Plantae

25

CHAPTER 25

Chapter Outline

Key Concepts	Applications
Identify the characteristics common to most plants.	• Identify what types of organisms are really plants.
Understand the concept of alternation of generations.	• Diagram the life cycle of plants.
Understand the basic characteristics of the major plant groups.	• Know the differences among all the kinds of plants. • Understand their evolutionary relationships. • Explain how plants adapted to terrestrial habitats. • Know the advantage of vascular tissue to plants.

25.1 What Is a Plant?

Because plants quietly go about their business of feeding and helping maintain life on Earth, they often are not noticed or appreciated by the casual observer. Yet we are aware enough about plants to associate them with the color green. Grass, garden plants, and trees are all predominantly green, the color associated with photosynthesis. It is the green pigment, chlorophyll, that captures light and allows the process of photosynthesis to store the energy as the chemical-bond energy needed by all other organisms. Yet in this quiet sea of green, there is incredible variety and complexity. Plants range in size from tiny floating duckweed the size of your pencil eraser to giant sequoia trees as tall as the length of a football field. A wide range of colors (e.g., red, yellow, orange, purple, white, pink, violet) stand out against the basic green we associate with plants. Bright spots of color are often flowers and fruit, where the colors may serve as attractants for animals.

Plants are adapted to live in just about any environment (figure 25.1). They live on the shores of oceans, in shallow freshwater, the bitter cold of the polar regions, the dryness of the desert, and the driving rains of tropical forests. There are plants that eat animals, plants that are parasites, plants that don't carry on photosynthesis, and plants that strangle other plants. They show a remarkable variety of form, function, and activity.

(a)

(b)

Figure 25.1

Variety of Flowering Plants
Flowering plants are adapted to living in many different kinds of environments and show much variety in size, color, and structure: (*a*) Cacti at the Saguaro National Monument, Arizona and (*b*) coconut palms along a tropical shore, Belize, Central America.

If we were asked to decide what all plants have in common, the list might include:

1. They are anchored to soil, rocks, bark, and other solid objects.
2. They have hard, woody tissues that support the plants and allow them to stand upright.
3. They are green and carry on photosynthesis.

Although there are exceptions to these criteria, they are good starting points to explore what it is to be a plant.

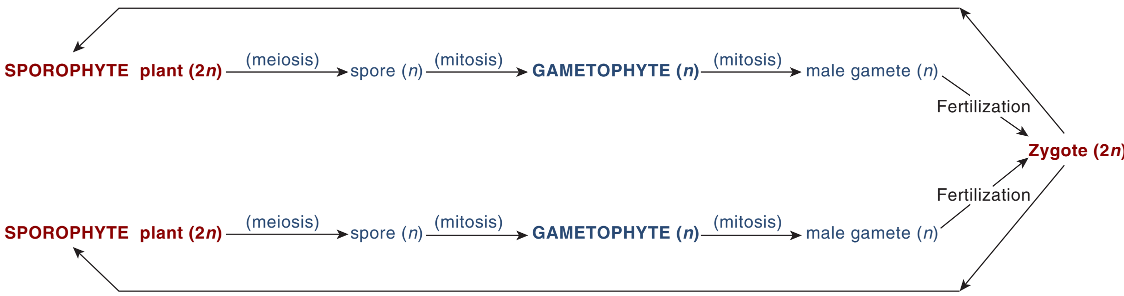
The first classification of plants was devised in the fourth century by one of Aristotle's students, Theophrastus of Eresus. His system of classification was based on the shapes of leaves and whether they were trees, shrubs, or herbs. In the first century A.D., a Greek physician, Dioscorides, classified plants according to their medicinal value. In 1623 a Swiss botanist, Gaspard Bauhin, was the first to begin naming plants using two-part Latin names. About 100 years later, Carolus Linnaeus (1707–1778) categorized plants according to the number and position of male parts in flowers. Although almost everyone has looked closely at a flower, few people recognize it as a structure associated with sexual reproduction in plants. It wasn't until more recently (early eighteenth century) that botanists such as John Ray began to base plant classification on a more detailed examination of plant parts and their hypothetical evolutionary relationships. Today, botanists classify plants based on the following assumptions:

1. Plants display various similarities and differences.
2. Plants that are similar in nearly all respects are members of the same species.
3. Species that share some of their features comprise a genus.
4. On the basis of their similar features, similar genera can be grouped into a family; and families can be organized into successively higher levels of a taxonomic hierarchy, the most broad category being the division.
5. The greater the number of shared features among plants, the closer their relationship.

The cladogram seen in table 25.1 located at the end of this chapter illustrates botanists' current thinking on the evolutionary relationships of the major subgroups of the kingdom Plantae.

25.2 Alternation of Generations

Plants live alternatively between two different forms during their **life cycle,** the series of stages in their life. One stage in the life cycle of a plant is a diploid ($2n$) stage called the **sporophyte** because special cells of this stage undergo meiosis and form numerous haploid, n, **spores.** The release of spores allows the plant to be dispersed through the environment



and explore new areas. In plants, spores are reproductive cells that are capable of developing into a haploid, multicellular adult without fusion with another cell. In land plants, a hard shell covers the spore.

When spores land in suitable areas they **germinate** (begin to grow) into their alternate stage in the life cycle, the **gametophyte.** Gametophytes are composed of haploid cells and look very different from the sporophyte plant. They are involved in the sexual reproduction of the plant since it is the gametophytes that produce male or female gametes. When the gametes unite at the time of fertilization, the newly formed embryo undergoes mitosis and grows into the sporophyte form of the next generation (see diagram above).

The term **alternation of generations** is used to describe the fact that plants cycle between two different stages in their life, the diploid sporophyte and haploid gametophyte. To understand plants, and how and why they may have evolved, we need to go back in time and examine how plant structures and functions were modified over time.

25.3 Ancestral Plants: The Bryophytes

One group of plants that shows primitive or ancestral characteristics is the bryophytes. All bryophytes have several things in common:

1. They are small, compact, slow-growing, green plants with motile sperm that swim to eggs.
2. There are no well-developed vascular tissues (tubes for conducting water through the plant body) and no mechanism that would provide support to large, upright plant parts such as stems.
3. Bryophytes do not have true leaves or roots as are found in more highly evolved plants.
4. Nutrients are obtained from the surfaces upon which they grow or from rainwater.
5. Their life cycle consists of two stages. The gametophyte (gamete-producing plant) dominates the sporophyte (spore-producing plant).

There are three types of bryophytes: Bryophyta (mosses), Hepatophyta (liverworts), and Anthocerotophyta (hornworts). Mosses grow as a carpet composed of many parts. Each individual moss plant is composed of a central stalk less than 5 centimeters tall with short, leaflike structures that are sites of photosynthesis. If you look at the individual cells in the leafy portion of a moss, you can distinguish the cytoplasm, cell wall, and chloroplasts (figure 25.2). You may also distinguish the nucleus of the cell. This nucleus is haploid (*n*), meaning that it has only one set of chromosomes. In fact, every cell in the moss plant body is haploid.

Although all the cells have the haploid number of chromosomes (the same as gametes), not all of them function as

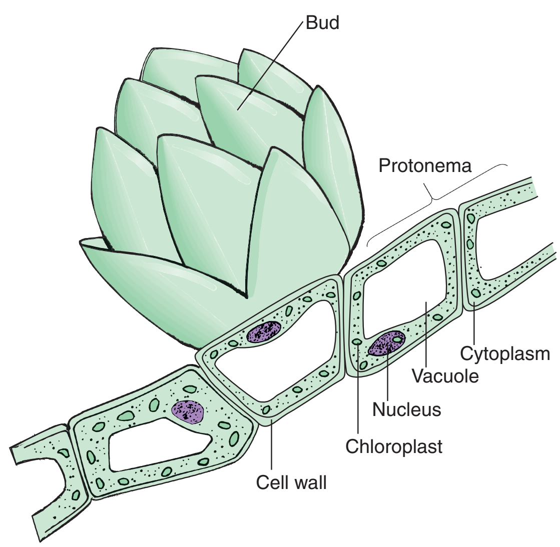


Figure 25.2

The Cells of a Moss Plant
The chain of cells seen here are typical plant cells. Note the large central vacuole and cell wall. The leaflike structure, the bud, grows from this filament.

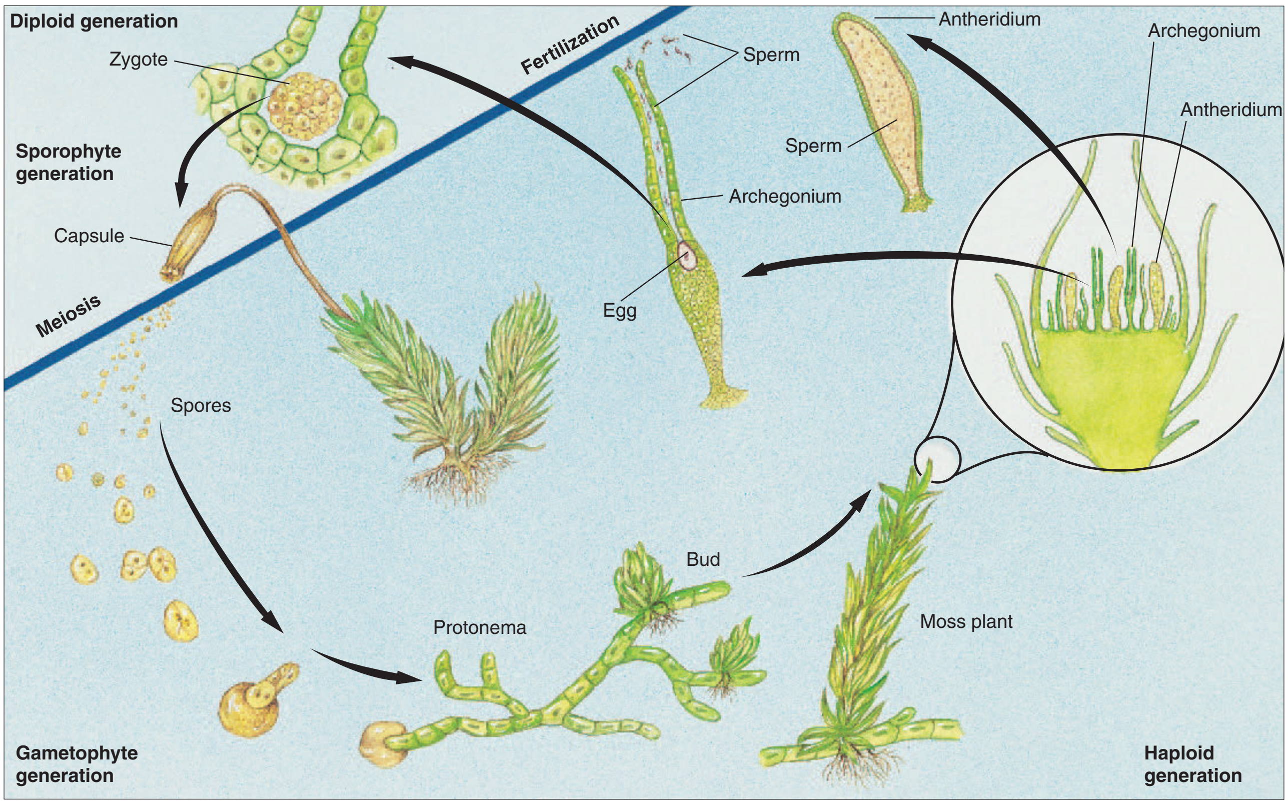


Figure 25.3

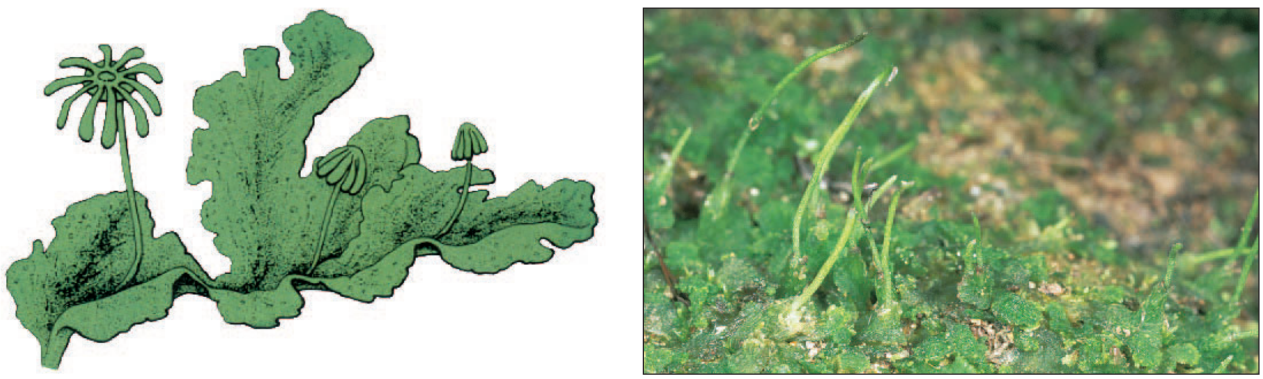
The Life Cycle of a Moss
In this illustration the portion with the darker-colored background represents cells that have the haploid (*n*) nuclei (gametophyte generation). The portion with a lighter-colored background represents cells that have the diploid (2*n*) nuclei (sporophyte generation). Notice that the haploid and diploid portions of the life cycle alternate.

gametes. Because this plant produces cells that are capable of acting as gametes, it is called the **gametophyte,** or gamete-producing stage in the plant life cycle. Special structures in the moss, called **antheridia,** produce mobile sperm cells capable of swimming to a female egg cell (figure 25.3). The sperm cells are enclosed within a jacket of cells (the antheridium) that opens when the sperm are mature. The sperm swim by the undulating motion of flagella through a film of dew from splashing rainwater, carrying their packages of genetic information. Their destination is the egg cell of another moss plant with a different package of genetic information. The egg is produced within a jacket called the **archegonium** (figure 25.3). There is usually only one egg cell in each archegonium. The sperm and egg nuclei fuse, resulting in a diploid cell, the zygote. The zygote grows, divides, and differentiates into an embryo. The gametophyte generation is dominant over the sporophyte generation in mosses. This means that the gametophyte generation is more likely to be seen.

The casual observer usually overlooks liverworts and hornworts (figure 25.4) because they are rather small, low-growing plants composed of a green ribbon of cells. The name *liverwort* comes from the fact that these plants resemble the moist surface of a liver. Although they do not have well-developed roots or stems, the leaflike ribbons of tissue are well suited to absorb light for photosynthesis.

25.4 Adaptations to Land

Botanists consider mosses and the other bryophytes the lowest step of the evolutionary ladder in the plant kingdom. They are considered "primitive" (ancestral) because they have not developed an efficient network of tubes or vessels that can be used to transport water throughout their bodies; they must rely on the physical processes of diffusion and osmosis to move dissolved materials through their bodies.



(a) (b)

Figure 25.4

Bryophytes: Liverworts and Hornworts
These ribbon-shaped plants are related to the mosses (*a*). Their name comes from the fact that they resemble thin layers of green-colored animal liver. Liverworts feel like a moist rubber material. The gametophyte is the stage of the life cycle that is most easily recognized. Similar to liverworts in many ways, there are about 100 species of hornworts (*b*) *Anthoceros sporophytes*.

The fact that mosses do not have a complex vascular system to move water limits their size to a few centimeters and their location to moist environments. Another characteristic of mosses points out how closely related they are to their aquatic ancestors, the algae: They require water for fertilization. The sperm cells must "swim" from the antheridia to the archegonia. Small size, moist habitat, and swimming sperm are considered characteristics of ancestral plants. In a primitive way, mosses have adapted to a terrestrial niche.

Vascular Tissue: What It Takes to Live on Land

A small number of currently existing plants show some of the more ancient directions of evolution. You might think of these evolutionary groups as experimental models or transitional plants. They successfully filled certain early terrestrial niches, but did not evolve into other niches. However, their features were important in the evolution of more successful land plants. The advances all have to do with cell specializations enabling a plant to do a better job of acquiring, moving, and retaining water while living out of an aquatic environment. Groups of closely associated cells that work together to perform a specialized or particular function are called tissues. The tissue important in moving water within a plant is called **vascular tissue.**

When a plant with vascular tissue is wounded it usually drips liquid, called *sap,* from the cut surface. This is because some of the thick-walled cells that serve as "pipes" or "tubes" for transporting liquids throughout the plant are broken and their contents leak out. Vascular tissues are used to transport water and minerals to the leaves where photosynthesis takes place. They also transport manufactured food from the leaves to storage sites found in the roots or the stems. Vascular tissues have cells connected end to end forming many long tubes, similar to a series of pieces of pipe hooked together (figure 25.5). The long celery strands that get stuck between your teeth are bundles of vascular tissue.

There are two kinds of vascular tissue: **xylem** and **phloem.** *Xylem* consists of a series of hollow cells arranged end to end so that they form a tube. These tubes carry water absorbed from the soil into the roots and transport it to the above-ground parts of the plant. Associated with these tube-like cells are cells with thickened cell walls that provide strength and support for the plant. *Phloem* carries the organic molecules produced in one part (e.g., leaves) of the plant to storage areas in other parts (e.g., roots). The specialization of cells into vascular tissues has allowed for the development of **roots, stems,** and **leaves.**

Roots

When you attempt to pull some plants from the ground, you quickly recognize that the underground parts, the roots, anchor them firmly in place. Roots have a variety of functions in addition to serving as anchors. Foremost among them is taking up water and other nutrients from the soil. The primary nutrients plants obtain from the soil are inorganic molecules, which are incorporated into the organic molecules they produce. By constantly growing out from the main plant body, roots explore new territory for available nutrients. As a plant becomes larger it needs more root surface to absorb nutrients and hold the plant in place. The actively growing portions of the root near the tips have large

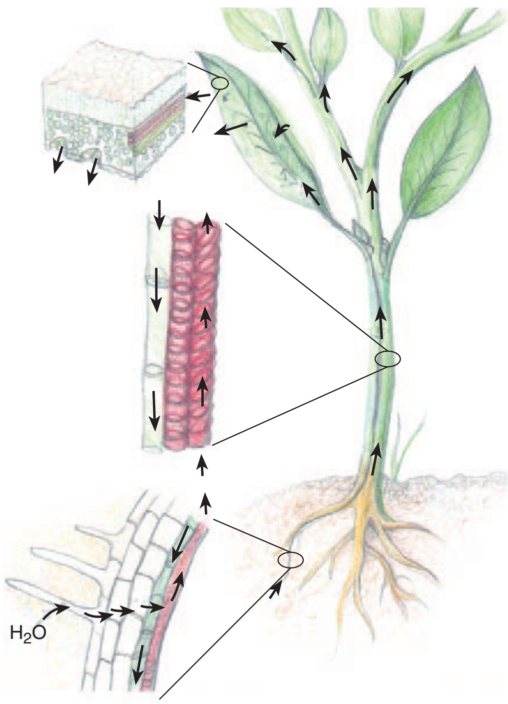


Figure 25.5

Vascular Tissue
The vascular tissues of plants are used to carry materials between the roots and leaves. One kind of tissue, called xylem (shown in red), carries dissolved raw materials from roots to leaves. Another kind, called phloem (shown in green), carries manufactured food from leaves to stems and roots. Notice the hollow nature of these tissues.

Figure 25.6

Kinds of Roots
The roots of grasses are often in the upper layers of the soil and form a dense network that traps water in the dry environment. The roots of trees and many other plants typically extend deep into the soil where they obtain moisture and serve as anchors that hold large plants upright.

numbers of small, fuzzy hairlike cell extensions called **root hairs** that provide a large surface area for the absorption of nutrients.

We eat many kinds of roots such as carrots, turnips, and radishes. The food value they contain is an indication of another function of roots. Most roots are important storage places for the food produced by the above-ground parts of the plant. Many kinds of plants store food in their roots during the growing season and use this food to stay alive during the winter. The food also provides the raw materials necessary for growth for the next growing season. Although we do not eat the roots of plants such as maple trees, rhubarb, or grasses, their roots are as important to them in food storage as those of carrots, turnips, and radishes (figure 25.6).

Stems

Stems are in most cases the above-ground structures of plants that support the light-catching leaves in which photosynthesis occurs. Many kinds of plants also have buds on their stems that may grow to produce leaves, flowers, or new branches. Trees have stems that support large numbers of branches; vines have stems that require support; and some plants, like dandelions, have very short stems with all their leaves flat against the ground. Stems have two main functions:

1. They serve as supports for the leaves.
2. They transport raw materials from the roots to the leaves and manufactured food from the leaves to the roots.

When you chew on toothpicks, which are stems or made from stems, you recognize that they contain hard, tough materials. These are the cell walls of the plant cells (refer to figure 25.5). All plant cells are surrounded by a cell wall made of the carbohydrate *cellulose*. Cellulose fibers are interwoven to form a box within which the plant cell is contained. Because the cell wall consists of fibers, it can be compared to a wicker basket. It has spaces between these cellulose fibers through which materials pass relatively easily. However, the cell wall does not stretch very much, and if the cell is full of water and other cellular materials it will become quite rigid. Because of these forces, the many cells that make up a plant stem are able to keep a large nonwoody plant upright. The word **herb** (L. *herba* = grass) actually refers to nonwoody plants such as the grasses and many annual flowers like petunias and marigolds. You might think of a plant body as being similar to the bubble wrap used to protect fragile objects during shipping. Each little bubble

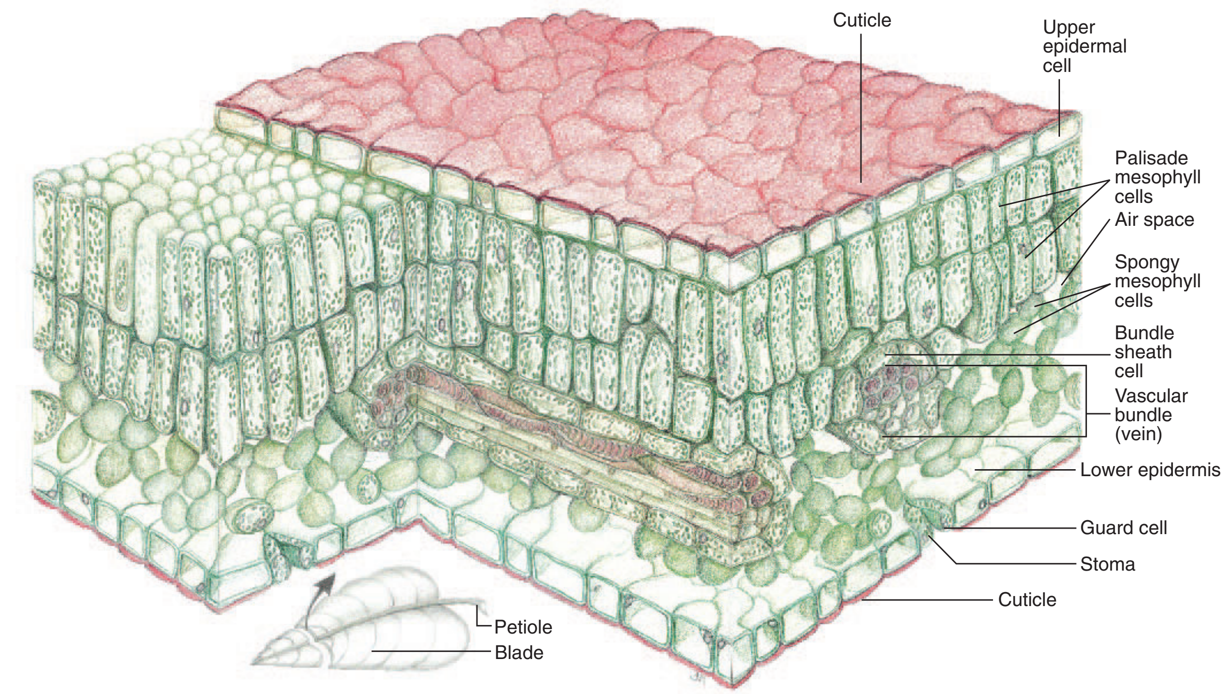


Figure 25.7

The Structure of a Leaf

Though a leaf is thin, it consists of several specialized layers. An outer layer (epidermis) has openings called stomates that can open and close to regulate the movement of gases into and out of the leaf. The internal layers have many cells with chloroplasts, air spaces, and bundles of vascular tissue all organized so that photosynthetic cells can acquire necessary nutrients and transport metabolic products to other locations in the plant.

contains air and can be easily popped. However in combination, they will support considerable weight.

In addition to cellulose, some plants deposit other compounds in the cell walls that strengthen them, make them more rigid, and bind them to other neighboring cell walls. **Woody vascular plants** deposit a material called *lignin* while the grasses deposit *silicon dioxide,* the same kind of material of which sand is made. Stems and roots of plants tend to have large numbers of cells with strengthened cell walls. This is such an effective support mechanism that large trees and bushes are supported against the pull of gravity and can withstand strong winds for centuries without being broken or blown over. Some of the oldest trees on Earth have been growing for several thousand years.

Stems not only provide support and nutrient transport, but also may store food. This is true of sugar cane, yams, and potatoes. Many plant stems are green and, therefore, involved in the process of photosynthesis.

Leaves

Green leaves are the major sites of photosynthesis for most plants. Photosynthesis involves trapping light energy and converting it into the chemical-bond energy of complex organic molecules like sugar (refer to chapter 6). Thus there is a flow of energy from the sun into the organic matter of plants. Light energy is needed to enable the smaller inorganic molecules (water and carbon dioxide) to be combined to make the organic compounds. In the process, oxygen is released for use in other biochemical processes such as aerobic cellular respiration.

Leaves have vascular tissue to allow for the transport of materials, but they also have cells containing chloroplasts. Chloroplasts are the cellular structures responsible for photosynthesis. They contain the green pigment chlorophyll. The organic molecules (e.g., glucose) produced by plants as a result of photosynthesis can be used by the plant to make the other kinds of molecules (e.g., cellulose and starch) needed for its structure and function. In addition, these molecules can satisfy the energy needs of the plant. Organisms that eat plants also use the energy captured by photosynthesis.

To carry out photosynthesis, leaves must have certain characteristics (figure 25.7). Because it is a solar collector, a leaf should have a large surface area. In addition, most plants have their leaves arranged so they do not shade one another. This assures that the maximum number of cells in the leaf will be exposed to sunlight. Most leaves are relatively thin in comparison to other plant parts. Thick leaves would not allow penetration of light to the maximum number of photosynthetic cells.

A drawback to having large, flat, thin leaves is an increase in water loss because of evaporation. To help slow water loss, the epidermal (skin) layer produces a waxy coat on the outside surface of the leaf. However, water loss is not always a disadvantage to the plant. The loss of water helps power the flow of more water and nutrients from the roots to the leaves. Water lost from the leaf is in effect pulled through the xylem into the leaf, a process called *transpiration*. Because too much water loss can be deadly, it is necessary to regulate transpiration. The amount of water, carbon dioxide, and oxygen moving into and out of the leaves of many plants is regulated by many tiny openings in the epidermis, called *stomates* (figure 25.8). The stomates can close or open to control the rate at which water is lost and gases are exchanged. Often during periods of drought or during the hottest, driest part of the day the stomates are closed, thus reducing the rate at which the plant loses water.

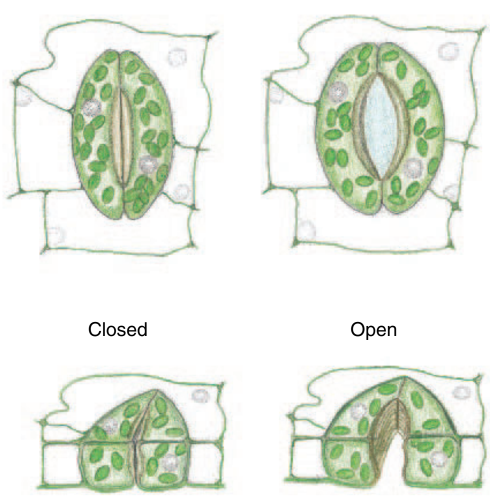


Figure 25.8

Stomates
The stomates are located in the covering layer (epidermis) on the outside of leaves. When these two elongated guard cells are swollen, the space between them is open and leaves lose water and readily exchange oxygen and carbon dioxide. In their less rigid and relaxed state, the two stomatal cells close. In this condition the leaf conserves water but is not better able to exchange oxygen and carbon dioxide with the outside air.

25.5 Transitional Plants: Non-Seed-Producing Vascular Plants

The transitional groups of plants [e.g., Psilotophyta (whisk ferns), Equisetophyta (horsetails), Lycopodophyta (club mosses), and Pteridophyta (ferns)] have vascular tissue (figure 25.9). Members of these divisions are evolutionary links between the nonvascular bryophytes and the highly successful land plants, the gymnosperms and angiosperms. These plants display many common features:

1. Their diploid sporophytes produce haploid spores by meiosis, which develop into gametophytes. The gametophytes produce sperm and egg in antheridia and archegonia. Sperms require water through which they swim in order to reach eggs.
2. Fertilization results in a multicellular embryo that gets its nutrients from the gametophyte. The embryo eventually grows into the sporophyte.

(a) (b)

Figure 25.9

Club Mosses
These plants are sometimes called ground pines because of their slight resemblance to the evergreen trees. Most club mosses grow only a few centimeters in height. The sporophyte is the stage of the life cycle that is most easily recognized. Club mosses are a group of low-growing plants that are somewhat more successful than bryophytes in adapting to life on land. They have a stemlike structure that holds the leafy parts above other low-growing plants, enabling them to compete better for available sunlight. Thus, they are larger than mosses and not as closely tied to wet areas. Although not as efficient in transporting water and nutrients as the stems of higher plants, the stem of the club moss, with its vascular tissue, is a hint of what was to come.

3. The sporophyte generation is more dominant in the life cycle than the gametophyte and is usually highly branched.
4. All have well-developed vascular tissue to transport water and nutrients.
5. Many have the ability to support upright, above-ground plant parts, for example, leaves.

With fully developed vascular tissues, these non-seed-producing plants are no longer limited to wet areas. They can absorb water and distribute it to leaves many meters above the surface of the soil. The ferns are the most primitive vascular plants truly successful at terrestrial living. They have not only a wider range and greater size than mosses and club mosses, but also an additional advantage: The sporophyte generation has assumed more importance and the gametophyte generation has decreased in size and complexity. Figure 25.10 illustrates the life cycle of a fern. The diploid condition of the sporophyte is an advantage because a recessive gene can be masked until it is combined with another identical recessive gene. In other words, the plant does not suffer because it has one bad allele. On the other hand, a mutation may be a good change, but time is lost by having it hidden in the heterozygous condition. In a haploid plant, any change, whether recessive or not, shows up. Not only is a diploid condition beneficial to an individual, but the population benefits when many alleles are available for selection (refer to chapter 11). As in most terrestrial plants, the sporophyte generation of ferns is the dominant generation. The green, leafy structure with which most people are familiar is the sporophyte generation.

Ferns take many forms, including the delicate, clover-like maidenhair fern of northern wooded areas; the bushy bracken fern (figure 25.11); and the tree fern, known

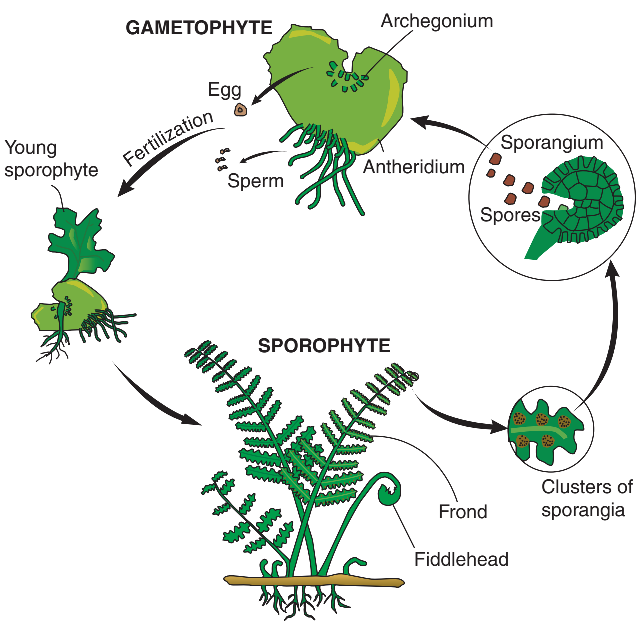


Figure 25.10

The Life Cycle of a Fern

In this illustration the dark green color represents cells that have diploid (2*n*) nuclei (sporophyte generation). On the back of some fern leaves there are small dots—clusters of sporangia. The sporangia produce spores. These spores develop into cells that have haploid (*n*) nuclei (gametophyte generation). This stage is shown in a light green color. Notice that the gametophyte and sporophyte generations alternate. Compare this life cycle with that of the moss (figure 25.3). In the moss the gametophyte generation is considered dominant, whereas in the fern the sporophyte is dominant. The sporophyte is the part of the fern most people recognize.

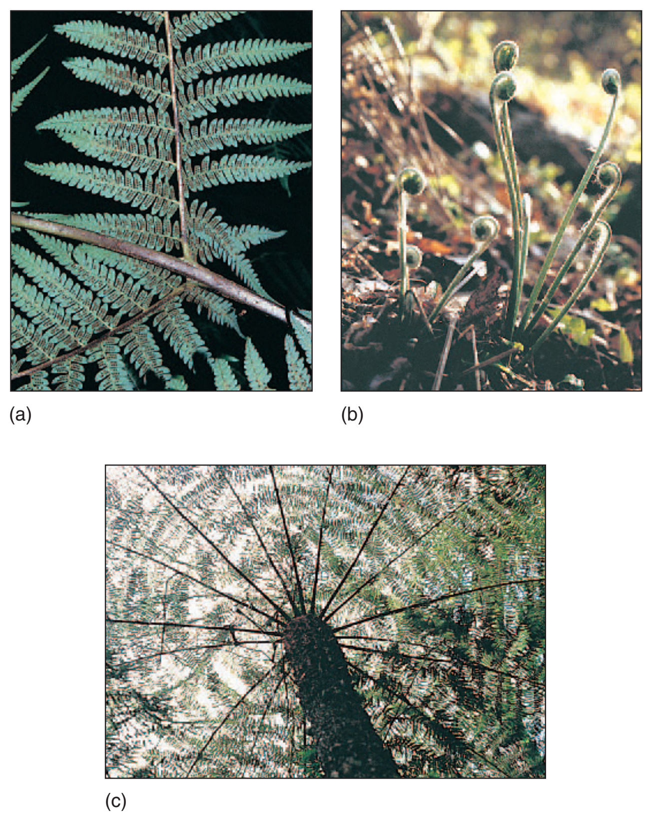


Figure 25.11

A Typical Fern

Most ferns live in shaded areas of the forest. The most recognized part of the life cycle of a fern is the sporophyte generation (*a*). As a fern leaf grows, it "unrolls" from a coiled structure known as a "fiddlehead" (*b*) because it resembles the coiled end of a violin, i.e., the head of the fiddle. Fiddleheads are often used in gourmet cooking. Some ferns reach tree-size (*c*) and can be used in the construction of basic dwellings.

primarily from the fossil record but seen today in some tropical areas. In spite of all this variety, however, they still lack one tiny but very important structure—the seed. Without seeds, ferns must rely on fragile spores to spread the species from place to place.

25.6 Advanced Plants: Seed-Producing Vascular Plants

Gymnosperms

The next advance made in the plant kingdom was the evolution of the **seed.** A seed is a specialized structure that contains an embryo enclosed in a protective covering called the *seed coat.* It also has some stored food for the embryo. The first attempt at seed production is exhibited in the conifers, which are cone-bearing plants such as pine trees. **Cones** are reproductive structures. The male cone produces **pollen.** Grains of pollen are actually the miniaturized male gametophyte plants. Each of these small dustlike particles contains a sperm nucleus. The female cone is usually larger than the male cone and produces the female gametophyte. Pollen is produced in smaller, male cones and released in such large quantities that clouds of pollen can be seen in the air when sudden gusts of wind shake the branches of the trees. The archegonia in the female gametophyte contain eggs. Pollen is carried by wind to the female cone, which holds the archegonium in a position to gather the airborne pollen. The process of getting the pollen from the male cone to the female cone is called **pollination.** Fertilization occurs when the sperm cell from the pollen unites with the egg cell in the archegonium. This may occur months or even years following pollination. The fertilized egg develops into an embryo within the seed (also called a mature *ovule*). The production of seeds and pollination are features of conifers that place them higher on the evolutionary ladder than ferns.

Because conifer seeds with their embryos inside are produced on the bare surface of woody, leaflike structures (the female cone), they are said to be *naked,* or out in the open (figure 25.12). The cone-producing plants such as conifers are called **gymnosperms,** which means "naked seed" plants. Producing seeds out in the open makes this very important part of the life cycle vulnerable to adverse environmental influences, such as attack by insects, birds, and other organisms.

Many gymnosperms generally produce needle-shaped leaves which do not all fall off at once. Such trees are said to be **nondeciduous.** (A few gymnosperms do lose their leaves all at once—for example, *Larix* (tamarack) and *Taxodium* (bald cypress)—like most angiosperms.) This term may be misleading because it suggests that the needles do not fall off at all. Actually, they are constantly being shed a few at a time.

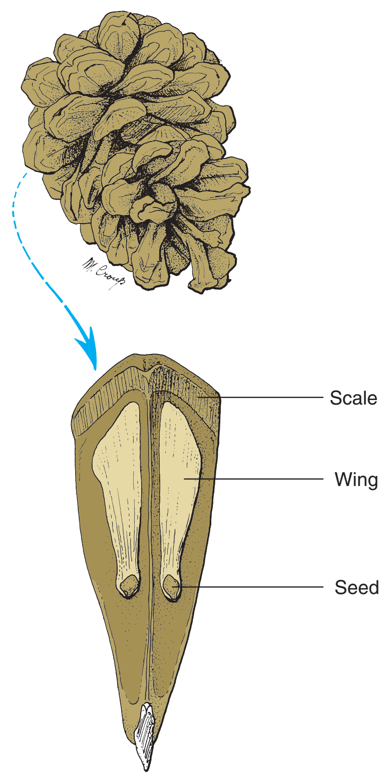


Figure 25.12

A Pine Cone with Seeds
On the scaly, leaflike portions of the cone are the seeds. Because these cones produce seeds "out in the open," they are aptly named the naked seed plants–gymnosperms. Pine tree seeds can be harvested by simply shaking a dried, open female cone. The seeds appear as small, brown, and papery winglike structures.

Perhaps you have seen the mat of needles under a conifer. Because these trees retain some green leaves year-round they are called *evergreens.* The portion of the evergreen with which you are familiar is the sporophyte generation; the gametophyte, or haploid, stages have been reduced to only a few cells, the pollen grains. Look closely at figure 25.13, which shows the life cycle of a pine with its alternation of haploid and diploid generations.

Gymnosperms are also called **perennials;** that is, they live year after year. Unlike **annuals,** which complete their life cycle in one year, gymnosperms take many years to grow from seeds to reproducing adults. The trees get taller and larger in diameter each year, continually adding layers of strengthening cells and vascular tissues. As a tree becomes larger, the strengthening tissue in the stem becomes more and more important.

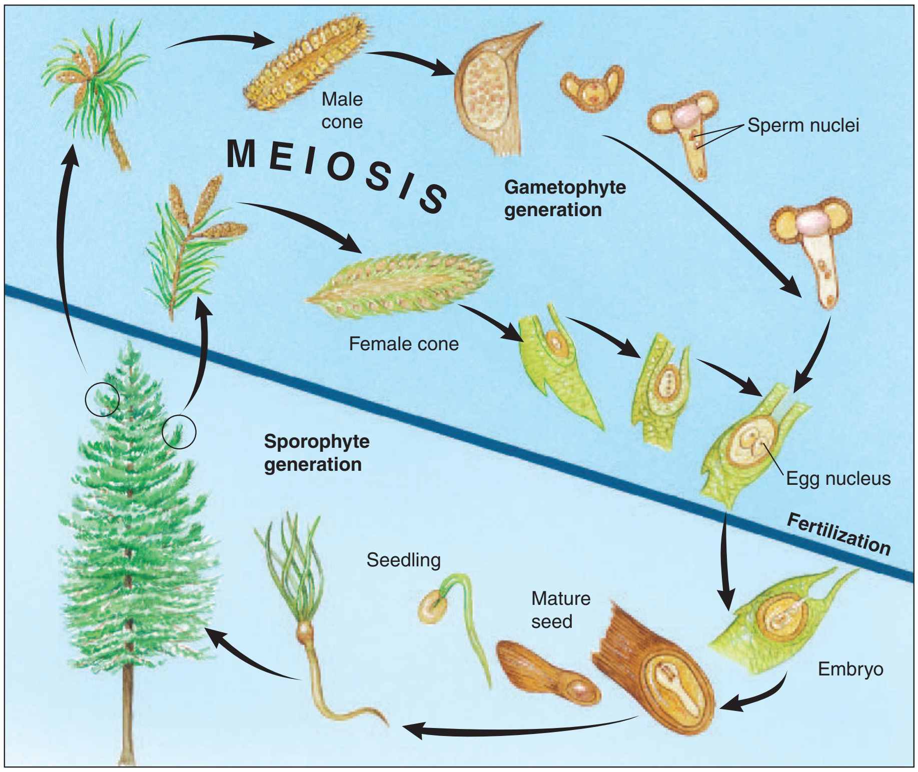


Figure 25.13

The Life Cycle of a Pine
In this illustration, the portion with the darker-colored background represents cells that have haploid (*n*) nuclei (gametophyte generation). The lightly colored background represents cells that have diploid (2*n*) nuclei (sporophyte generation). Notice that the gametophyte and sporophyte generations alternate, and that the sporophyte is dominant in the gymnosperms. Compare this life cycle of the pine with the life cycle of the moss (figure 25.3) and that of the fern (figure 25.10). Notice the ever-increasing dominance in the sporophyte generation.

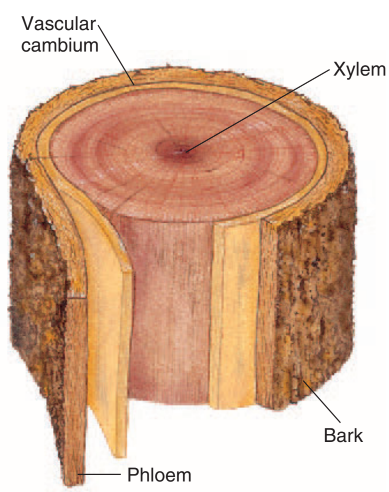


Figure 25.14

A Cross Section of Woody Stem
Notice that the xylem makes up most of what we call wood. The approximate age of a tree can be determined by counting the growth rings seen on the cut surface. It is also possible to learn something about the environment from these rings. Wide rings indicate good growth years with high rainfall, whereas narrow rings indicate poor growth and low rainfall. Can you picture the relative positions of the labeled structures 20 years from now?

A layer of cells in the stem, called the **cambium,** is responsible for this increase in size. Xylem tissue is the innermost part of the tree trunk or limb, and phloem is outside the cambium. The cambium layer of cells is positioned between the xylem and the phloem. Cambium cells go through a mitotic cell division, and two cells form. One cell remains cambium tissue, and the other specializes to form vascular tissue. If the cell is on the inside of the cambium ring, it becomes xylem; if it is on the outside of the cambium ring, it becomes phloem. As cambium cells divide again and again, one cell always remains cambium, and the other becomes vascular tissue. Thus, the tree constantly increases in diameter (figure 25.14).

The accumulation of the xylem in the trunk of gymnosperms is called **wood.** Wood is one of the most valuable biological resources of the world. We get lumber, paper products, turpentine, and many other valuable materials from the wood of gymnosperms. You are already familiar with many examples of gymnosperms, three of which are pictured in figure 25.15.

Angiosperms

The group of plants considered most highly evolved is known as the **angiosperms.** This name means that the seeds, rather than being produced naked, are enclosed within the surrounding tissues of the **ovary.** The ovary

(a) (b) (c)

Figure 25.15

Several Gymnosperms
Do you recognize these gymnosperms? They are (*a*) redwood, (*b*) Torrey pine, and (*c*) cedar. One cedar known as the cedar of Lebanon *(Cedrus libani)* is displayed on the national flag of Lebanon and is regarded as a symbol of strength, prosperity, and long life. These trees were used in ancient times as a source of perfumes, and their wood was used to make coffins. In fact, coffins made from cedar and found in the pyramids have been found intact and still smell of cedar fragrance. In many parts of the world, cedar wood is used in "cedar chests" because their aromatic molecules are able to inhibit the destructive effects of wool-eating moths.

and other tissues mature into a protective structure known as the **fruit.** Many of the foods we eat are the seed-containing fruits of angiosperms: green beans, melons, tomatoes, and apples are only a few of the many edible fruits (figure 25.16).

Angiosperm trees generally produce broad, flat leaves. In colder parts of the world, most angiosperms lose all their leaves during the fall. Such trees are said to be **deciduous** (figure 25.17). (However, there are exceptions. Some angiosperms are nondeciduous, keeping their leaves and staying green throughout the winter, for example, American holly—*Ilex opaca.*) However, the majority of angiosperms are not trees; they are small plants like grasses, "weeds," vines, houseplants, garden plants, wildflowers, and green houseplants. Look closely at figure 25.18, which shows the life cycle of an angiosperm with its alternation of haploid and diploid generations.

The **flower** of an angiosperm is the structure that produces sex cells and other structures that enable the sperm cells to get to egg cells. The important parts of the flower are the female **pistil** (composed of the *stigma, style,* and *ovary*) and the male **stamen** (composed of the *anther* and *filament*). In figure 25.19, notice that the egg cell is located inside the ovary. Any flower that has both male and female parts is called a **perfect flower;** a flower containing just female or just male parts is called an **imperfect flower.** Any additional parts of the flower are called **accessory structures** because fertilization can occur without them. **Sepals,** which form the outermost whorl of the flower, are accessory structures that serve a protective function. **Petals,** also accessory structures, increase the probability of fertilization. Before the sperm cell (contained in the pollen) can join with the egg cell, it must somehow get to the egg. This is the process called *pollination.* Some flowers with showy

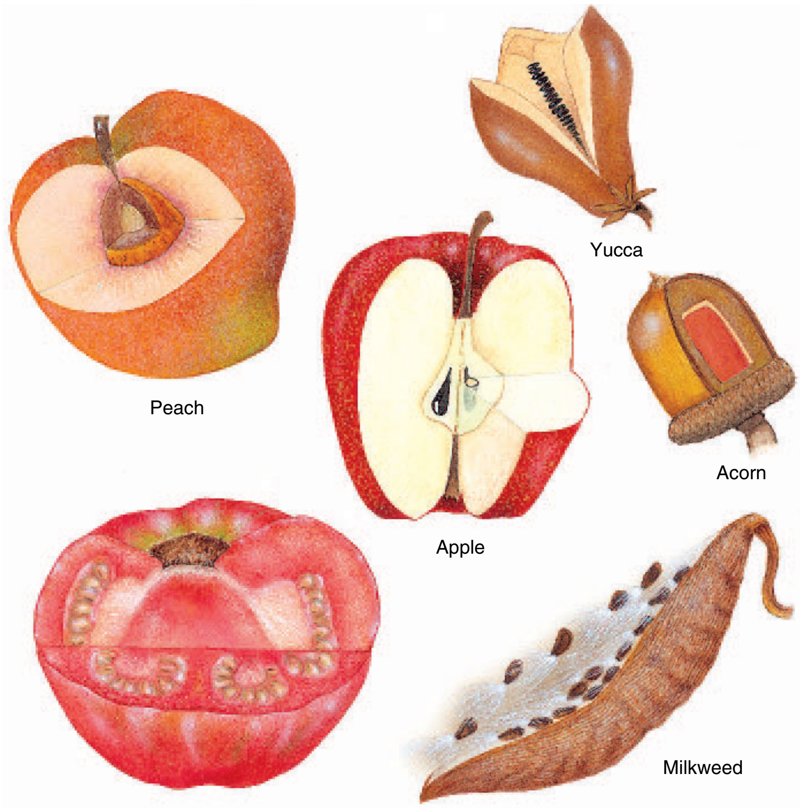


Figure 25.16

Types of Edible and Inedible Fruits
Fruits are the structures that contain seeds. The seed containers of the peach, apple, and tomato are used by humans as food. The other fruits are not usually used by humans as food. Although these are familiar foods, it is becoming increasingly common to find "unusual" fruits and vegetables in our food markets as the time needed to transport foods from around the world decreases. Still, it has been estimated that a full one-third of our foods are lost to spoilage.

petals are adapted to attracting insects, which unintentionally carry the pollen to the pistil. Others have become adapted for wind pollination. The important thing is to get the genetic information from one parent to the other.

All the flowering plants have retained the evolutionary advances of previous groups. That is, they have well-developed vascular tissue with true roots, stems, and leaves. They have pollen and produce seeds within the protective structure of the ovary.

There are over 300,000 kinds of plants that produce flowers, fruits, and seeds (Outlooks 25.1). Almost any plant you can think of is an angiosperm. If you made a list of these familiar plants, you would quickly see that they vary a great deal in structure and habitat. The mighty oak, the delicate rose, the pesky dandelion, and the expensive orchid are all flowering plants. How do we organize this diversity into some sensible and useful arrangement? Botanists classify all angiosperms into one of two groups: **dicots** or **monocots.** The names *dicot* and *monocot* refer to a structure in the seeds of these plants. If the embryo has two **seed leaves** (*cotyledons*), the plant is a dicot; those with only one seed leaf are the monocots (figure 25.20). A peanut is a dicot; lima beans and apples are also dicots; grass, lilies, and orchids are all monocots. Even with this separation, the diversity is staggering. The characteristics used to classify and name plants are listed in figure 25.21, which includes a comparison of the extremes of these characteristics.

Figure 25.17

Fall Colors
The color change you see in leaves in the fall of the year in certain parts of the world is the result of the breakdown of the green chlorophyll. Other pigments (red, yellow, orange, brown) are always present but are masked by the presence of the green chlorophyll pigments. In the fall, a layer of waterproof tissue forms at the base of the leaf and cuts off the flow of water and other nutrients. The cells of the leaf die and their chlorophyll disintegrates, revealing the reds, oranges, yellows, and browns that make a trip through the countryside a colorful experience.

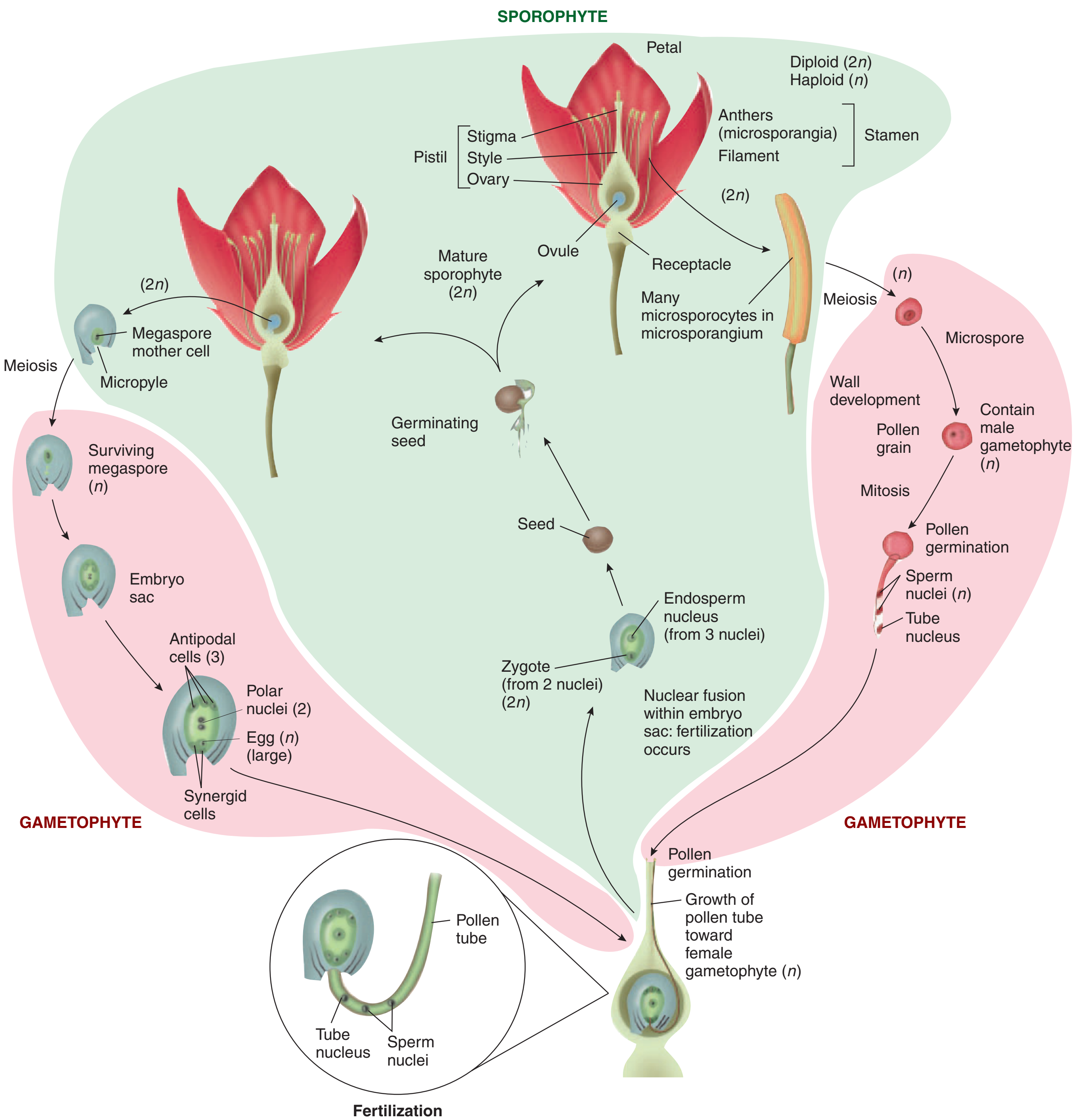


Figure 25.18

Life Cycle of Angiosperm

Compare the life cycle of a conifer with this angiosperm. Although there are significant differences, the sporophyte dominates the gametophyte, which has been reduced to a small portion of the life cycle.

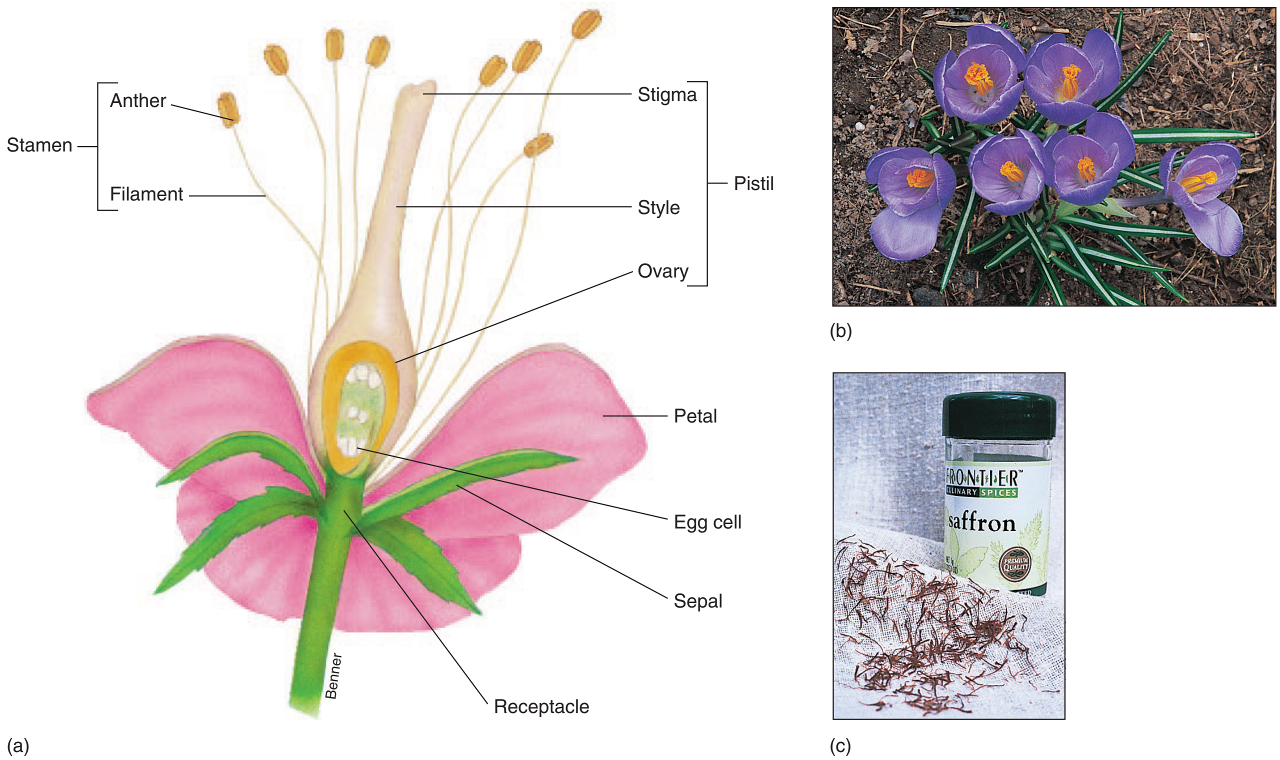


Figure 25.19

The Flower

The flower (*a*) is the structure in angiosperms that produces sex cells. Notice that the egg is produced within a structure called the ovule. The seeds, therefore, will not be naked, as in the gymnosperms, but will be enclosed in a fruit. The dried, fragrant stigmas of the (*b*) crocus flower (*Crocus sativus*) are used as the cooking spice, saffron (*c*). Their small size and difficulty in harvesting makes this spice extremely expensive.

OUTLOOKS 25.1

Spices and Flavorings

Think about all the plant materials we use to season our foods. Black pepper comes from the hard, dried berries of a tropical plant, *Piper nigrum.* Cayenne pepper is made from the ground-up fruits of *Capsicum annum,* and the hot, spicy chemical in the fruit and seeds is known as capsaicin. The seeds of the dill plant, *Anethum graveolens,* are used to flavor pickles and many other foods. The dried or fresh leaves of many herbs such as thyme, rosemary, chives, and parsley are also used as flavorings. If you examine your kitchen cabinet, you may also find the following: cinnamon from the bark of a tree found in India; cloves, which are the dried flower buds of a tropical tree; ginger from the root of a tropical plant of Africa and China; and nutmeg from the seed of a tropical tree of Asia.

Centuries ago, spices like these were so highly prized that fortunes were made in the "spice trade." Beginning in the early 1600s, ships from Europe regularly visited the tropical regions of Asia and Africa, returning with cargoes of spices and other rare commodities that could be sold at great profit. Consequently, India has been greatly influenced by Britain, Indonesia has been greatly influenced by the Netherlands, and Britain and France have influenced the development of different portions of Africa.

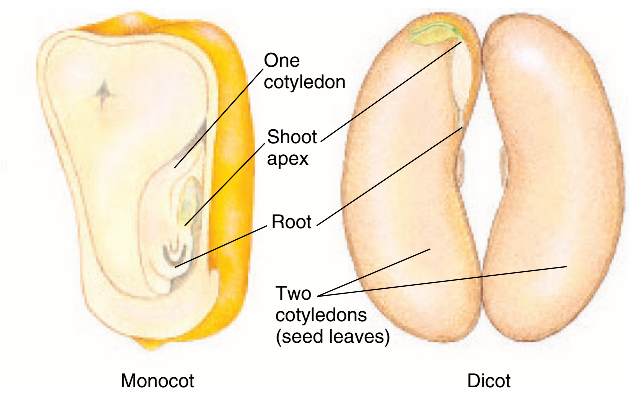


Figure 25.20

Embryos in Dicots and Monocots
The number of seed leaves (cotyledons) attached to an embryo is one of the characteristics botanists use to classify flowering plants. It has been estimated that about 80% of all angiosperms are dicots.

25.7 Response to the Environment—Tropisms

Our casual impression of plants is that they are unchanging objects. However, on closer examination we recognize that plants change over time. They grow new leaves in the spring, produce flowers and fruits at certain times of the year, and grow toward a source of light. Furthermore, they will respond to organisms that harm them, and may even mount an attack against competitors. Any action resulting from a particular stimulus is referred to as a **tropism.**

One of the first responses studied in plants is their ability to grow toward a source of sunlight. This action is known as *phototropic* motion. The value of this response is obvious because plants need light to survive. The mechanism that allows this response involves a hormone. In the case of plants growing toward light, the growing tip of the stem produces a hormone, **auxin,** that is transported down the stems. The hormone stimulates cells to elongate, divide, and grow. If the growing tip of a plant is shaded on one side, the shaded side produces more of the hormone than the lighted side. The larger amount of auxin on the shaded side causes greater growth in that area and the tip of the stem bends toward the light. When all sides of the stem are equally illuminated the stem will grow equally on all sides and will grow straight. If you have house plants near a window it is important to turn them regularly or they will grow more on one side than the other (figure 25.22).

Plants also respond to changes in exposure to daylight. They are able to measure day length and manufacture hormones that cause changes in the growth and development of specific parts of the plant. Some plants produce flowers only when the days are getting longer, some only when the days are getting shorter, and some only after the days have reached a specific length. Other activities are triggered by changing day length. Probably the most obvious is the mechanism that leads to the dropping of leaves in the fall.

Many kinds of climbing vines are able to wrap rapidly growing, stringlike *tendrils* around sturdy objects in a matter of minutes. As the tendrils grow, they slowly wave about. When they encounter an object, their tropic response is to wrap around it and anchor the vine. Once attached, the tendrils change into hard, tough structures that bind the vine to its attachment. Sweet peas, grape vines, and the ivy on old buildings spread in this manner. Ivy can cause great damage as it grows and its tendrils loosen siding and serve as a haven for the growth of other destructive organisms (figure 25.23).

Plants may even have the ability to communicate with one another. When the leaves of plants are eaten by animals, the new leaves produced to replace those lost often contain higher amounts of toxic materials than the original leaves. An experiment carried out in a greenhouse produced some interesting results. Some of the plants had their leaves mechanically "eaten" by an experimenter, whereas nearby plants were not harmed. Not only did the cut plants produce new leaves with more toxins, but the new growth on neighboring, nonmutilated plants had increased toxin levels as well. This raises the possibility that plants communicate in some way, perhaps by the release of molecules that cause changes in the receiving plant.

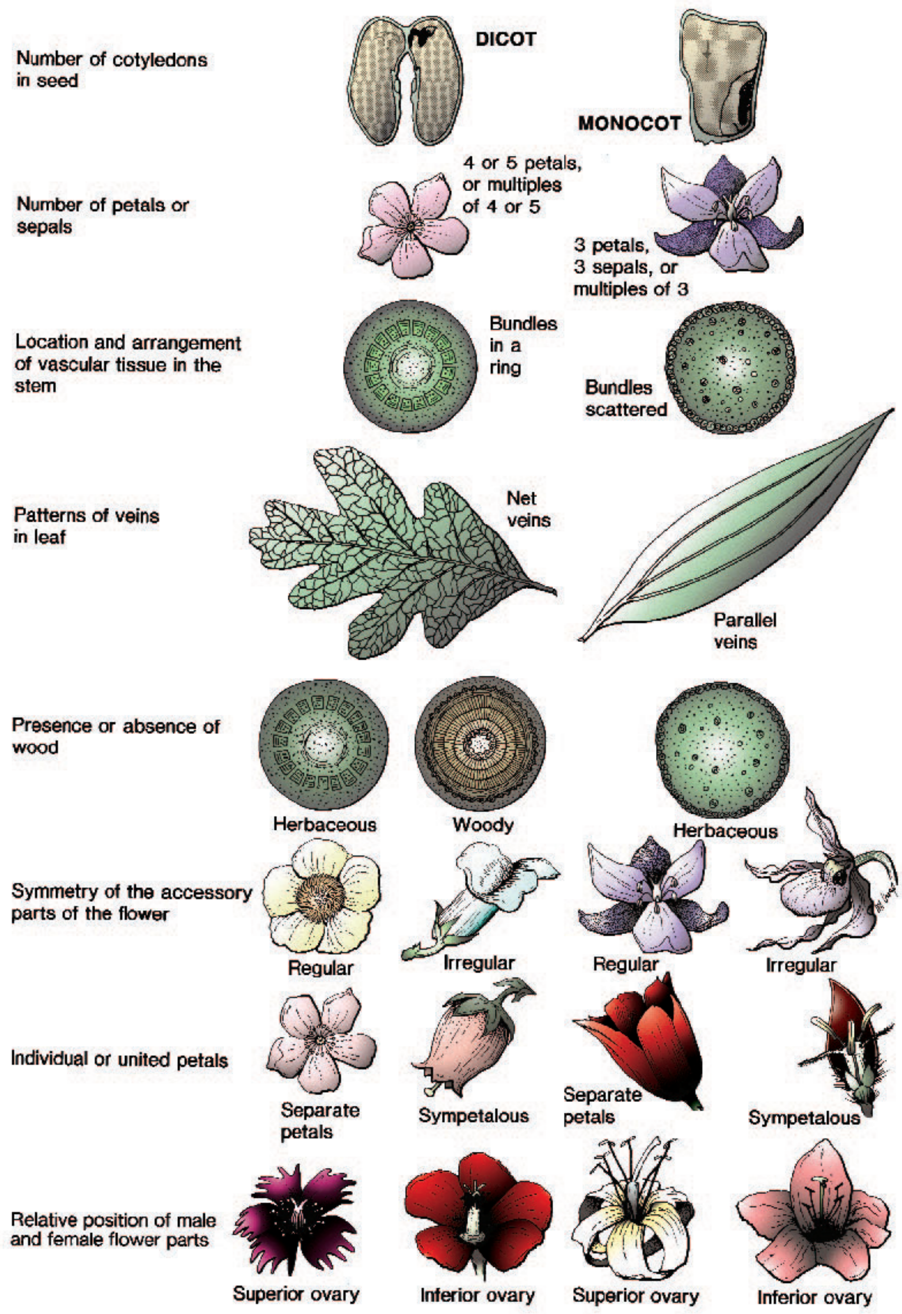


Figure 25.21

A Comparison of Structures in Dicots and Monocots
Botanists classify all angiosperms into these two groups.

Figure 25.22

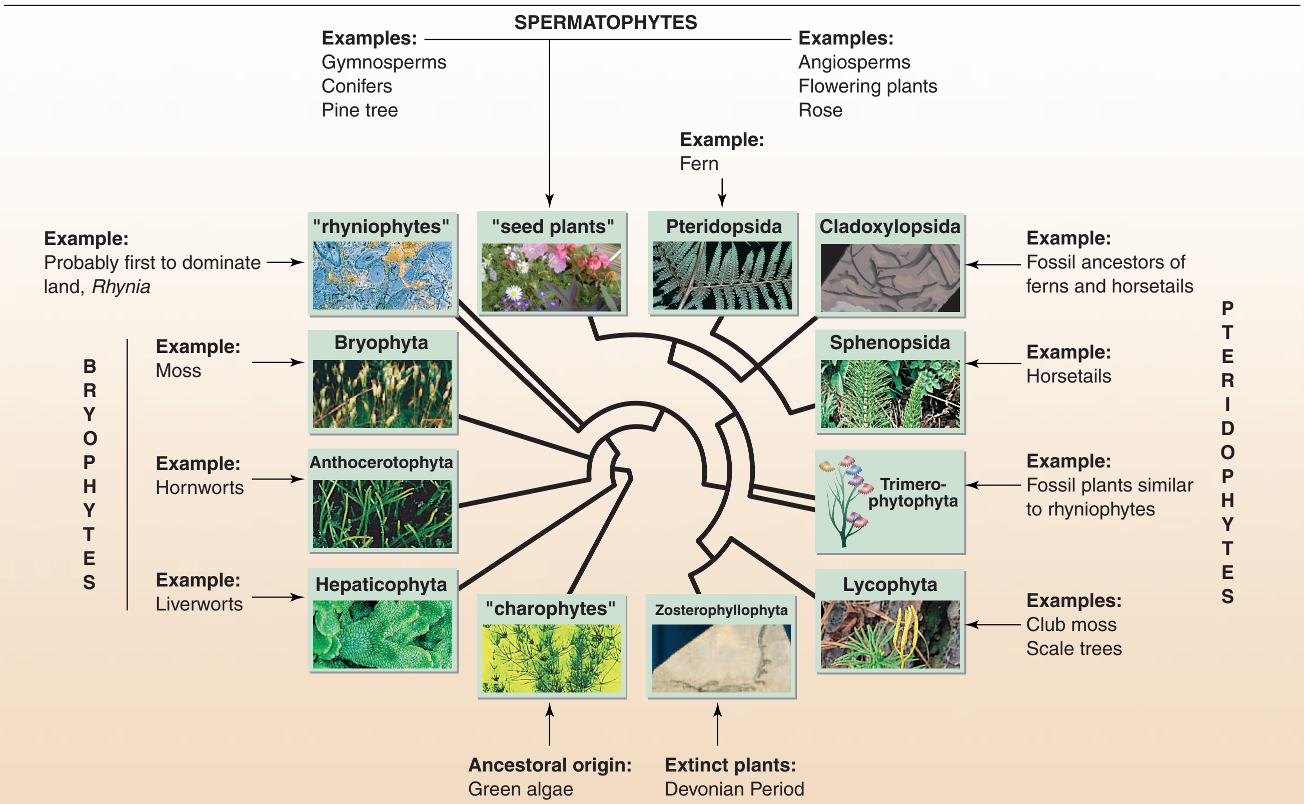
Phototropism
The above-ground portions of plants grow toward a source of light. One of the first studies done on phototropism was done by Charles Darwin and his son Francis in the late 1870s. They studied canary grass *(Phalaris canariensis)* and oats *(Avena sativa)*. They concluded that the process was controlled in some way by the tip of the plants. Later this was substantiated with the discovery of the plant hormone, auxin. Auxin proved to be a plant hormone that controls cell elongation and stimulates plant growth toward light.

Figure 25.23

Clinging Stems
Some stems are modified to wrap themselves around objects and give support. The *tendrils* of this grapevine are a good example. The tendrils of the Virginia creeper (*Parthenocissus* sp.) have adhesive pads that help them stick to objects.

Table 25.1

A CLADOGRAM OF PLANTS



SUMMARY

The plant kingdom is composed of organisms that are able to manufacture their own food by the process of photosynthesis. They have specialized structures for producing the male sex cell (the sperm) and the female sex cell (the egg). The relative importance of the haploid gametophyte and the diploid sporophyte that alternate in plant life cycles is a major characteristic used to determine an evolutionary sequence. The extent and complexity of the vascular tissue and the degree to which plants rely on water for fertilization are also used to classify plants as primitive (ancestral) or complex. Among the gymnosperms and the angiosperms, the methods of production, protection, and dispersal of pollen are used to name and classify the organisms into an evolutionary sequence. Based on the information available, mosses are the most primitive plants. Liverworts and club mosses are experimental models. Ferns, seed-producing gymnosperms, and angiosperms are the most advanced and show the development of roots, stems, and leaves.

The kingdom Plantae is summarized in table 25.1.

THINKING CRITICALLY

Some people say the ordinary "Irish" potato is poisonous when the skin is green, and they are at least partly correct. A potato develops a green skin if the potato tuber grows so close to the surface of the soil that it is exposed to light. An alkaloid called *solanine* develops under this condition and may be present in toxic amounts. Eating such a potato raw may be dangerous. However, cooking breaks down the solanine molecules and makes the potato as edible and tasty as any other.

The so-called Irish potato is of interest to us historically. Its real country of origin is only part of the story. Check your local library to find out about this potato and its relatives. Are all related organisms edible? Where did this group of plants develop? Why is it called the Irish potato?

CONCEPT MAP TERMINOLOGY

Construct a concept map to show relationships among the following concepts.

accessory structures
angiosperm
dicot
flower
leaves
monocot
root hairs
roots
stems

KEY TERMS

accessory structures
alternation of generations
angiosperms
annual
antheridia (singular, antheridium)
archegonium
auxin
cambium
cone
deciduous
dicot
flower
fruit
gametophyte
germinate
gymnosperms
herb
imperfect flowers
leaves
life cycle
monocot
nondeciduous
ovary
perennial
perfect flowers
petals
phloem
pistil
pollen
pollination
root
root hairs
seed
seed leaves
sepals
spores
sporophyte
stamen
stem
tropism
vascular tissues
wood
woody vascular plants
xylem

e—LEARNING CONNECTIONS *www.mhhe.com/enger10*

Topics	Questions	Media Resources
25.1 What Is a Plant?	1. What characteristics distinguish algae in the kingdom Protista from the organism of the kingdom Plantae?	**Quick Overview** • Characteristics of plants **Key Points** • What is a plant?
25.2 Alternation of Generations	2. What are the dominant generations in mosses, ferns, gymnosperms, and angiosperms?	**Quick Overview** • A different type of life cycle **Key Points** • Alternation of generations
25.3 Ancestral Plants: The Bryophytes		**Quick Overview** • Mosses, liverworts, and hornworts **Key Points** • Ancestral plants: The bryophytes
25.4 Adaptations to Land	3. What is the significance of the cambium tissue in woody perennials?	**Quick Overview** • Vascularization **Key Points** • Adaptations to land
25.5 Transitional Plants: Non-Seed-Producing Vascular Plants	4. What are the differences between the xylem and the phloem? 5. Ferns have not been successful as gymnosperms and angiosperms. Why?	**Quick Overview** • Ferns **Key Points** • Transitional plants: Non-seed-producing vascular plants **Experience This!** • Rooting plants
25.6 Advanced Plants: Seed-Producing Vascular Plants	6. List three characteristics shared by mosses, ferns, gymnosperms, and angiosperms. 7. What were the major advances that led to the development of angiosperms? 8. How is a seed different from pollen, and how do both of these differ from a spore? 9. How are cones and flowers different? 10. How are cones and flowers similar?	**Quick Overview** • Pines and flowering plants **Key Points** • Advanced plants: Seed-producing **Animations and Review** • Gymnosperms • Angiosperms • Fruits **Interactive Concept Maps** • Seed producers
25.7 Response to the Environment—Tropisms		**Quick Overview** • Responses from a plant? **Key Points** • Response to the environment: Tropisms **Interactive Concept Maps** • Text concept map **Review Questions** • Plantae