agriculture today, and how will we meet these challenges? Should we change the way we grow food crops?

Throughout this chapter, look for connections to the CASE STUDY to help you answer these questions.

Oranges, as well as other citrus fruits, are being threatened by citrus greening disease.

LESSON 23.1 Roots, Stems, and Leaves

KEY QUESTIONS
- *What are the main tissue systems of plants?*
- *What are the different structures and functions of roots?*
- *What are the functions of stems and how does growth in stems occur?*
- *What are the different structures and functions of leaves?*
- *What are the major forces that transport water and nutrients in a plant?*

HS-LS1-1: Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS1-2:** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. **HS-LS1-3:** Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. **HS-LS1-5:** Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

VOCABULARY
epidermis • meristem
taproot • fibrous root
Casparian strip • node
vascular bundle
primary growth
secondary growth
mesophyll • stoma
transpiration • guard cells
capillary action

READING TOOL
In your **Biology Foundations Workbook,** explain how each of the listed systems work to make plants grow and thrive.

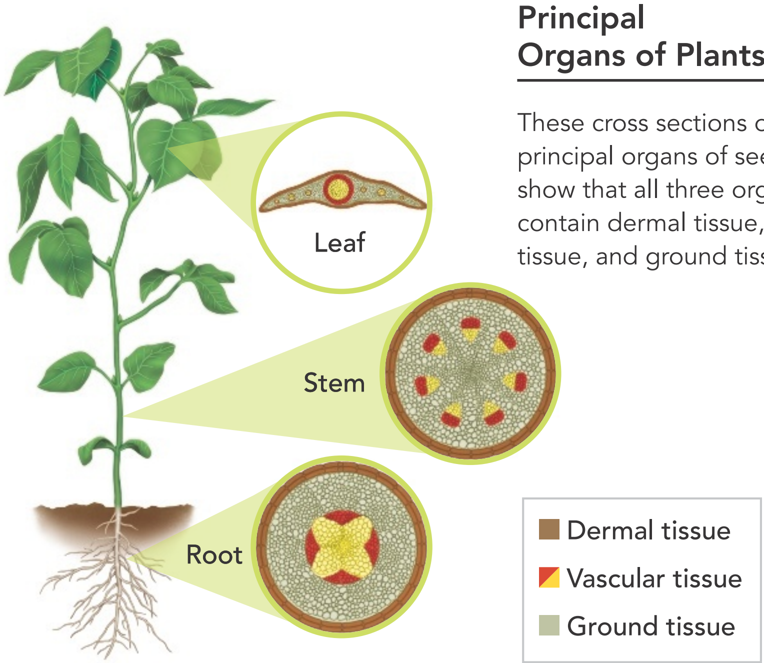
Compared to animals, plants don't seem to do much. But look deeper. Plants transport material, grow, repair themselves, and respond to the environment. They may act at a pace that seems slow to us, but their cells and tissues interact in remarkably effective ways.

Plant Tissue Systems

Within the roots, stems, and leaves of plants are specialized tissue systems, shown in **Figure 23-1**. Dermal tissue covers a plant almost like a skin. Vascular tissue helps to support the plant and serves as its "bloodstream," transporting water and nutrients. Ground tissue produces and stores food.

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.



Dermal Tissue Dermal tissue in young plants consists of a single layer of cells called the **epidermis**. The outer surfaces of epidermal cells are covered with a waxy layer called the cuticle, which protects against water loss. ***Dermal tissue is the protective outer covering of a plant.*** In some plants, dermal tissue may be many cell layers deep and may be covered with bark. In roots, dermal tissue includes root hair cells that absorb water, passing it along to ground and vascular tissue, where it is carried to the rest of the plant.

VIDEO

Learn why leaves change color.

Vascular Tissue Vascular tissue includes xylem, a water-conducting tissue, and phloem, a tissue that carries nutrients. As you can see in **Figure 23-2**, xylem and phloem consist of long, slender cells that connect almost like sections of pipe. ***Interactions between vascular tissues support the plant body and transport water and nutrients throughout the plant.***

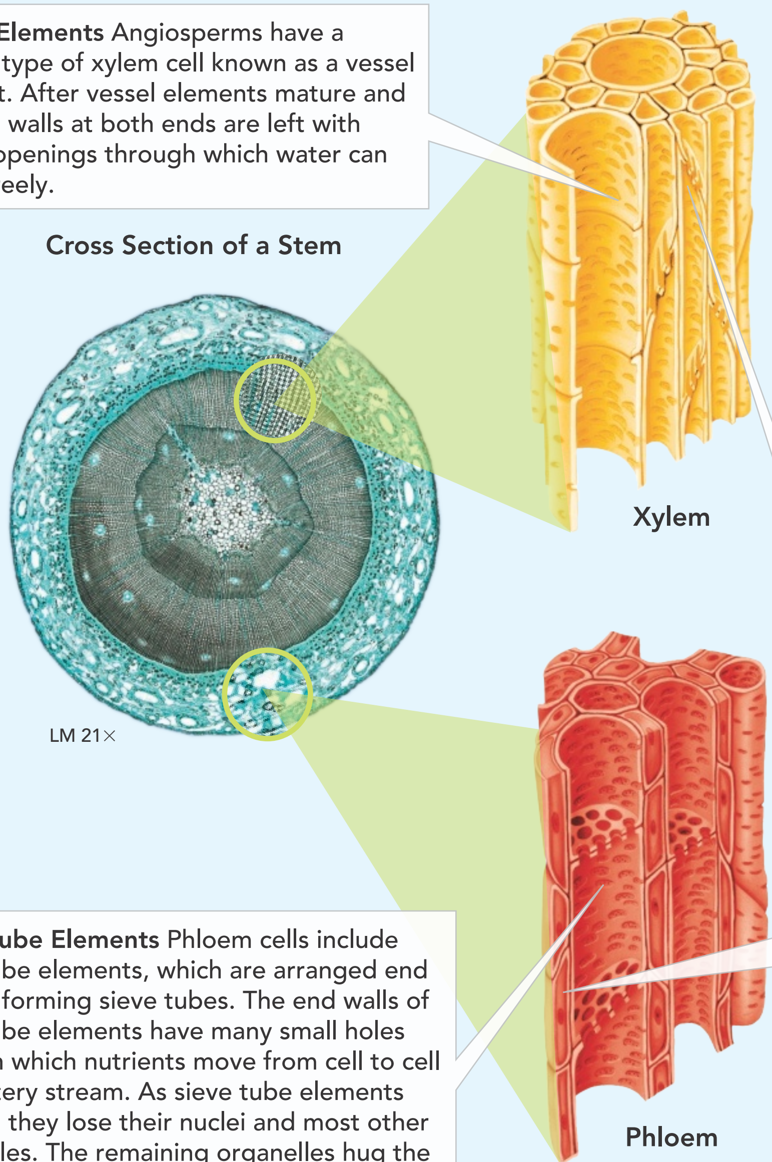
Up Close

Figure 23-2

Vascular Tissue

Xylem and phloem form the vascular transport system that moves water and nutrients throughout a plant.

Vessel Elements Angiosperms have a second type of xylem cell known as a vessel element. After vessel elements mature and die, cell walls at both ends are left with slitlike openings through which water can move freely.



Tracheids All seed plants have xylem cells called tracheids. 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. The inner regions of the wall, known as pits, allow water to diffuse from tracheids into surrounding ground tissue.

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.

Sieve Tube Elements Phloem cells include 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.

Ground Tissue The edible portions of plants—like potatoes, squash, and asparagus—are mostly ground tissue. ***Ground tissue produces and stores sugars, and contributes to physical support of the plant.*** Ground tissue is divided into three types based on the characteristics of the cell wall. Most ground tissue consists of parenchyma (puh RENG kih muh) cells with thin cell walls and a central vacuole surrounded by cytoplasm.

Ground tissue may also contain two other cell types. 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 tissue like the shells around a walnut seed tough and strong.

BUILD VOCABULARY

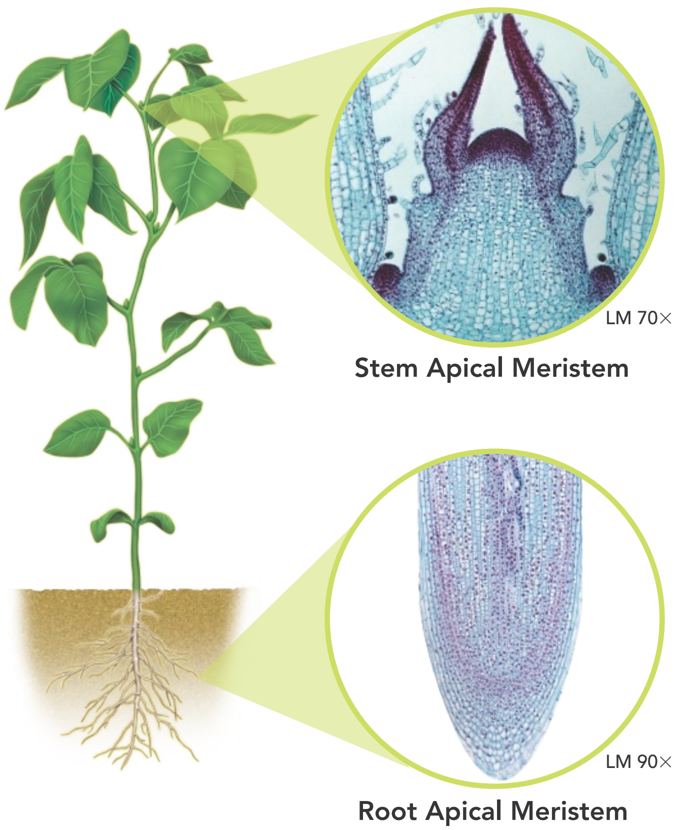
Related Word Forms *Apex* and *apical* are related word forms. *Apex* is a noun meaning the "narrowed or pointed end," or tip, and *apical* is an adjective describing "something related to or located at the apex."

Plant Tissues and Growth Unlike animals, even the oldest trees produce new tissue 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. Because the tip of a stem or root is known as its apex, meristems in these rapidly growing regions are called apical meristems. **Figure 23-3** shows examples of stem and root apical meristems.

Figure 23-3

Apical Meristems

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



Meristems and Flower Development Flower development begins when the pattern of gene expression changes to transform the apical meristem of a plant into a floral meristem. Floral meristems produce the plant's reproductive organs as well as the colorful petals that surround them.

READING TOOL

Make a three-column chart to summarize information about roots, stems, and leaves.

READING CHECK **Infer** How do meristems differ from other regions of a plant?

Roots

Can you guess how large a typical plant's root system is? 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!

As soon as a seed begins to sprout, it puts out its first roots to draw water and nutrients from the soil. Rapid cell growth pushes the tips of the growing roots into the soil, providing raw materials for the developing stems and leaves.

Types of Root Systems The two main types of root systems are taproot systems and fibrous root systems, shown in **Figure 23-4**. 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.

In plants like grasses, the primary root is replaced by branched roots that grow 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 anchor topsoil in place.

Figure 23-4

A Comparison of Two Root Systems

Dandelions have a taproot system, while grasses have a fibrous root system.

Structure and Function of Roots Dermal, vascular, and ground tissue are all found in roots, as shown in **Figure 23-5**. ***A mature root has an outside layer, called the epidermis, and also contains vascular tissue and a large area of ground tissue.***

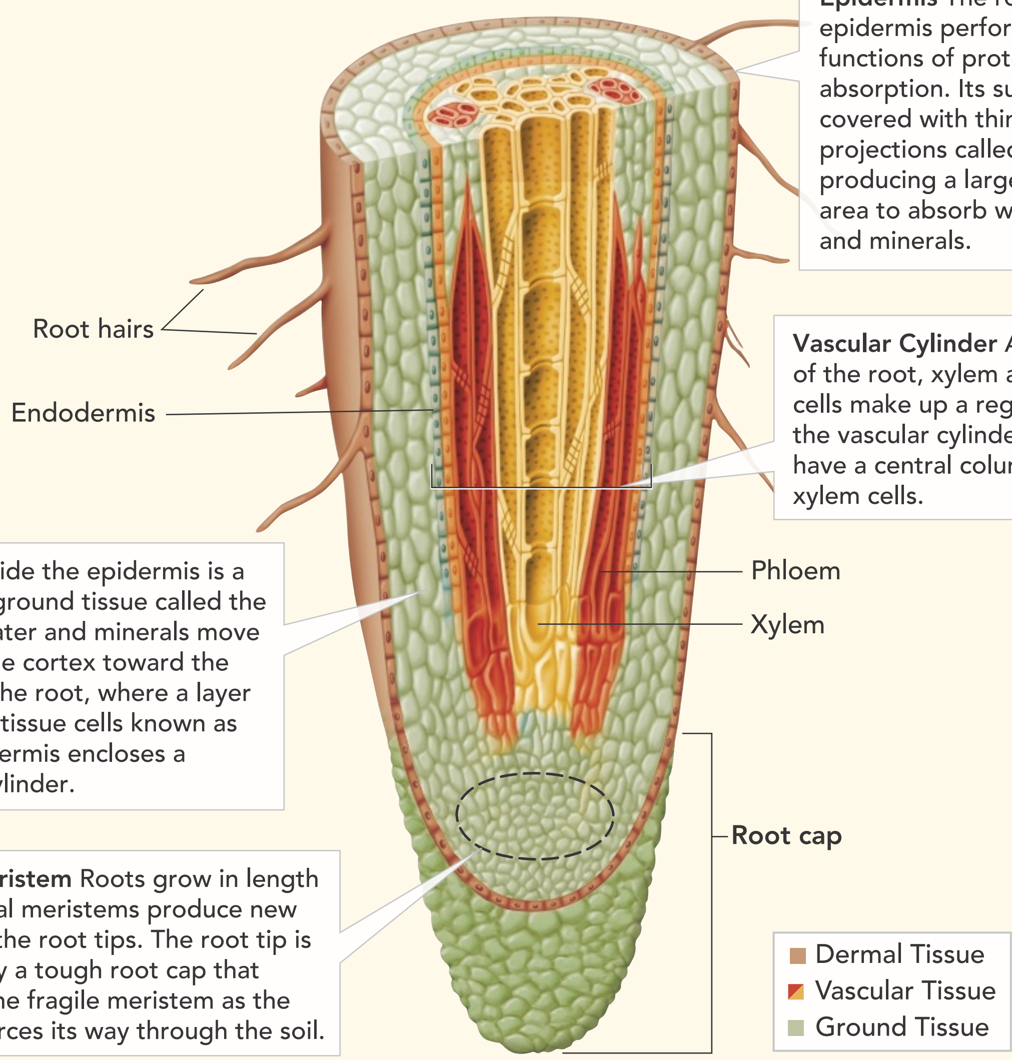
How does a root go about the job of absorbing water and minerals from the soil? Although it might seem to, water does not just "soak" into the root from soil. It takes energy on the part of the plant to absorb water. ***Roots support a plant, anchor it in the ground, store food, and absorb water and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

CASE STUDY

Figure 23-5

Anatomy of a Root

A root consists of a central vascular cylinder surrounded by ground tissue and the epidermis. When bananas are infected with Panama disease, the *Fusarium* fungus colonizes the xylem and blocks the flow of water.



Epidermis The root's epidermis performs the dual functions of protection and absorption. Its surface is covered with thin cellular projections called root hairs, producing a large surface area to absorb water and minerals.

Vascular Cylinder At the center of the root, xylem and phloem cells make up a region called the vascular cylinder. Roots have a central column of xylem cells.

Cortex Inside the epidermis is a region of ground tissue called the cortex. Water and minerals move through the cortex toward the center of the root, where a layer of ground tissue cells known as the endodermis encloses a vascular cylinder.

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.

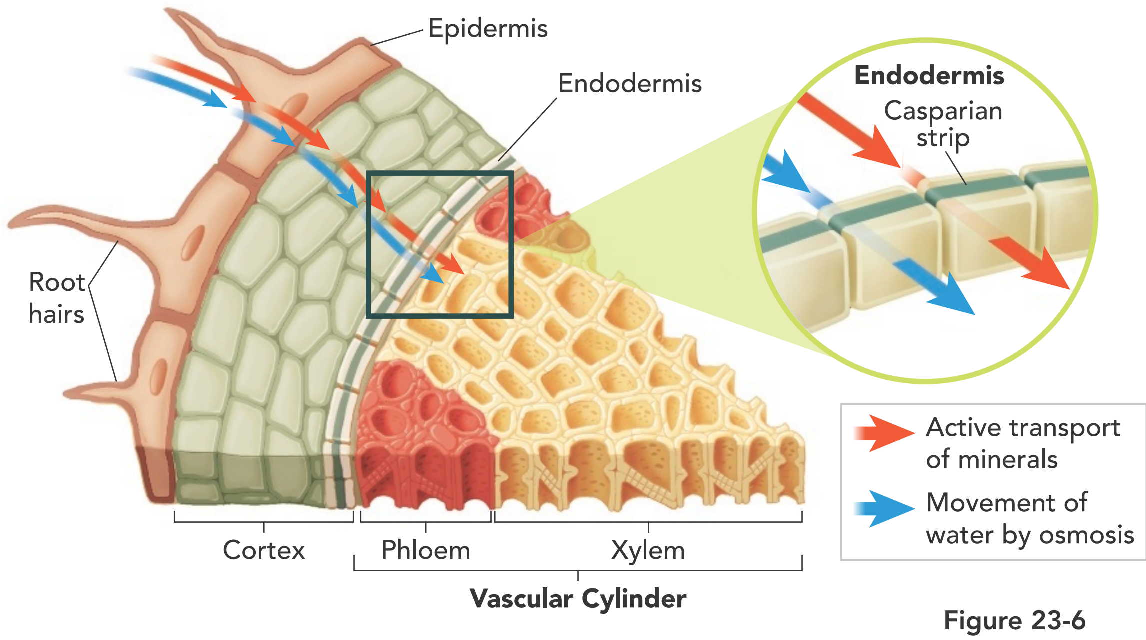


Figure 23-6

Water Passage Into a Root

A root absorbs water and dissolved nutrients from the soil. **Interpret Visuals** What is the function of the Casparian strip?

Uptake of Plant Nutrients Soil is a complex mixture of sand, silt, clay, air, and organic matter. Plants must absorb from the soil a variety of inorganic nutrients, such as nitrogen, phosphorus, potassium, magnesium, sulfur, and calcium. In addition, smaller amounts of other nutrients, called trace elements, are just as important. The cell membranes of root hairs and other cells in the root epidermis contain active transport proteins that use energy from ATP to pump dissolved nutrient ions from the soil into the plant.

Water Movement and the Vascular Cylinder You may recall that osmosis is the movement of water across a membrane toward an area where the concentration of dissolved material is higher. As the plant pumps mineral ions into its cells, water moves by means of osmosis into the root and toward the vascular cylinder, as shown in **Figure 23-6**. In this way, cells in all three tissue systems of the plant interact to transport water into the root.

The vascular cylinder is enclosed by a layer of cells known as the endodermis. Where these cells meet, their cell walls form a special waterproof zone called the **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. The waxy Casparian strip forces water and minerals to move through the cell membranes of endodermis cells rather than in between the cells. As a result, there is a one-way passage of water and nutrients into the vascular cylinder.

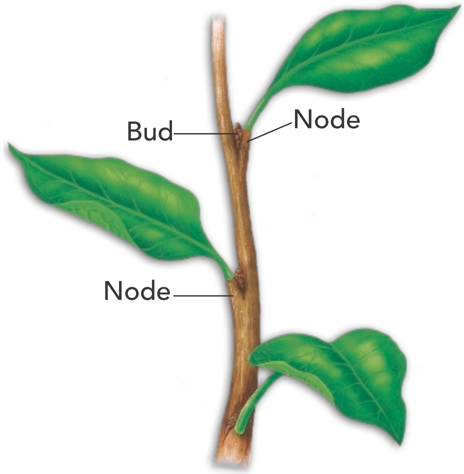
Root Pressure Contained within the Casparian strip, the water has just one place to go—up. Root pressure forces water through the vascular cylinder and into the xylem. As more water moves from the cortex into the vascular cylinder, water in the xylem is forced upward through the root into the stem.

READING CHECK **Explain** How does water move into roots?

Figure 23-7

Anatomy of a Stem

Stems produce leaves from their nodes and new branches from buds. Stems hold leaves up to the sunlight, which is needed for the plant to carry out photosynthesis.



Stems

While visiting the salad bar for lunch, you decide to add some sliced water chestnuts and bamboo shoots on top. Then you place some asparagus and potato salad on the side. These good things all come from the same part of the plant. Can you guess which one?

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. ***Stems produce leaves, branches, and flowers, hold leaves up to the sun, and transport substances throughout the plant.***

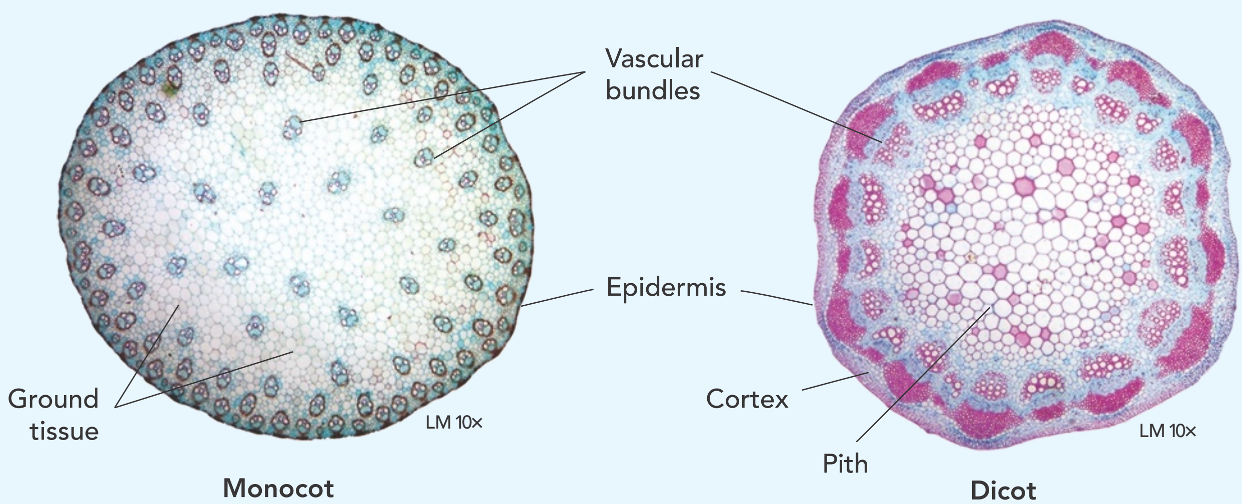
Anatomy of a Stem Stems contain the plant's three tissue systems: dermal, vascular, and ground tissue. Growing stems contain distinct **nodes**, where leaves are attached, as shown in **Figure 23-7**. Small buds where leaves attach to the nodes contain apical meristems that produce new stems and leaves. In larger plants, stems develop woody tissue that helps support leaves and flowers.

The arrangement of tissues in a stem follows two basic patterns. In monocots, clusters of xylem and phloem tissue, called **vascular bundles**, are scattered throughout ground tissue within the stem. Among gymnosperms and dicots, vascular bundles are arranged in a ring. Parenchyma cells inside the ring of vascular tissue are known as pith, while those outside form the cortex of the stem. You can see a comparison of monocot and dicot stems in **Figure 23-8**.

Figure 23-8

Comparing Monocot and Dicot Stems

These cross sections of monocot and dicot stems show their similarities and differences. **Observe** How does the arrangement of the vascular bundles differ?



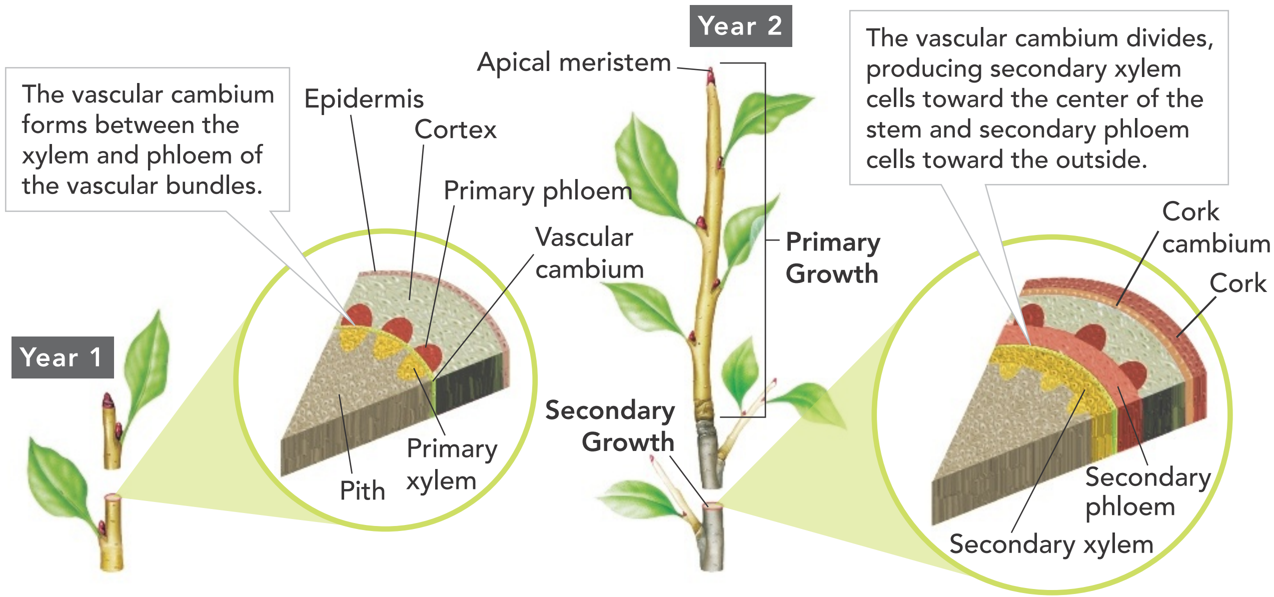


Figure 23-9

Primary and Secondary Growth

New cells produced by the apical meristem cause stems to grow in length (primary growth). Meanwhile, the vascular cambium increases the stem's width (secondary growth).

Primary and Secondary Growth

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. However, plant growth is still carefully controlled and regulated, following patterns that produce the characteristic size and shape of the adult plant.

Primary Growth The growth of new cells produced by the apical meristems at the ends of a plant is called **primary growth**. The increase in length in a plant due to primary growth is shown in **Figure 23-9**. ***Primary growth of stems is the result of elongation of cells produced in the apical meristem.***

Secondary Growth As a plant grows larger, the older stems and roots must increase in thickness as well as in length. This increase in the thickness of stems and roots is known as **secondary growth**. Meristems within stems and roots are responsible for this secondary growth.

A tissue known as vascular cambium produces vascular tissues and increases the thickness of stems over time. Cork cambium produces the outer covering of stems. ***Secondary growth takes place in meristems called the vascular cambium and cork cambium.***

When secondary growth first begins, the vascular cambium is just a thin layer of cells. Divisions in the vascular cambium then give rise to new layers of xylem and phloem, thickening the stem and producing secondary xylem, which becomes the tissue we call "wood." In woody trees and shrubs, tissues outside the vascular cambium produce a thick bark that protects the growing stem.

READING CHECK **Compare and Contrast** How is secondary growth different from primary growth?

INTERACTIVITY

Explore the internal structures of roots and stems.

INTERACTIVITY

Investigate the different adaptations found in different leaves.

Leaves

We hear a lot these days about "green industry," such as biofuels and material recycling, but the most important manufacturing sites on Earth are already green. They are the leaves of plants. Using energy captured in their leaves, plants make the sugars, starches, and oils that feed virtually all animals, including us.

Anatomy of a Leaf

To carry out photosynthesis, leaves must have a way of obtaining carbon dioxide and water. ***The structure of a leaf is optimized to absorb light and carry out photosynthesis.*** To maximize the collection of sunlight, most leaves have a thin, flattened part called a blade. The blade is attached to the stem by a thin stalk called a petiole, as shown in **Figure 23-10**. Leaves have an outer covering of dermal tissue and inner regions of ground and vascular tissues.

Dermal Tissue Leaf epidermis is a specialized layer of tough, irregularly shaped cells with thick outer walls that resist tearing. The epidermis of most leaves is protected by a waxy cuticle that limits the loss of water through evaporation.

Vascular Tissue Cells in 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 cells are bundled in leaf veins that run from the stem throughout the leaf.

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

Figure 23-10

Anatomy of a Leaf

Leaves absorb light and carry out most of the photosynthesis in a plant. **Compare and Contrast** Compare the structure of the two types of mesophyll cells in a leaf.

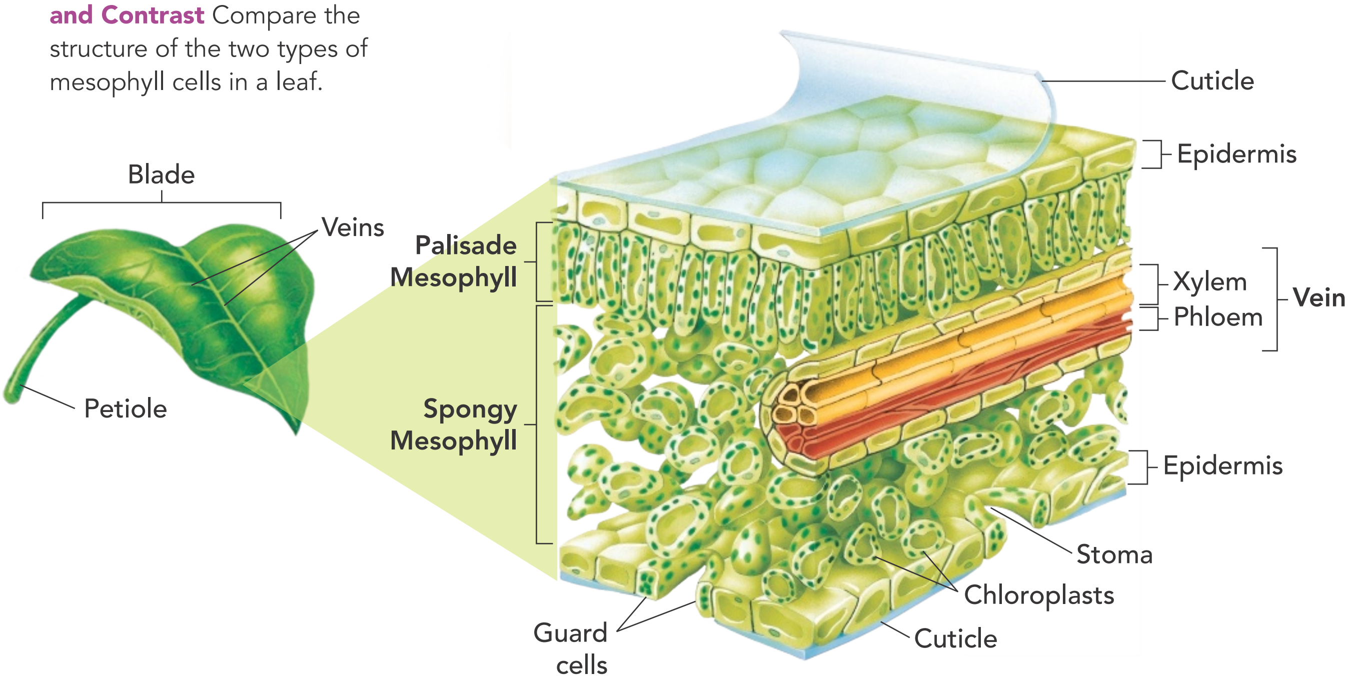


Figure 23-11

Photosynthesis

To perform photosynthesis, leaves need water, carbon dioxide, and the energy of sunlight. Only a small fraction of the water that plants bring to leaves is used for photosynthesis. The rest is lost through transpiration.

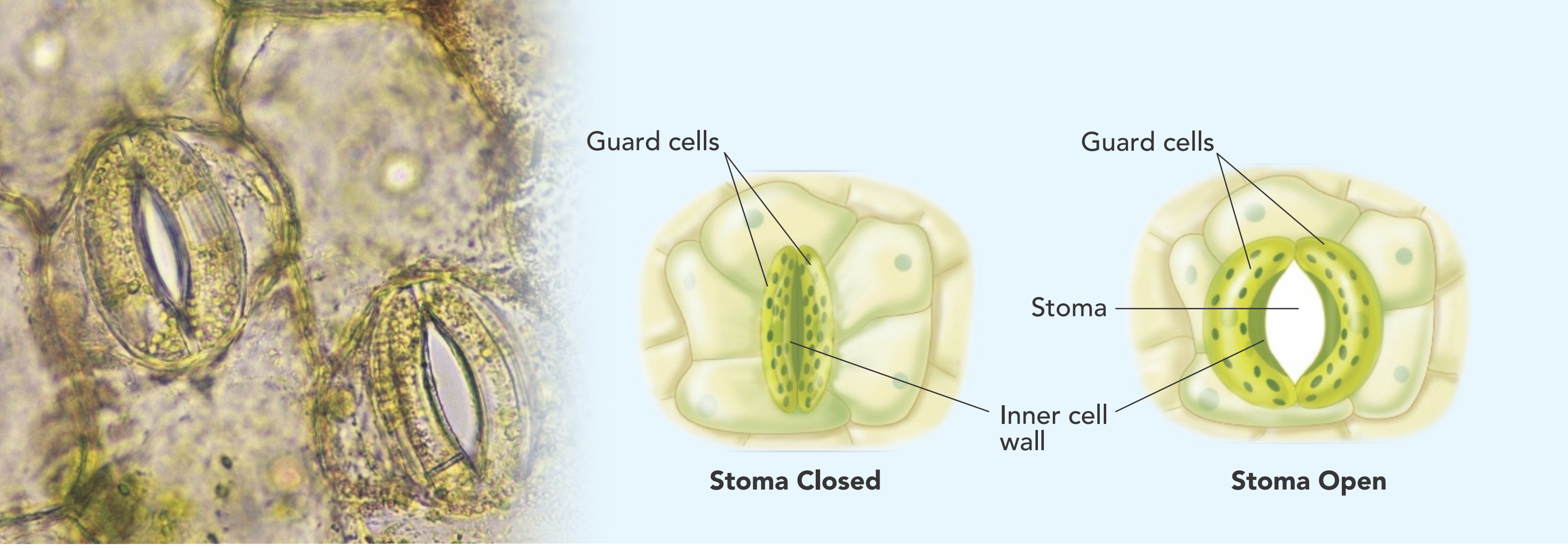
Photosynthesis The mesophyll tissue in leaves like those shown in **Figure 23-11** is highly specialized for photosynthesis. Beneath the upper epidermis is a layer of cells called the palisade mesophyll, containing closely packed cells that absorb light that enters the leaf. Beneath the palisade layer 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.

Gas Exchange and 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 flooding or over-watering. 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.***



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INTERACTIVITY

Figure 23-12

How Guard Cells Function

Plants regulate the opening and closing of their stomata to balance water loss with rates of photosynthesis.

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 23-12**. 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.

READING CHECK **Describe** What determines when the stoma are open and when they are closed?

Transport in Plants

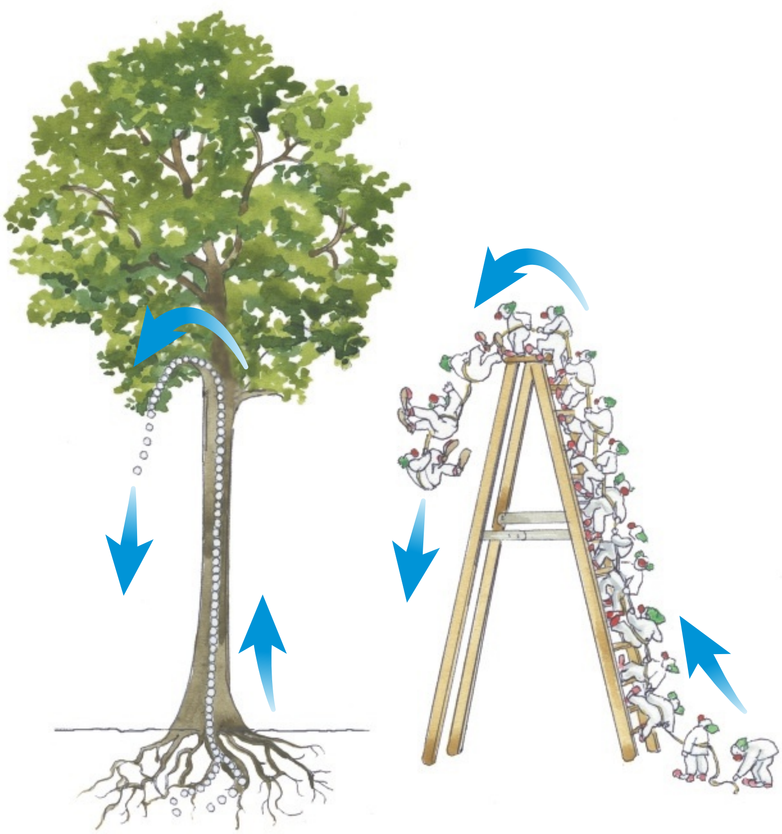
Look at a tall tree. Think about how much work it would be if you had to haul water up 15 or 20 meters to the top of that tree. Now think of a giant redwood, a hundred meters high. How does water get to the top?

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.

Transpirational Pull

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 23-13** shows an analogy for transpirational pull.



Visual Analogy

Figure 23-13

Transpiration Pull

Imagine a chain of circus clowns who are tied together as they climb a ladder. When the clowns at the top fall off the ladder, they pull up the clowns behind them. Similarly, a chain of water molecules extends from the leaves of a plant down to the roots. As water exits the leaves through transpiration, they pull up the molecules behind them.

Figure 23-14

Capillary Action

Capillary action causes water to move much higher in a narrow tube than in a wide tube.

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 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 23-14**.

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 lifts water upward through the xylem tissues of a plant.***

Quick Lab — Guided Inquiry

What Is the Role of Leaves in Transpiration?

1. Put on your apron and safety goggles. Use a scalpel to cut 1 cm off the bottoms of three celery stalks. ***CAUTION:*** Use the scalpel with care. Always direct a sharp edge or point away from yourself and others.
2. Remove the leaves from one stalk. Use a cotton swab to apply petroleum jelly to both sides of all the leaves on another stalk. Place all three stalks into a plastic container holding about 200 mL of water and several drops of food coloring.
3. Place the plastic container in a sunny location. Observe the celery at the end of the class and the next day. Record your observations each day.

ANALYZE AND CONCLUDE

1. **Observe** In which stalk did the colored water rise the most? The least?
2. **Infer** What effect did the petroleum jelly have on transpiration? What part of the leaf did the petroleum jelly affect?
3. **Construct Explanations** Based on your findings in this investigation, how are leaves involved in transpiration?

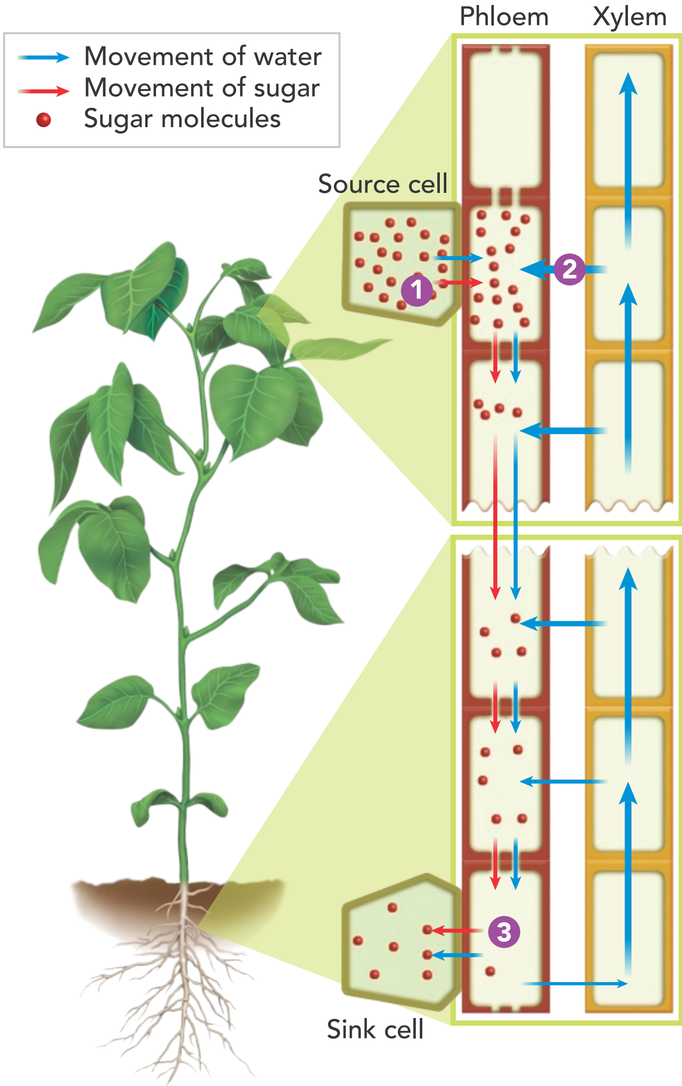
Nutrient Transport How do sugars move in the phloem? The leading explanation of phloem transport is known as the pressure-flow hypothesis, shown in **Figure 23-15**. As you know, unlike the cells that form xylem, the sieve tube cells in phloem remain alive. Transport in the phloem involves three steps. ❶ Active transport moves sugars into the sieve tube from surrounding tissues. ❷ Water then follows by osmosis, creating pressure in the tube at the source of the sugars. ❸ 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.

Figure 23-15

Pressure-Flow Hypothesis

The diagram shows the movement of sugars as explained by the pressure-flow hypothesis.



HS-LS1-1, HS-LS1-2, HS-LS1-3, HS-LS1-5

LESSON 23.1 Review

KEY QUESTIONS

1. Describe the functions and organization of tissue systems in a seed plant.
2. Describe the main function of roots.
3. What are three important functions of stems?
4. Relate the structure and purpose of a leaf.
5. Describe the mechanisms that move water and sugars through a plant.

CRITICAL THINKING

6. **Predict** Describe what would happen over time to a tree sapling that could grow only taller, not wider.
7. **Construct an Explanation** Only a small fraction of the water that plants take in is used as a reactant for photosynthesis. What happens to the rest of the water? How does a plant benefit from this use of water?
8. **Develop Models** Draw a model of a plant that shows the movement of materials in and out of the plant, as well as between roots, stems, and leaves.

LESSON 23.2

Plant Hormones and Tropisms

KEY QUESTIONS

- *What roles do plant hormones play?*
- *What are examples of environmental stimuli to which plants respond?*
- *How do plants respond to seasonal changes?*

HS-LS1-1: Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.
HS-LS1-3: Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

VOCABULARY
hormone
target cell
receptor
auxin
apical dominance
tropism
phototropism
thigmotropism
gravitropism
photoperiodism

READING TOOL

Compare the different vocabulary terms from this lesson in your **Biology Foundations Workbook.** Explain how they are similar or different in the way they support plants.

Plants grow in response to environmental factors such as light, moisture, temperature, and gravity. But how do roots "know" to grow down, and how do stems "know" to grow up? How do the tissues of a plant determine the right time of year to produce flowers? Somehow, plant cells manage to act together as a single organism.

Hormones

Hormones are chemical signals that affect the growth, activity, and development of cells and tissues. In plants, hormones may act on the same cells in which they are made, or they may travel to different cells and tissues. ***Plant hormones serve as signals that control the development of cells, tissues, and organs. They also coordinate responses to the environment.*** These two functions fit together well, because plants respond to the environment mainly by changing their development.

Cells affected by a particular hormone are called **target cells**. To respond to a hormone, a target cell must contain hormone **receptors**—usually proteins—to which hormone molecules bind. The response will depend on what kinds of receptors are present in the target cell. One kind of receptor might alter metabolism; a second might speed growth; a third might inhibit cell division. Thus, depending on the receptors present, a given hormone may cause a different response in roots than it does in stems or flowers, and the effects may change as cells add or remove receptors. Cells that do not contain receptors are generally unaffected by hormones.

Auxins The first step in the discovery of plant hormones came more than a century ago, and was made by a scientist already familiar to you. In 1880, Charles Darwin and his son Francis published the results of a series of experiments exploring the mechanism behind a grass seedling's tendency to bend toward light as it grows.

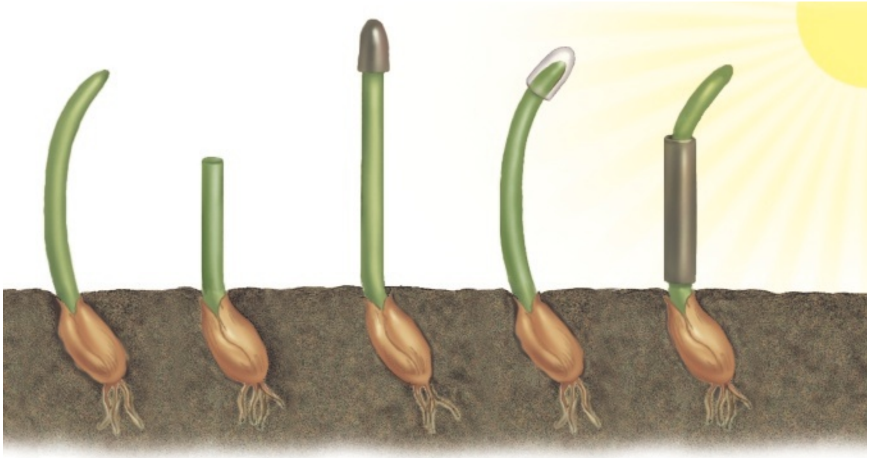


Figure 23-16

How Plants Detect Light

The Darwins conducted controlled experiments to determine which region of a plant senses light. When they removed the seedling tip or placed an opaque cap over the tip, they observed no bending toward light. But when they placed a clear cap on the tip or an opaque shield around the base, they observed bending similar to that seen in the control. **Control Variables** What variable did the Darwins control for by comparing the results of seedlings treated with a clear cap versus no cap?

The results of their experiments, shown in **Figure 23-16**, suggested that the tip of the seedling somehow senses light. The Darwins hypothesized that the tip produces a substance that regulates cell growth. More than forty years later, the regulatory substances produced by the tips of growing plants were identified and named *auxins*. **Auxins** stimulate cell elongation and the growth of new roots, among other roles that they play. They are produced in the shoot apical meristem and transported to the rest of the plant.

Auxins and Cell Elongation One of the effects of auxins is to stimulate cell elongation. As the Darwins saw in their experiment, when light hits one side of the shoot, auxins collect in the shaded part of the shoot. This change in concentration stimulates cells on the dark side to lengthen. As a result, the shoot bends away from the shaded side and toward the light, as shown in **Figure 23-17**.

INTERACTIVITY

Investigate how hormones affect plant growth.

READING CHECK Identify What are auxins?

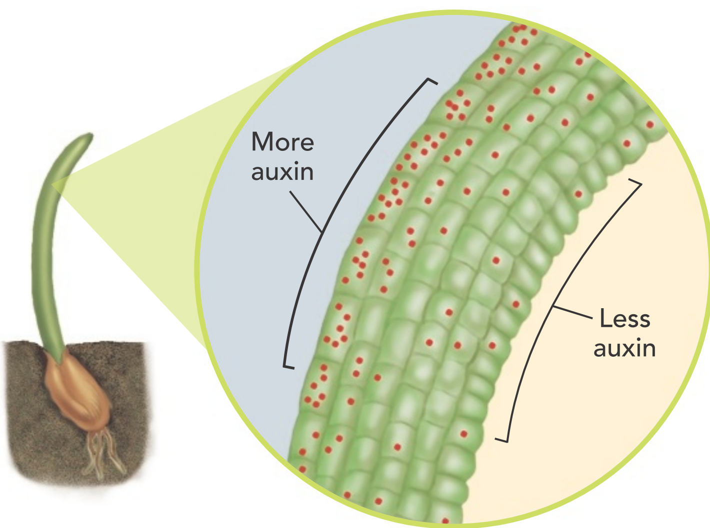


Figure 23-17

Auxins and Cell Elongation

Cells elongate more on the shaded side of the shoot, where there is a higher concentration of auxins.

Figure 23-18

Apical Dominance

The basil plant on the right has had its apical meristem pinched off, in contrast to the plant on the left, which hasn't. **Observe** How are the two plants different?

Auxins and Branching Auxins also regulate cell division in meristems. As a stem grows in length, it produces lateral buds. As you may have noticed, the buds near the top of the plant grow more slowly than those near the base of a plant. The reason for this delay is that growth at the lateral buds is inhibited by auxins. Because auxins move out from the apical meristem, the closer a bud is to the stem's tip, the more it is inhibited. This phenomenon is called **apical dominance**. If you snip off the tip of a plant, these lateral buds begin to grow more quickly and the plant becomes bushier, as you can see in **Figure 23-18**. This is because the apical meristem—the source of the growth-inhibiting auxins—has been eliminated.

READING TOOL

Compare and contrast the effects of auxins and cytokinins on plant growth.

Cytokinins

Cytokinins are plant hormones that are produced in growing roots and in developing fruits and seeds. Cytokinins stimulate cell division, interact with auxins to help to balance root and shoot growth, and stimulate regeneration of tissues damaged by injury. Cytokinins also delay the aging of leaves and play important roles in the early stages of plant growth.

Cytokinins often produce effects opposite to those of auxins. For example, root tips make cytokinins and send them to shoots; shoot tips make auxins and send them to roots. This exchange of signals keeps root and shoot growth in balance. Auxins stimulate the initiation of new roots, and they inhibit the initiation and growth of new shoot tips. Cytokinins do just the opposite. So if a tree is cut down, the stump will often make new shoots because auxins have been removed and cytokinins accumulate near the cut.

Ethylene

One of the most interesting plant hormones, ethylene, is actually a gas. Fruit tissues release small amounts of the hormone ethylene, stimulating fruits to ripen. Ethylene also plays a role in causing plants to seal off and drop organs that are no longer needed. For example, petals drop after flowers have been pollinated, leaves drop in autumn, and fruits drop after they ripen. Ethylene signals cells at the base of the structure to seal off from the rest of the plant by depositing waterproof materials in their walls.

Gibberellins For years, farmers in Japan knew of a disease that weakened rice plants by causing them to grow unusually tall. The plants would flop over and fail to produce a high yield of rice grain. Farmers called the disease the "foolish seedling" disease. In 1926, Japanese biologist Eiichi Kurosawa discovered that a fungus, *Gibberella fujikuroi*, caused this extraordinary growth. His experiments showed that the fungus produced a growth-promoting substance.

In fact, the chemical produced by the fungus mimicked hormones produced naturally by plants. These hormones, called gibberellins, stimulate growth and may cause dramatic increases in size, particularly in stems and fruits. An example of the effect of gibberellins is shown in **Figure 23-19**.

Abscisic Acid Gibberellins also interact with another hormone, abscisic acid, to control seed dormancy. Abscisic acid inhibits cell division and halts growth. Recall that seed dormancy allows the embryo to rest until conditions are right for growth. When seed development is complete, abscisic acid stops the seed's growth and shifts the embryo into a dormant state. The embryo rests until environmental events shift the balance of hormones. Such events may include a strong spring rain that washes abscisic acid away. (Gibberellins do not wash away as easily.) Without the opposing effect of abscisic acid, the gibberellins can signal germination.

READING CHECK **Summarize** Describe the roles of cytokinins, ethylene, gibberellins, and abscisic acid in plants.

Figure 23-19

Gibberellins

Gibberellin hormones can cause incredible growth spurts, like those seen in the cabbage plants on the right.

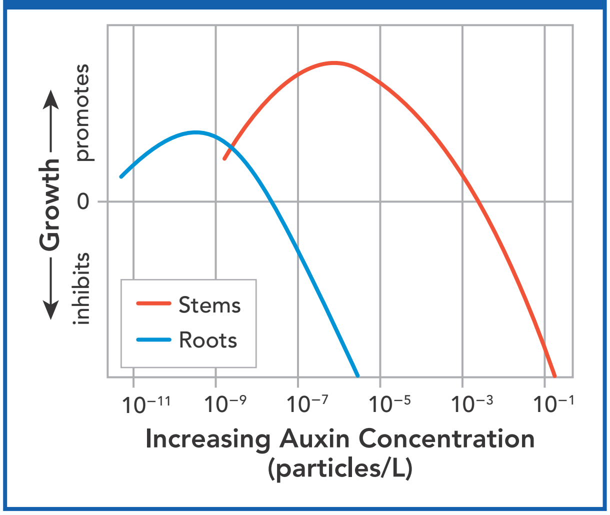
Analyzing Data

Auxins and Plant Growth

This graph shows the results of experiments in which carrot cells were grown in the presence of varying concentrations of auxins. The blue line shows the effects on root growth. The red line shows the effects on stem growth.

1. **Analyze Graphs** At what auxin concentration are the stems stimulated to grow the most?
2. **Analyze Graphs** How is the growth of the roots affected by the auxin concentration at which stems grow the most?
3. **Apply Scientific Reasoning** If you were a carrot farmer, what concentration of auxin should you apply to your fields to produce the largest carrot roots?

Effects of Hormone Concentration on Plant Growth



Tropisms and Rapid Movements

Like other living things, plants move to respond to the environment. Many plant movements are slow, but some are so fast that even animals cannot keep up with them.

BUILD VOCABULARY

Word Origins The word **tropism** comes from a Greek word that means "turning."

Tropisms

Plant sensors that detect environmental stimuli signal elongating organs to reorient their growth. These growth responses are called **tropisms**. ***Plants respond to environmental stimuli such as light, touch, and gravity.*** These three tropisms are shown in **Figure 23-20**.

Light The tendency of a plant to grow toward a light source is called **phototropism**. This response can be so quick that young seedlings reorient themselves in a matter of hours. Recall that changes in auxin concentration are responsible for phototropism. Experiments have shown that auxins migrate toward shaded tissue, possibly due to changes in membrane permeability in response to light.

Touch Some plants even respond to touch, a process called **thigmotropism**. Vines and climbing plants exhibit thigmotropism when they encounter an object, such as a tree or trellis, and wrap around it. Other plants, such as grape vines, have extra growths called tendrils that emerge near the base of the leaf and wrap tightly around any object they encounter.

Gravity Auxins also affect **gravitropism**, the response of a plant to gravity. For reasons still not understood, auxins migrate to the lower sides of horizontal roots and stems. In horizontal stems, the migration causes the stem to bend upright. In horizontal roots, however, the migration causes roots to bend downward.

INTERACTIVITY

Figure 23-20

Three Tropisms

Plant tropisms include phototropism, thigmotropism, and gravitropism. Phototropism causes a plant to grow toward a light source. One effect of a thigmotropism is that plants curl and twist around objects, such as the trellis. Gravitropism is the response of a plant to gravity.

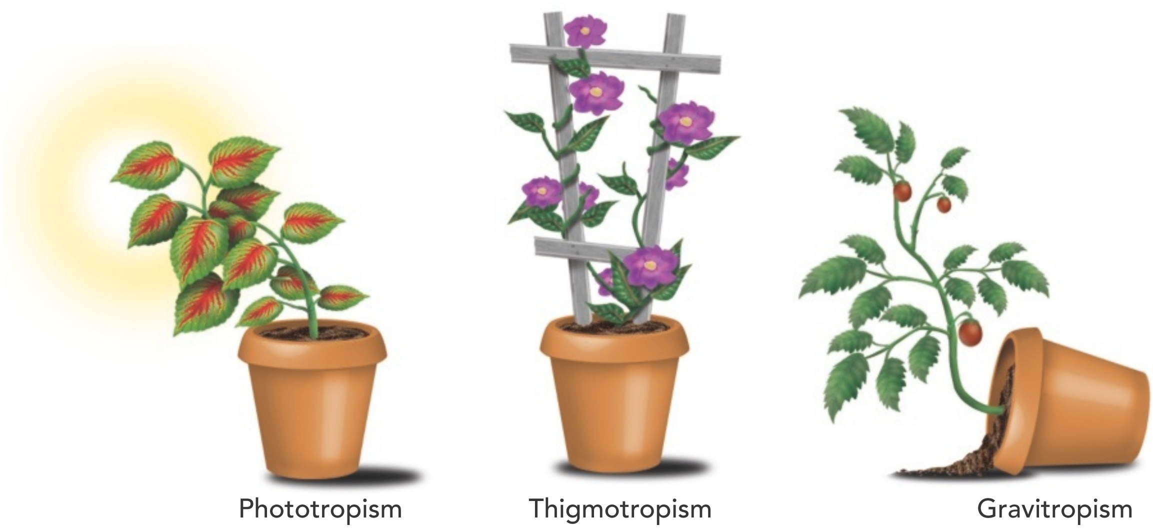
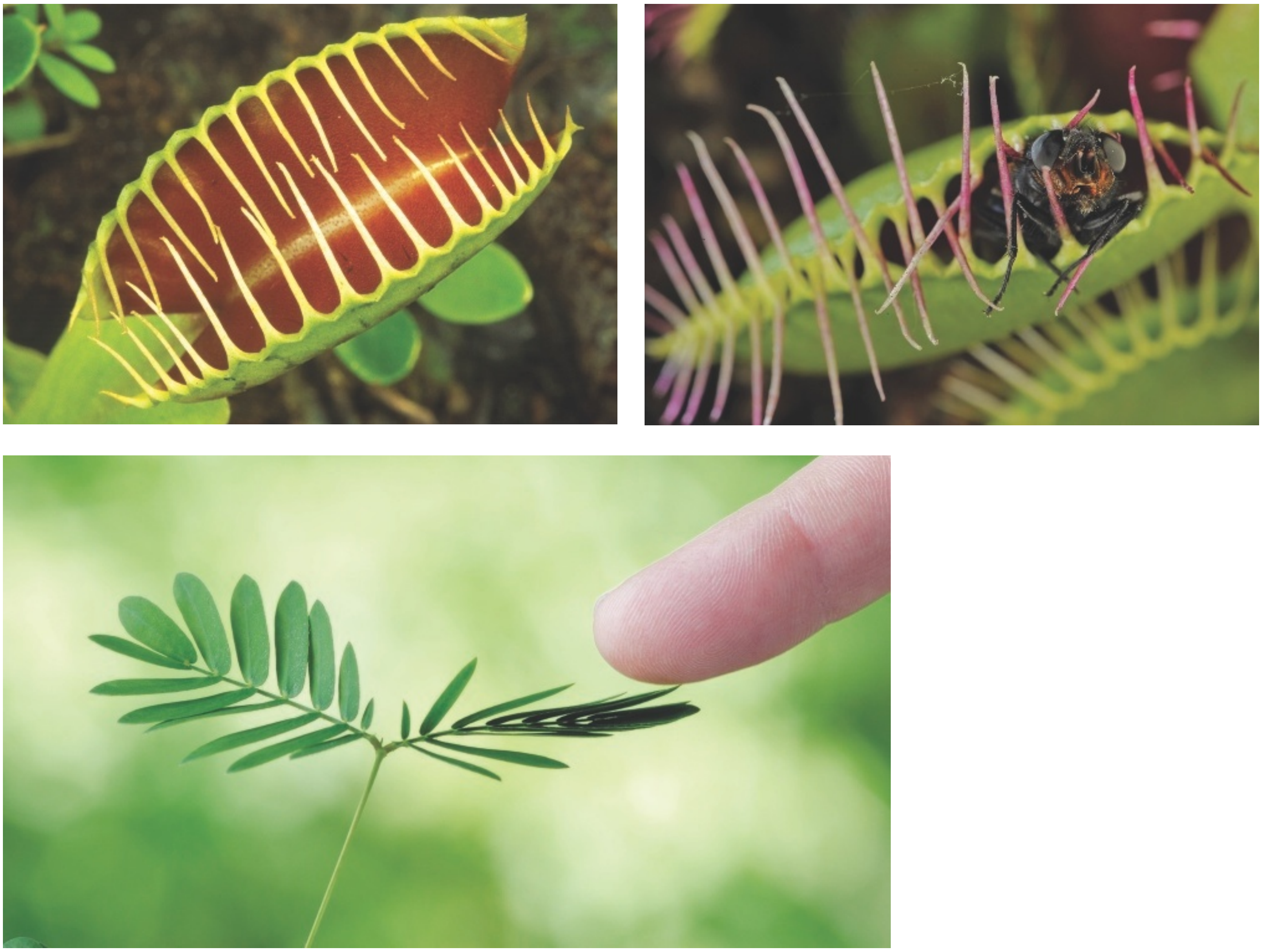


Figure 23-21

Rapid Movements

The leaves of the Venus flytrap can close quickly onto an unsuspecting insect, which the plant then breaks apart for its nitrogen and other nutrients. The mimosa plant responds to touch by folding in its leaves quickly. This response is produced by decreased osmotic pressure in cells near the base of each leaflet. **Infer** What adaptive value might this response have?



Rapid Movements Some plant responses are so rapid that it would be a mistake to call them tropisms. One example of a rapid response is what happens if you touch a leaf of the *Mimosa pudica*, appropriately called the "sensitive plant." Within only two or three seconds of being touched, its two leaflets fold together completely.

The carnivorous Venus flytrap, shown in **Figure 23-21**, also demonstrates a rapid response. When an insect lands on a flytrap's leaf, it triggers sensory cells on the inside of the leaf, sending electrical signals from cell to cell. A combination of changes in osmotic pressure and cell wall expansion interact, snapping the leaf shut so quickly that the insect is trapped inside—and digested.

READING CHECK **Integrate Information** How do tropisms help plants survive in their environments?

INTERACTIVITY

Explore how photoperiodism affects plants.

Response to Seasons

"To every thing there is a season." Nowhere is this more evident than in the regular cycles of plant growth. Year after year, some plants flower in the spring, others in the summer, and still others in the fall. Plants such as chrysanthemums and poinsettias flower when days are short and are therefore called short-day plants. Plants such as spinach and irises flower when days are long and are therefore known as long-day plants.

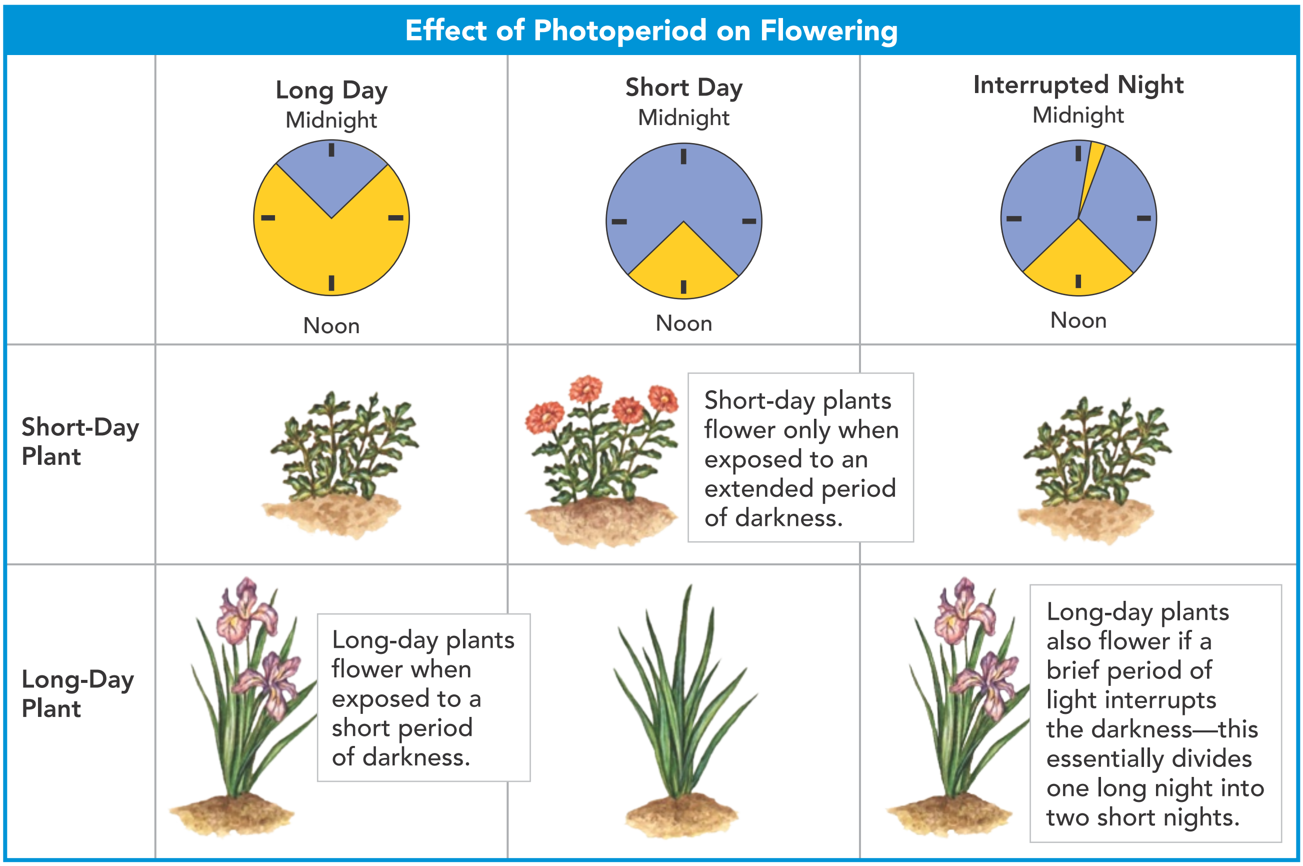
Photoperiod and Flowering How do all these plants manage to time their flowering so precisely in response to the environment? In the early 1920s, scientists discovered that tobacco plants flower according to their photoperiod, the number of hours of light and darkness they receive. Additional research showed that many other plants also respond to changing photoperiods, a response called **photoperiodism**. This type of response is summarized in **Figure 23-22**. ***Photoperiodism is a major factor in the timing of seasonal activities such as flowering and growth.***

It was later discovered that a plant pigment called phytochrome (FYT oh krohm) is responsible for plant responses to photoperiod. Phytochrome absorbs red light and activates a number of signaling pathways within plant cells. By mechanisms that are still not understood completely, plants respond to regular changes in these pathways. These changes determine the patterns of a variety of plant responses.

Figure 23-22

Effects of Photoperiod

Changes in the photoperiod can affect the seasonal timing of flowering. **Form an Opinion** Are "short-day plant" and "long-day plant" the best names for categorizing these plants, or would it be better to name plants after their responses to night length? Explain your reasoning.



Winter Dormancy

Phytochrome also regulates the changes in activity that prepare many plants for dormancy as winter approaches. Recall that dormancy is the period during which an organism's growth and activity decrease or stop. ***As cold weather approaches, many plants prepare by turning off photosynthetic pathways, transporting materials from leaves to roots, and sealing off leaves from the rest of the plant.***

Leaf Loss In temperate regions, many flowering plants lose their leaves during the colder months. At summer's end, the phytochrome in leaves absorbs less light as days shorten and nights become longer. Auxin production drops, but the production of ethylene increases. This triggers a series of events that gradually shut down the leaf. As chlorophyll breaks down, other pigments—including yellow carotenoids and red anthocyanins—become visible, producing the beautiful colors of autumn.

Changes to Meristems Hormones also produce changes in apical meristems. Instead of continuing to produce leaves, meristems produce thick, waxy scales that form a protective layer around new leaf buds. Enclosed in its coat of scales, a terminal bud can survive the coldest winter days, as shown in **Figure 23-23**. At the onset of winter, xylem and phloem tissues pump themselves full of ions and organic compounds. The resulting solution acts like antifreeze in a car, preventing the tree's sap from freezing. This is one of several mechanisms plants use to survive the bitter cold.

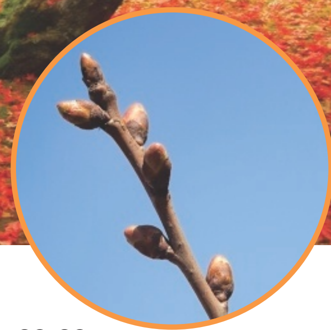


Figure 23-23

Adaptations for Winter

In autumn, leaves shut down photosynthesis and fall from deciduous trees. Meanwhile, meristems at the tips of the branches produce thick, waxy scales that cover and protect new stem and leaf buds through the harsh winter.

HS-LS1-1, HS-LS1-3

LESSON 23.2 Review

KEY QUESTIONS

1. Describe how hormones contribute to homeostasis.
2. Describe three examples of tropisms in plants.
3. Summarize plant responses to seasonal changes.

CRITICAL THINKING

4. **Plan an Investigation** How could a garden-store owner determine what light conditions are needed for a particular flowering plant to bloom?
5. **Apply Scientific Reasoning** Review what you learned about evolution by natural selection in Chapter 17. Then, using what you know about natural selection, describe how plant adaptations for dormancy may have developed over time.

LESSON 23.3

Plants and People

KEY QUESTIONS

- *Which crops are the major food supply for humans?*
- *What are some examples of benefits besides food that humans derive from plants?*

HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

READING TOOL

For each section within the lesson, identify the main idea and one to three supporting details. Fill in the table in your **Biology Foundations Workbook.**

VIDEO

Discover what an ethnobotanist found out about regarding plants and zombies.

A stroll through the produce section of a grocery store will convince you that plants are important. Even a medium-sized store will contain products made from scores of different plants. But which ones are the most important? Are there certain plants that we simply couldn't live without?

Agriculture

Agriculture—the systematic cultivation of plants—did not begin with humans. In fact, the very first animals to practice agriculture may have been ants. On the island of Fiji, ants not only live inside a plant called *Squamellaria*, but they harvest its seeds, spread them around, and fertilize them. Evidence indicates that ants began "farming" this way several million years before humans first tried to grow plants for food.

Worldwide Patterns Many scholars now trace the beginnings of human civilization to the cultivation of crop plants. Evidence suggests that agriculture developed separately in many parts of the world about 10,000 to 12,000 years ago. Once people discovered how to grow plants for food, the planting and harvesting of crops tended to keep them in one place for much of the year, leading directly to the establishment of social institutions. Even today, agriculture is the principal occupation of more human beings than any other occupation.

Today, farming is the foundation on which human society is built. North America has some of the richest, most productive cropland in the world. As a result, farmers in the United States and Canada produce so much food that they are able to feed millions of people around the world as well as their own citizens.

Hundreds of different plants—nearly all of which are angiosperms—are raised for food in various parts of the world. Yet, despite this diversity, much of human society depends upon just a few of these plants. ***Worldwide, most people depend on a few crop plants, such as rice, wheat, soybeans, and corn, for the bulk of their food supply.*** The same crops are also used to feed livestock.

You may not have thought of it this way, but the food we eat from most crop plants comes from their seeds. For nutrition, most of humanity worldwide depends on the endosperm of only a few carefully cultivated species of grass. The pattern in the United States follows this trend. Roughly 80 percent of all U.S. cropland is used to grow just four crops: wheat, corn, soybeans, and hay. Of these crops, three—wheat, corn, and hay—are derived from grasses.

Devoting so much land to just a few crops can boost efficiency, but it presents certain dangers as well. Growing the same crop year after year depletes the soil of the same set of nutrients each season and increases dependency on chemical fertilizers. It also makes it more likely that insect pests and diseases associated with those crops will become more common, threatening the food supply.

READING TOOL

As you read, write down the important events that have occurred in the history of agriculture.

INTERACTIVITY

Explore how developments in agriculture have affected human life.

New Plants The discovery and introduction of new crop plants has frequently changed human history. Potatoes are native to South America. Before they were discovered in the Americas, many important crops—including corn, peanuts, and potatoes—were unknown in Europe. The introduction of these plants changed European agriculture rapidly. We think of boiled potatoes, for example, as a traditional staple of German and Irish cooking, but 400 years ago, potatoes were new to the diets of Europeans.

By continuing to introduce such new plants into cultivation, the genetic diversity of the food supply can be strengthened and the likelihood that a single pest or disease will devastate farming can be reduced. Current trends along these lines have included the reintroduction of "heirloom" plants that were once cultivated but are not currently used in large-scale agriculture, such as the "heirloom" potatoes shown in **Figure 23-24**.

Figure 23-24

Heirloom Potatoes

Potatoes that were once common have been reintroduced into the marketplace.

Figure 23-25

Seed Banks

Seed banks help safeguard biodiversity. If stored properly, seeds could remain viable for hundreds, even thousands of years.

Changes in Agriculture

Between 1950 and 1970, a worldwide effort to combat hunger and malnutrition led to dramatic improvements in farming techniques and crop yields. This effort came to be called the green revolution because it greatly increased the world's food supply. Green revolution technologies enabled many countries to end chronic food shortages and, in some cases, become exporters of surplus food.

At the heart of the green revolution was the use of high-yield varieties of seed and fertilizer. While some farmers today still use traditional fertilizers such as manure, artificial fertilizers helped to make the green revolution possible.

Fertilizers and pesticides must be used with great care. When large amounts of nitrogen- and phosphate-containing fertilizer are used near wetlands and streams, runoff from the fields may contaminate the water. Pesticides can also pose a health risk. Chemical pesticides are poisons, and have the potential to harm wildlife and leave dangerous chemical residues in food.

Industrial Agriculture

Improved farming methods have made it possible to increase crop yields and produce food more cheaply, helping to alleviate hunger throughout the world. However, the large-scale cultivation of a small number of crop species has also reduced genetic diversity and left much of our food supply vulnerable to insects and disease. In certain parts of the world, whole forests have been slashed and burned to make room for immense plantations devoted to products like palm oil to be exported to developed countries. As the world population continues to increase, it will be necessary to safeguard the genetic diversity of crop plants and to deal with the challenges posed by industrial farming methods. Seed banks, as shown in **Figure 23-25**, are one of these safeguards.

Exploration Lab

Open-ended Inquiry

How Do Plant Adaptations Compare?

Problem How have the plants in your area adapted to their environment?

Plants have adaptations that enable them to survive in their specific environments. In this investigation, you will take a field trip to explore and observe plants in your neighborhood. You will identify how these plants reproduce, grow, and develop. You will also investigate adaptations of the plants to their environment.

You can find this lab in your digital course.

INTERACTIVITY

Figure 23-26

Products from Plants

Plant products include wood for musical instruments and cotton for clothing. The rosy periwinkle provides drugs for treating cancer.

Fiber, Wood, and Medicine

Some of the most important uses of plants have nothing to do with food. ***Plants produce the raw materials for our homes and clothes, and some of our most powerful and effective medicines.*** Some examples of plant products are shown in **Figure 23-26**. If you're reading this page out of the printed book, you are turning paper pages made from the conifer forests of North America, possibly sitting on a chair made from oak tree xylem, and probably wearing at least one piece of clothing made from the fibers of the cotton plant. Plants are also the source of many medicines and powerful drugs, including some that can be used to fight cancer.

VIDEO

Examine the interactions plants and people have had over time.

HS-ETS1-1

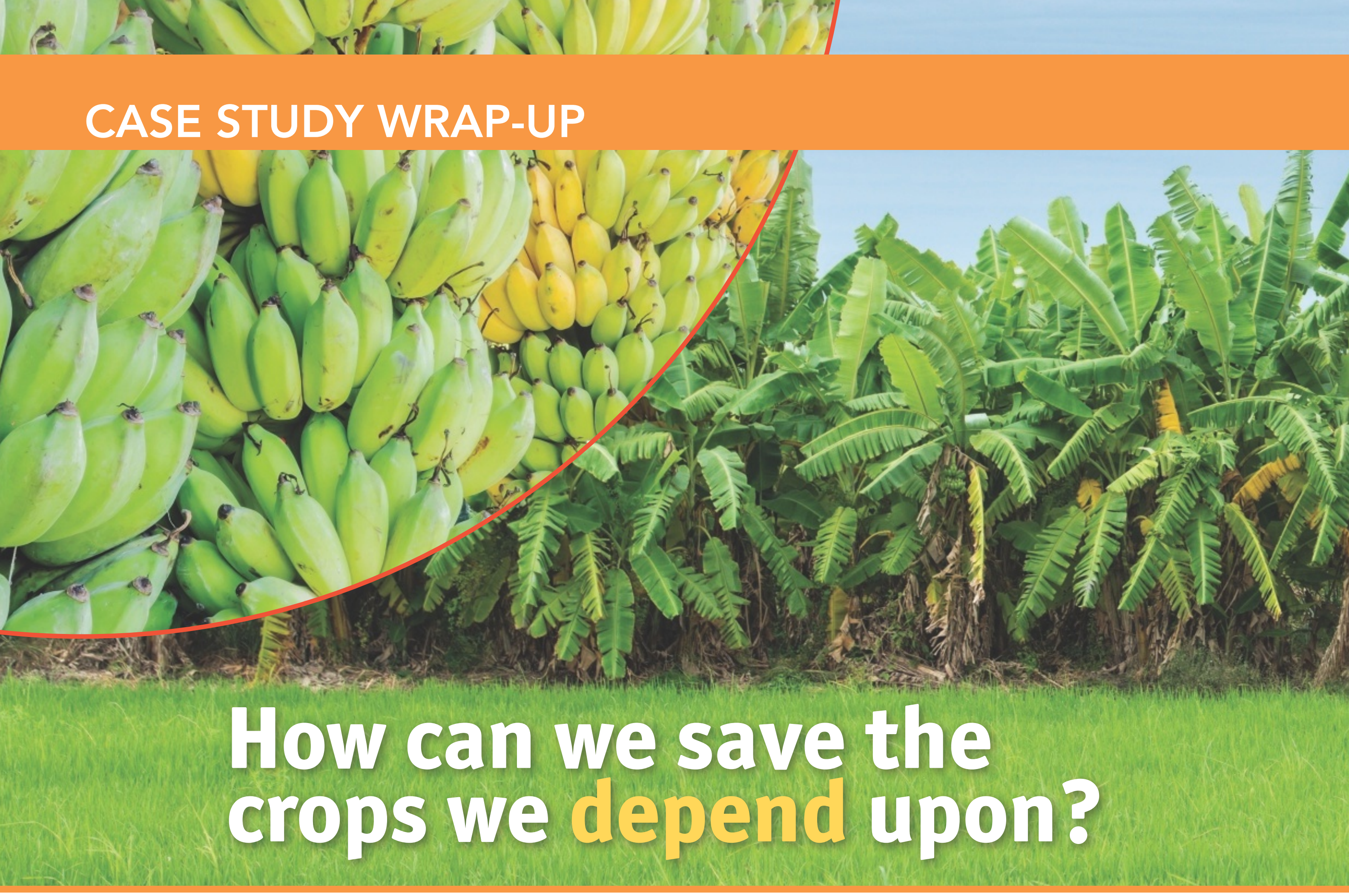
LESSON 23.3 Review

KEY QUESTIONS

1. Name four crops that make up the base of the world's food supply.
2. Describe the importance of plants in modern life.

CRITICAL THINKING

3. **Evaluate Claims** The textbook claims that farming is the foundation on which human society is built. Use evidence and logical reasoning to support this claim.
4. **Synthesize Information** How are food crops different from wild plants? Include specific examples to support your answer.
5. **CASE STUDY** What are some of the drawbacks of the modern, large-scale cultivation of food crops? Cite a specific example to support your answer.



CASE STUDY WRAP-UP

How can we save the crops we depend upon?

Modern agriculture has brought many benefits as well as drawbacks.

HS-LS2-7, HS-ETS1-1, CCSS.ELA-LITERACY.RST.9-10.1, CCSS.ELA-LITERACY.WHST.9-10.7

Make Your Case

As we've seen, fully 60 percent of the food energy found in the human diet comes from just three crops: wheat, corn, and rice. What would happen if the soil could no longer support these crops? Or if a disease decimated the harvests upon which millions depend? Should we grow more varieties of edible plants instead of concentrating on just a few?

Engaging in Argument from Evidence

1. **Research a Problem** Go to your local supermarket or produce stand and make a list of the plant products (produce) that are sold. Then, determine which of these plants can grown locally and which plants cannot.
2. **Support Your Explanation with Evidence** Would you recommend growing some alternative varieties of plants in your local area? Based on your research, make a recommendation and support your recommendation with evidence.

Careers on the Case

Work Toward a Solution

Agriculture involves the efforts of more than one specialist. For example, orchard growers know the best ways to raise fruit trees, prevent infestations, and harvest the fruit. To pollinate the flowers, however, they rely on people who know all about bees.

Beekeeper

Beekeepers manage colonies of bees who live in hives in order to provide honey and other related products. They must maintain the health of the hives so that the bees survive. Beekeepers can work for themselves or as part of a larger commercial organization.

VIDEO

Watch this video to learn about other careers in biology.

Society on the Case

Eat Local!

The next time you buy tomatoes at the supermarket, take a look at their skins. Commercially raised tomatoes tend to be varieties with relatively thick skins, which protect them from jostling. After the tomatoes are picked from the vine, they are processed, packaged, and shipped. Then they travel hundreds, even thousands of miles to market. The tomatoes lose freshness on their journey, and the cost of transport is included in their price.

How can you find a fresh, tasty tomato, with thin skin and a rich, juicy texture? One way is to buy it from a local farm. Today, many small farms grow fruits and vegetables specifically to sell in their communities or at farmers' markets in nearby cities. Their customers get fresh produce of high quality, at a competitive price.

Beginning in the 1980s, small-scale farmers in the United States began using an economic model called community supported agriculture (CSA). In this model, community members pay a seasonal fee, or subscription, to the farmer or to a group of farmers. The subscription entitles them to a share of the harvest. This allows the farmer and the community to share the risks and benefits of farming. The subscribers may also pledge to contribute time and effort to raising the crop.

Of course, you could also raise your own tomatoes or other favorite fruits and vegetables. Many communities are establishing gardens in parks, vacant lots, and the rooftops of city buildings. You can even grow many vegetables in a pot on a patio or any other open space.

STUDY GUIDE

Lesson Review

Go to your Biology Foundations Workbook for longer versions of these lesson summaries.

23.1 Roots, Stems, and Leaves

Plants have three main tissue systems: dermal, vascular, and ground. Dermal tissue is the protective outer covering of a plant. Vascular tissues support the plant body and transport water and nutrients throughout the plant. Ground tissue produces and stores sugars, and contributes to the physical support of the plant.

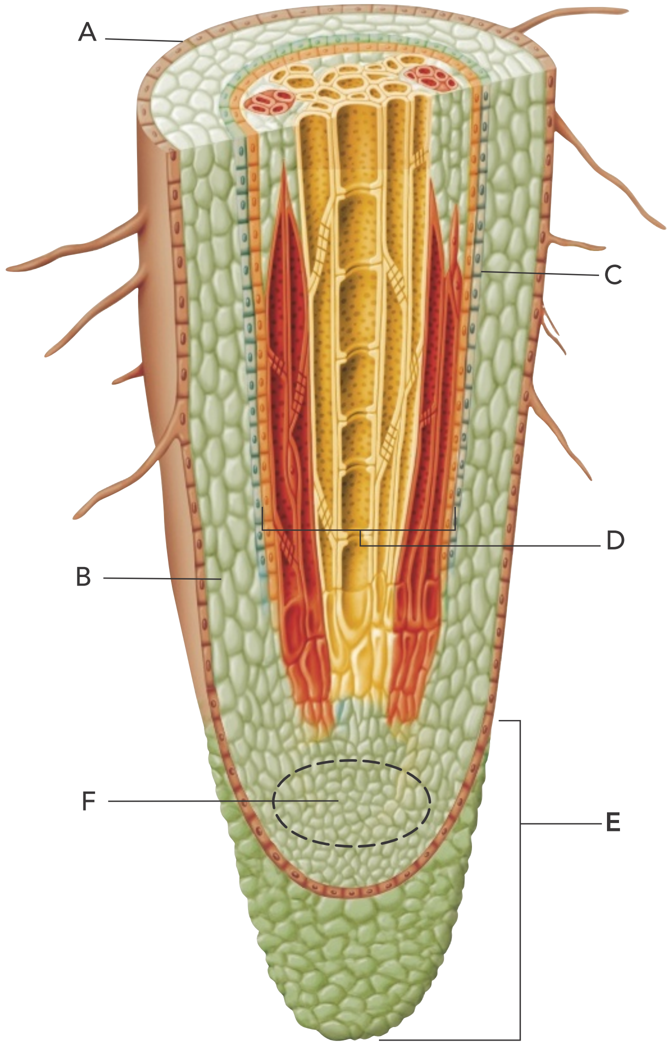
The root system of a plant plays a key role in water and mineral transport. Roots support a plant, anchor it in the ground, store food, and absorb water and dissolved nutrients from the soil. The cells and tissues of a root are specialized to carry out these functions. A mature root has an outside layer, called the epidermis, and also contains vascular tissue and a large area of ground tissue.

Stems produce leaves, branches, and flowers, hold leaves up to the sun, and transport substances throughout the plant. Primary growth of stems is the result of elongation of cells produced in the apical meristem. Secondary growth takes place in meristems called the vascular cambium and cork cambium.

The structure of a leaf is optimized to absorb light and carry out photosynthesis. 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.

The combination of transpiration and capillary action lifts water upward through the xylem tissues of a plant. Changes in nutrient concentration drive the transport of fluid through phloem tissue in directions that meet the nutritional needs of the plant.

- epidermis
- meristem
- taproot
- fibrous root
- Casparian strip
- node
- vascular bundle
- primary growth
- secondary growth
- mesophyll
- stoma
- transpiration
- guard cells
- capillary action



Interpret Visuals Identify the structures labeled A through F to complete the diagram of root structure.

23.2 Plant Hormones and Tropisms

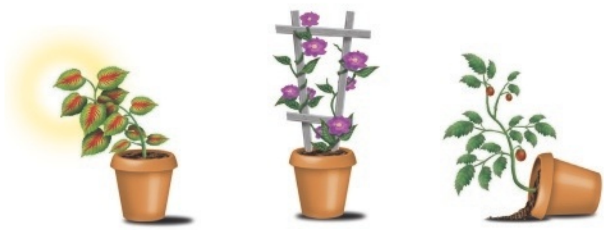
Plant hormones serve as signals that control development of cells, tissues, and organs. They also coordinate responses to the environment. Plant hormones include auxins, cytokinins, gibberellins, abscisic acid, and ethylene.

Plants respond to environmental stimuli through tropisms. Phototropism is the tendency of a plant to grow toward the light; gravitropism is the response of a plant to gravity; and thigmotropism is the response to touch.

Plants also respond to seasonal changes by reacting to differences in to the number of hours of lightness and darkness. Photoperiodism is a major factor in the timing of seasonal activities such as flowering and growth.

As cold weather approaches, many plants prepare by turning off photosynthetic pathways, transporting materials from leaves to roots, and sealing off leaves from the rest of the plant.

- hormone
- target cell
- receptor
- auxin
- apical dominance
- tropism
- phototropism
- thigmotropism
- gravitropism
- photoperiodism



Identify Label and describe each of the tropisms illustrated.

23.3 Plants and People

Worldwide, most people depend on a few crop plants, such as rice, wheat, soybeans, and corn, for the bulk of their food supply.

Plants produce the raw materials for our homes and clothes, and some of our most powerful and effective medicines

Construct an Explanation How are seed banks useful for modern agriculture?

Organize Information

Complete the table by filling in the missing information.

Plant Organ	Structures	Function
Roots	1.	2.
Stems	3.	4.
Leaves	5.	6.

Design a Rooftop Garden

Design a Solution

HS-LS2-7, HS-ETS1-2, CCSS.ELA-LITERACY.RST.9-10.10, CCSS.ELA-LITERACY.WHST.9-10.2, CCSS.ELA-LITERACY.WHST.9-10.8

STEM Imagine covering the rooftop of a building with live plants. This idea has been developed into the technology known as a green roof. When designing a green roof, an architect must consider not only the structural properties of the building, but also the ecology of the site and its surroundings.

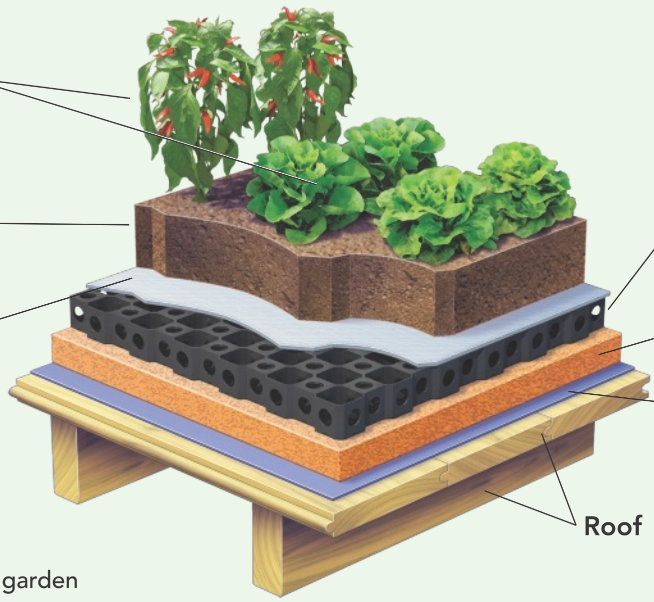
The area and depth of a green roof depend on many factors, including the roof's accessibility, the plants selected, the load capacity of the building, and the budget for installation and upkeep. The types of plants selected for a green roof depend on the climate of the area. The climate also determines what type of irrigation system is needed to keep the plants healthy.

Rainstorms can overwhelm wastewater systems in urban areas because water runs off buildings. A green roof retains more water than a conventional roof. This results in less runoff volume, which puts less stress on wastewater systems.

Asphalt and concrete surfaces of buildings and infrastructure absorb solar energy and re-radiate it to the environment. This process contributes to hotter summer temperatures in cities compared to surrounding areas. Solar energy can also raise the temperature inside a building. Green roofs can help reduce these warming effects.

Your task is to design a green roof system for a building of your choosing. The building may be one that you are already familiar with, such as your home or your school, or it may be a place that you have never visited before. Your design plan should explain the problem you aim to solve, the factors that guide your decision making, and details about the installation, materials, and cost of your green roof.

ENGINEERING PROJECT



Parts of a rooftop garden

1. **Define the Problem** Research the site of your proposed green roof installation. What problem are you trying to solve? In what ways is the problem ecological? In what ways is the problem economic? Explain.

2. **Develop Models** Research the different types of green roof systems available and the materials used in their construction. Compare the advantages and disadvantages of each system. With the help of your class, brainstorm ways to "green" your roof.

3. **Design a Solution** Your green roof must meet certain performance requirements in order to successfully solve the problem. These requirements are your design criteria. You also must specify the constraints that limit the scope of your design solution. Modify your model to meet your design criteria and constraints. Use your classmates' feedback to help you further modify and refine your roof design. Explain how your revised design optimizes the achievement of your design criteria.

4. **Communicate Information** Write a proposal to the owner of the site of your green roof design. Your proposal should outline the costs and benefits of installing the green roof and make a convincing case for adopting your design.

CHAPTER 23

ASSESSMENT

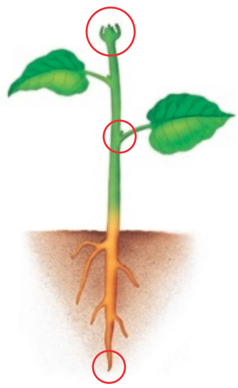
KEY IDEAS AND TERMS

23.1 Roots, Stems, and Leaves

HS-LS1-1, HS-LS1-2, HS-LS1-3, HS-LS1-5

1. The plant organ that supports the plant body and carries nutrients between different parts of the plant is the
   a. root. c. leaf.
   b. stem. d. flower.

2. Which type of plant tissue would be found ONLY in the circled areas of the plant shown?
   a. meristem tissue
   b. vascular tissue
   c. dermal tissue
   d. ground tissue



3. Tracheids and vessel elements make up
   a. phloem. c. xylem.
   b. trichomes. d. meristem.

4. Phloem functions primarily in
   a. transport of water.
   b. growth of the root.
   c. transport of products of photosynthesis.
   d. increasing stem width.

5. What is the principal difference between mature xylem and mature phloem cells?

6. What are the three main functions of leaves?

7. Explain how movement of sugars in the phloem contributes to the homeostasis in a plant.

8. How does the arrangement of vascular bundles in monocot stems differ from that of dicot stems?

23.2 Plant Hormones and Tropisms

HS-LS1-1, HS-LS1-3

9. Chemical signals in plants affecting the growth, activity, and development of cells and tissues are called
   a. hormones.
   b. enzymes.
   c. auxins.
   d. phytochromes.

10. Substances that stimulate cell division and cause dormant seeds to sprout are
    a. gibberellins.
    b. auxins.
    c. cytokinins.
    d. phytochromes.

11. Photoperiod is a measurement of
    a. water level.
    b. day length.
    c. gravity.
    d. nutrients.

12. Explain how auxins act in opposition to cytokinins.

13. What is a tropism? Give one example of a tropism that affects plant stems and another example of a tropism that affects roots.

14. Describe two different ways in which a plant may respond to changes in photoperiod.

15. Describe what happens to deciduous plants during winter dormancy.

23.3 Plants and Humans

HS-ETS1-1

16. The first indications of human agriculture occurred about
    a. 1000 years ago.
    b. 10,000 years ago.
    c. 100,000 years ago.
    d. 1,000,000 years ago.

17. What effect could plant species extinction have on therapeutic drug development?

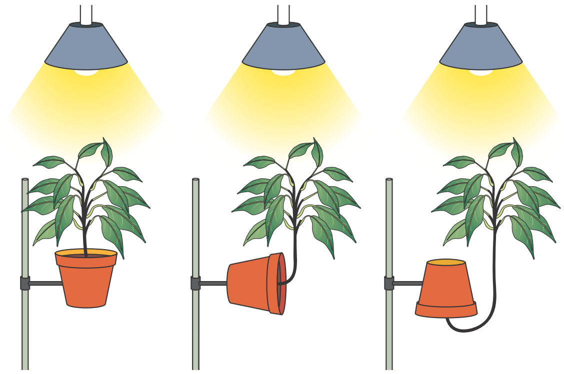
18. What is an advantage of "heirloom" plants?

CRITICAL THINKING

19. **Construct an Explanation** The seeds of lupines, an Arctic plant, can remain dormant for thousands of years, and still germinate when conditions are favorable. How might this trait provide an advantage to lupines in their environment?
20. **Predict** How would the function of a plant root be affected if it lacked a Casparian strip?
21. **Form a Hypothesis** While transplanting a houseplant to a larger pot, you notice that the roots had been very crowded in the old pot. Over the next few weeks, the plant's growth and overall appearance improve greatly. Develop a testable hypothesis that explains this observation.
22. **Apply Concepts** In the art of bonsai, gardeners keep trees small by cutting the roots and tips of the branches. The trunk of the tree, however, continues to increase in width. How do you explain the ever-increasing width of the trunk?
23. **Communicate Information** Describe a particular plant thigmotropism and hypothesize how it benefits the plant.
24. **Infer** The bulk of human plant foods comes from seeds, which constitute only a small part of the plant body. Explain how this is possible.
25. **Compare and Contrast** Compare and contrast the benefits and the dangers of using pesticides and fertilizers to grow food crops.
26. **Form a Hypothesis** Form a hypothesis to explain why plants are a good source of medicines.
27. **Apply Scientific Reasoning** How is it helpful for seed dormancy to be controlled by two types of hormones—gibberellins and abscisic acid—instead of just one type of hormone?
28. **Construct an Explanation** Spinach is a long-day plant that grows best with a night length of 10 hours or less. How does this fact explain the range of locations and seasons in which spinach plants can thrive?
29. **Compare and Contrast** Describe the benefits and drawbacks of using fertilizers and pesticides on gardens and farms.

Use the diagram to answer questions 30–33.

Recall that growth responses of plants to external stimuli are called *tropisms*. A tropism is positive if the affected plant part grows toward the stimulus. The response is negative if the plant part grows away from the stimulus. The experiment shown below was intended to test the effect of gravitropism on plant growth. The conclusion drawn from the experiment was that the plant stems grow upward due to negative gravitropism.



30. **Interpret Data** Describe the three experimental setups and the result of each.
31. **Form a Hypothesis** What was the probable hypothesis for this experiment?
32. **Interpret data** From the experimental setups shown, was the hypothesis successfully tested? Explain.
33. **Evaluate Information** Indicate what kinds of changes you would make to improve this experimental design.

CROSSCUTTING CONCEPTS

34. **Systems and System Models** How does transpiration pull water up a plant?
35. **Cause and Effect** Describe the mechanism that opens and closes guard cells on leaves. Explain how the plant benefits from this mechanism.

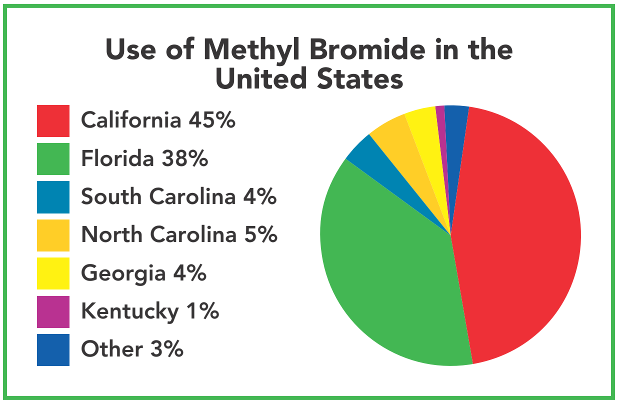
MATH CONNECTIONS

Analyze and Interpret Data

CCSS.MATH.CONTENT.MP2, CCSS.MATH.CONTENT.HSS.IC.B.6

Refer to the text and circle graph below to answer questions 36 and 37.

Methyl bromide is a chemical used to kill both weeds and insects. In the United States, a total of 27,000 tons of methyl bromide are used annually on farms and orchards, mostly in Florida and California. The circle graph shows the use of methyl bromide by state.



Source: U.S. Geological Survey

36. **Calculate** About how many tons of methyl bromide are used on Florida farms every year?
37. **Draw Conclusions** A scientist wants to compare the use of methyl bromide in Florida with its use in other states. Which information would be most useful for the scientist to research?
    a. the acres of farms and orchards in each state
    b. the most common crops grown in each state
    c. the percentages of methyl bromide used in states not named in the graph.
    d. the specific Florida farms or orchards that use the most methyl bromide

LANGUAGE ARTS CONNECTIONS

Write About Science

CCSS.ELA-LITERACY.WHST.9-10.2, CCSS.ELA-LITERACY.WHST.9-10.8

38. **Write Explanatory Texts** Describe how several different types of tissues in a leaf work together to help the leaf function.
39. **Gather Information** Choose a plant that is important in your region. Examples could include a crop plant, a plant used in landscaping, or a weed or other pest. Research the classification, origins, and life cycle of this plant, as well as any strategies for raising or controlling the plant. Write an essay to communicate your research. Use digital media to enhance your essay and add interest.

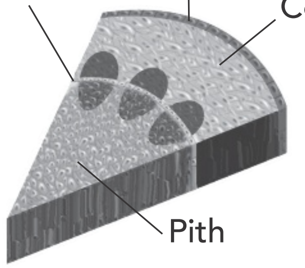
Read About Science

CCSS.ELA-LITERACY.RST.9-10.2

40. **Summarize Text** Review Lesson 23.1 and the notes you took. How do roots, stems, and leaves work together to support a plant?

END-OF-COURSE TEST PRACTICE

1. Primary growth and secondary growth both contribute to the growth of plants. Some of the tissues involved in plant growth are shown in the illustration below.



How does cell division in the vascular cambium contribute to plant growth?

I. Cell division in the vascular cambium results in an increase in stem thickness.
II. Cell division in the vascular cambium results in secondary xylem.
III. Cell division in the vascular cambium results in secondary phloem.

A. I. only
B. II. only
C. I. and III. only
D. II. and III. only
E. I., II., and III.

2. A plant pumps mineral ions into its root cells. Which of the following describes one of the functions of these ions?

A. The ions allow water to enter the roots by osmosis.
B. The ions absorb light so the plant can carry out photosynthesis.
C. The ions form the apical meristem, where water is absorbed.
D. The ions are stored in the ground tissue to provide support for the plant.
E. The ions form the pith, where water is absorbed.

3. Kate places her new houseplant near a window in her room. After a few weeks she notices the plant stems are bent toward the window. Which of the following explains how the stems are able to bend?

A. Cytokinin stimulates cell division on the sunny side of the plant's roots.
B. Abscisic acid inhibits cell division on the sunny side of stems.
C. *Gibberella fujikuroi* stimulates the plant to grow unusually tall.
D. Auxin stimulates cell elongation on the shady side of the stems.
E. Auxin concentrates at the tip of a shoot and direct growth towards light.

4. An environmental scientist is concerned about the reduced biodiversity of farm crops due to modern agricultural practices. Which would be the most effective solution to safeguard against a loss of biodiversity?

A. concentrating on a few crops to plant every year
B. developing hybrid crops that improve yields
C. establishing a seed bank to preserve wild relatives of farm crops
D. draining wetlands for use as farm land
E. promoting the use of powerful chemicals to kill farm pests

ASSESSMENT

For additional assessment practice, go online to access your digital course.

If You Have Trouble With...

Question	1	2	3	4
See Lesson	23.1	23.1	23.2	23.3
Performance Expectation	HS-LS1-2	HS-LS1-2	HS-LS1-3	HS-LS2-7