Unit 7

PLANTS

CHAPTERS

"The day passed delightfully. Delight itself, however, is a weak term to express the feelings of a naturalist who, for the first time, has wandered by himself in a Brazilian forest. The elegance of the grasses, the novelty of the parasitical plants, the beauty of the flowers, the glossy green of the foliage, but above all the general luxuriance of the vegetation, filled me with admiration."

Charles Darwin, *Voyage of the Beagle*

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SciLINKS NSTA

National Science Teachers Association *sci*LINKS Internet resources are located throughout this unit.

These autumn leaves show bright colors because they have lost most of their chlorophyll.

Rafflesia arnoldii *has the largest known flowers. Although they are large and beautiful, these flowers emit the smell of rotting meat, which attracts flies as pollinators.*

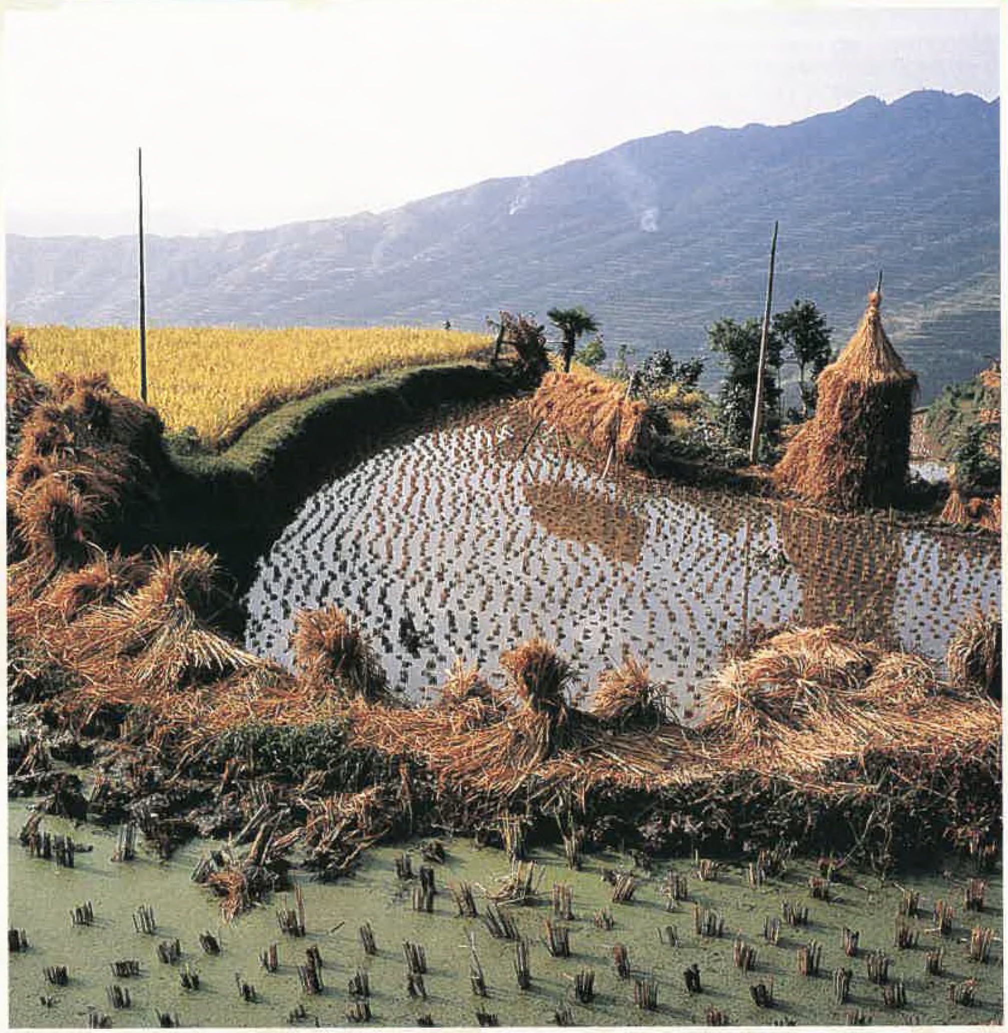
Strawberry plants have aboveground stems that are able to form new plants.

Orchid cactus

This cotton boll developed from the ovary of a flower of a cotton plant.

CHAPTER 29

THE IMPORTANCE OF PLANTS



Rice fields, often called paddies, thrive in regions with abundant rainfall. Rice is a prime food source for more than 60 percent of the world's population. About 90 percent of the world's rice is grown in Asia, primarily in China and India.

FOCUS CONCEPT: *Interdependence of Organisms*

As you read, pay attention to the relationship between plants and humans. Recognize how plants have changed over time. Describe how plants have been used to improve human existence.

PLANTS AND PEOPLE

Plants are essential to our survival because they produce virtually all our food. We eat plants either directly, in the form of fruits, vegetables, and grains, or indirectly, by eating animals that consume plants. Plants also provide medicines, clothing, paper, cosmetics, and many other products. Plants play a major role in the continuous cycling of the Earth's water, oxygen, carbon dioxide, and mineral nutrients. The study of plants is called ***botany*** *(BAHT-nee).*

SECTION

29-1

OBJECTIVES

▲ Describe ways that people use plants.

● Distinguish between cereals, root crops, legumes, fruits, and vegetables.

■ Explain how humans have increased food production in the world.

◆ List three plants that are widely used as medicines.

PLANTS AS FOOD

Of the more than 350,000 plant species, people use at least 10,000 species for food. Incredibly, fewer than 20 plant species provide more than 90 percent of our food supply. The cultivation of plants for food probably began about 11,000 years ago in the Middle East. Wheat, barley, lentils, and peas were the first domesticated food crops. Growing plants and raising animals for human use is called **agriculture** (AG-ri-KUHL-chuhr). People propagated, or reproduced, individual plants that had valuable characteristics, such as plants that produced the largest or tastiest fruits.

In the 11,000 years that humans have been cultivating plants, we have changed many of the plants so much that they could not grow and survive without us. For example, the wild wheat stalk, as shown in Figure 29-1, breaks easily in the wind, an adaptation that increases the dispersal of its seeds. But early farmers used seeds from plants with stalks that did not break easily for replanting. When these plants were grown, the seeds could be harvested before they fell from the plant. This form of selection—with people acting as selecting agents—has resulted in high-quality food plants.

You have probably eaten Thompson Seedless grapes, McIntosh apples, or Valencia oranges. They are just three examples of the several hundred thousand different cultivars. The word *cultivar* is a contraction of the terms *cultivated* and *variety*. **Cultivars** (KUHL-ti-VAHRZ) are selected by people, and they have at least one distinguishing characteristic that sets them apart from other members of their species. The famous Japanese flowering cherry trees in Washington, D.C., Yoshino cherries, are another example of a cultivar.

FIGURE 29-1
Wheat is one of the world's most important food crops. It is used to make breads, crackers, macaroni, and spaghetti.

Word Roots and Origins

agriculture

from the Latin *ager,* meaning "field," and *cultura,* meaning "cultivation"

FOOD CROPS

Food crops are usually classified partly by use and partly by family. The classification system in Table 29-1 is not like the taxonomic classification used by scientists because most categories contain species that are not closely related. Also, many crops fit into more than one category. For example, corn is a cereal, but it can also be classified as an oil crop, a sweetener, a vegetable, and a beverage.

Cereals

Cereals are grasses that contain grains. Grains are the edible, dry fruits of a cereal. Over half of the world's cultivated land is devoted to cereal crops, such as rice, wheat, corn, oats, sorghum, rye, and millet. Worldwide, cereals provide about 50 percent of the calories in the average human diet. In addition, much of the harvested grain is used for animal feed, so it is indirectly consumed by people as meat, poultry, eggs, and dairy products.

Wheat and corn are produced in the largest amounts. Wheat grows well in moderate to cold climates, including parts of the United States, Russia, and Canada. The United States is the leading producer of corn, also called maize. Rice is different from other cereals because it grows best in shallow water, as shown on page 560. Rice thrives in areas with warm temperatures.

TABLE 29-1 ***Food Crops***

Category	Example plants
Cereals	rice, wheat, corn, oats, sorghum, rye, barley, millet
Root crops	potato, cassava, sweet potato, yam, taro
Legumes	soybean, peanut, bean, pea, alfalfa, lentils
Fruits	apple, peach, banana, grape, orange, blueberry, pineapple, cherry, mango, pear
Nuts	peanut, walnut, cashew, pecan, coconut, almond, macadamia, filbert, pistachio
Vegetables	spinach, cabbage, sweet corn, pea, turnip, asparagus, tomato, artichoke, zucchini
Forages	cereals, legumes, grasses
Oils	cottonseed, rapeseed, palm, sesame, soybean, corn, safflower, sunflower
Beverages	coffee, tea, cola, cacao, fruit juice, grape (wine), corn (whiskey), barley and hops (beer)
Sweeteners	sugar cane, sugar beet, sugar maple, corn
Spices	pepper, cinnamon, vanilla, paprika, cloves, saffron, nutmeg, ginger, allspice
Herbs	rosemary, thyme, sage, dill, basil, oregano, mint
Flavorings	cacao (chocolate), coconut, carob, licorice, quinine
Colorings	red beet, anatto, turmeric, saffron, carrot
Additives	guar, locust bean, citrus (pectin), gum arabic, chicle tree
Garnishes	sesame, caraway, and poppy seeds; parsley; pimento
Snacks	popcorn, sunflower seeds, pumpkin seeds

Root Crops

Root crops are roots or underground stems that are rich in carbohydrates. In many parts of the world, root crops substitute for cereals in providing the major part of the diet. However, diets of root crops or cereals alone are usually low in some important amino acids. To correct this deficiency, other foods, such as legumes or animal protein, must be eaten.

Root crops include potatoes, beets, carrots, radishes, rutabagas, and turnips. You may have eaten tapioca pudding, which comes from a plant grown in the tropics called cassava, shown in Figure 29-2.

FIGURE 29-2

An important root crop in South America is cassava, which has thick roots that are eaten like potatoes. The starch-filled roots of cassava can be 30–120 cm (1–4 ft) long.

Legumes

Legumes are members of the pea family and bear protein-rich seeds in pods. Soybean, shown in Figure 29-3, is the most important legume crop because it is produced in the largest amount and has many important uses. Soybean is used to make vegetable oil, soy milk, soy sauce, tofu, and margarine. Alfalfa and clover are legumes used mainly as feed for livestock. Legumes are important in agriculture because they improve the nitrogen content of soil. Recall from Chapter 24 that the bacteria *Rhizobium* form a symbiotic relationship with many legumes.

Fruits, Vegetables, and Nuts

Many "vegetables" we know, such as tomatoes, green beans, and squash, are actually taxonomically classified as fruits. A **fruit** is the part of a flowering plant that usually contains seeds. Foods derived from the leaves, stems, seeds, and roots of nonwoody plants are often called **vegetables.** Vegetables are excellent sources of many important vitamins and minerals, making them an essential part of a healthy diet. Most **nuts** have a hard outer layer and contain a dry, one-seed fruit. Nuts include almonds, walnuts, pecans, and hazelnuts. Peanuts are commonly considered to be nuts but are taxonomically classified as legumes.

FIGURE 29-3

Soybean is an important legume crop grown in the midwestern and southern parts of the United States. The soybean plant is covered with short, fine hairs and is usually 60–120 cm (2–4 ft) tall. It is an inexpensive and useful source of protein.

Spices, Herbs, and Flavorings

Other food crops add variety and pleasure to our diet by flavoring our water, beverages, and food. More than half the population get daily stimulation from caffeine in coffee, tea, and cola drinks. Both **spices** and **herbs** are used to add taste to food. In general, spices come from plant parts other than the leaf and are tropical. Herbs usually come from leaves and usually can be grown in a home garden. Flavorings, such as chocolate and coconut, are not usually considered spices or herbs and are therefore placed in a separate category. Another flavor, quinine, is used to make tonic water. **Quinine** comes from the bark of the cinchona tree and is used to treat malaria.

Food Production

For decades, experts have been predicting widespread food shortages due to the continuing increase in the world population.

Eco Connection

Making Your Own Fertilizer—Composting

Many people are making their own fertilizer through a technique called composting. Compost is a type of organic fertilizer made from decayed plant matter. Compost improves the texture of soil and provides inorganic nutrients for plants.

It's easy to start your own compost pile. Collect dead plant matter, such as grass clippings, leaves, coffee grounds, or sawdust. Make a pile by alternating layers of plant matter with a thin layer of soil or manure. Sprinkle water on the pile to speed the process of decay. After the compost has been allowed to decay for about six months, it should be ready for use in your garden.

Word Roots and Origins

pesticide

contains the suffix *-cide,* from the Latin *cida,* meaning "cut down" or "kill"

However, massive food shortages have not occurred mainly because of increased use of irrigation, fertilizers, and pesticides. Improvements in cultivars; farm machinery; food preservation techniques; and methods of controlling diseases, weeds, and pests have also helped improve food production. **Fertilizers** supply plants with essential mineral nutrients like nitrogen and phosphorus. **Pesticides** are chemicals that kill undesirable organisms that eat crops, such as some insects.

People have made many trade-offs to support an adequate food supply. The negative consequences include massive soil erosion, depletion of fossil fuel and water supplies, pollution, and destruction of wild populations of plants and animals as more land is cultivated.

NONFOOD USES OF PLANTS

In addition to providing us with food, plants provide us with thousands of other essential products. It is hard to imagine how we could live without plants, given the variety of products that contain substances from plants.

Medicines

The ancient Greeks treated headaches with the bark of white willow, which contains the chemical salicin. This use gave scientists the idea to test a similar chemical, acetylsalicylic (uh-SEET-uhl-SAL-uh-SIL-ik) acid. The willow is in the genus *Salix,* hence the names *salicin* and *salicylic.* You know acetylsalicylic acid as **aspirin,** the world's most widely used medicine. Besides pain relief, aspirin is used to thin blood and thereby prevent heart attacks and strokes. Plants were our first medicines, and early plant biologists, like Linnaeus, were often medical doctors. Many modern medicines either still come from plants or were originally obtained from plants and are now synthesized in the laboratory. Table 29-2 lists examples of plants that

TABLE 29-2 *Plants in Medicine*

Plant	Genus name	Drug	Use
Cinchona	*Cinchona*	quinine	treat malaria and certain disorders of heart rhythm
Foxglove	*Digitalis*	digitalis	treat heart disease, help regulate heart rate
Yam	*Dioscorea*	cortisone	treat inflammation and allergies
White willow	*Salix*	acetylsalicylic acid (aspirin)	relieve pain, prevent heart attacks and strokes
Yew	*Taxus*	taxol	treat ovarian cancer, breast cancer, and some types of lung cancer

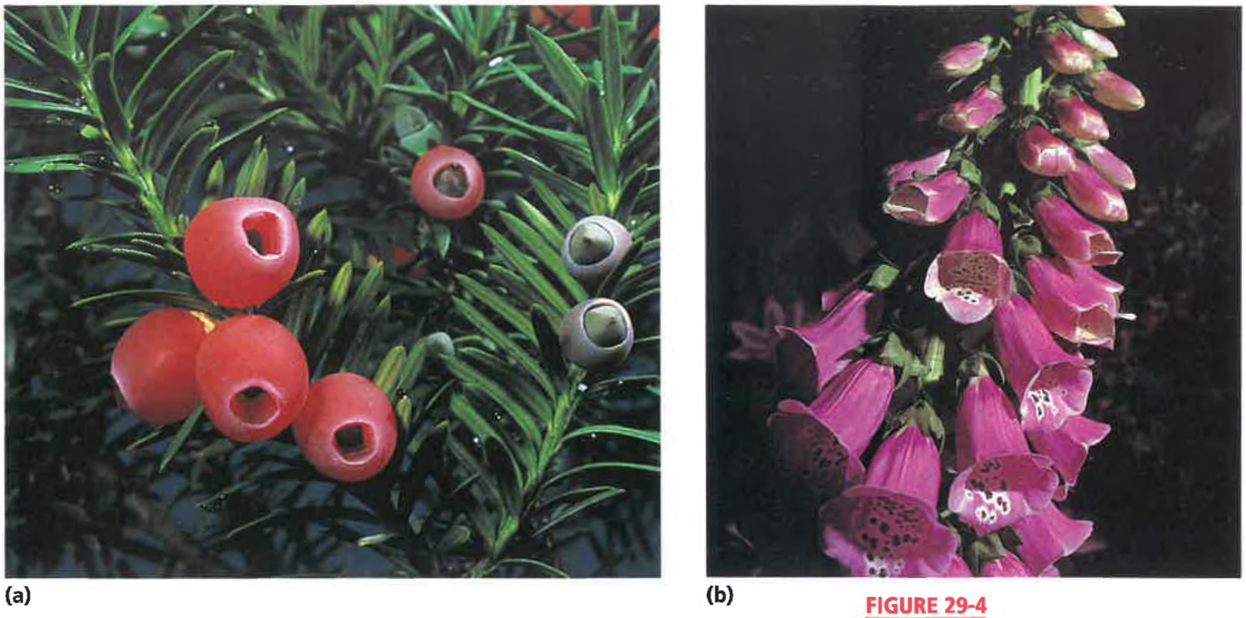


FIGURE 29-4

(a) Taxol, originally derived from the bark of the Pacific yew, is a recently discovered cancer drug. This evergreen tree or shrub produces seeds that look like berries. (b) Foxglove, the source of digitalis, is used in the treatment of heart disease. The beautiful flowers grow in a cluster.

are used in medicine. Two of these plants, yew and foxglove, are shown in Figure 29-4. Scientists are currently evaluating thousands of plant species that may have medicinal properties. Scientists are very concerned about the destruction of rain forests because many rain-forest plant species have yet to be researched. In addition to medicines, plants provide many other products, which are summarized in Table 29-3 on page 566.

Your local health-food store carries a wide range of plant products that claim to prevent disease or improve health. These substances are not regulated by the Food and Drug Administration (FDA). For example, it is reported that garlic and *Echinacea* (purple coneflower) may improve immune response. Consumers should remember that the effectiveness and safety of herbal remedies have not been confirmed by the rigorous scientific testing that new medicines must undergo before receiving FDA approval. The FDA, pharmaceutical companies, and health-care providers are working together to investigate the claims of those who market these remedies.

Clothing and Fabric Dyes

Figure 29-5 shows cotton, which is used to make most of our clothing. The original jeans of Levi Strauss were made with sailcloth woven from hemp. Strauss later switched to cotton. Some expensive clothing is woven with linen, which is made from the flax plant. Artificial fabrics, like rayon, arnel, and cellulose acetate, are made from processed wood fibers. Leather is made from animal hides, but it is usually treated with tannin, a chemical obtained from many tree species. Tanning makes leather stronger and prevents it from rotting.

Prior to the mid-1800s, fabrics were dyed with natural plant dyes. Today most clothing is colored with dyes manufactured from coal, which consists of the remains of ancient plants.

FIGURE 29-5

Cotton, the world's most widely used source of clothing, consists of hairs attached to the seed.

TABLE 29-3 *Nonfood Uses of Plants*

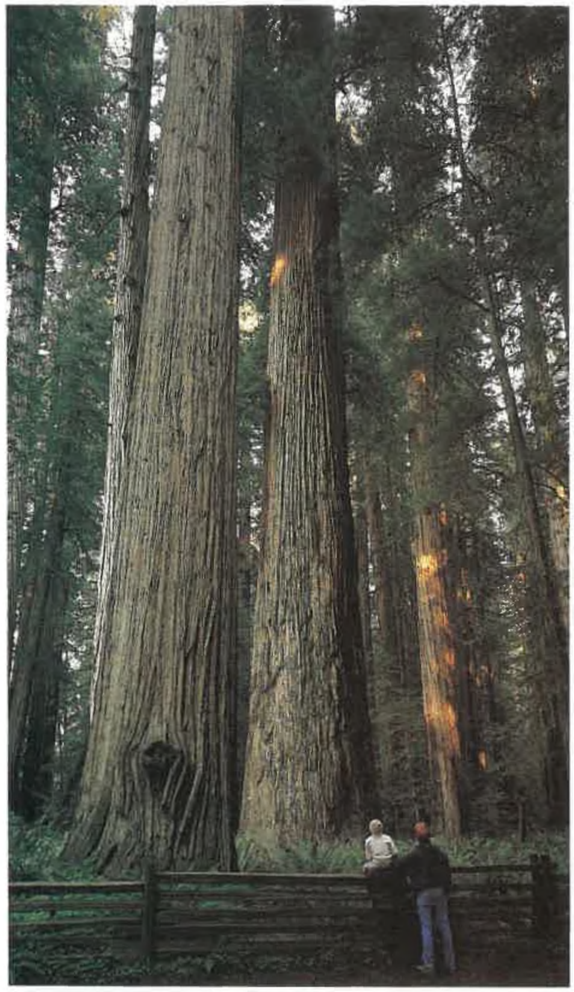
Use	Example plants
Brooms/brushes	broomcorn, palms, coconut
Building materials	trees, bamboo, reeds, palms, grasses
Carpets/mats	jute, coconut (coir), cotton, trees
Clothing	cotton, flax (linen), ramie, pineapple, trees (rayon and arnel)
Cosmetics	corn, avocado, carrot, almond, cacao, soybean, macadamia, aloe
Fabric dyes	indigo (blue), madder (red), onion (yellow), black walnut (brown), peach (green), maple (pink)
Fuels	trees, bamboo, water hyacinth, grain alcohol, vegetable oils, gopher plant
Furniture	redwood, oak, rattan, teak, willow (wicker), rushes
Hair dyes	henna, rhubarb, chamomile, black walnut
Incense	frankincense, myrrh, cinnamon
Inks	soybean, flax (linseed oil), tung-oil tree
Leather	black wattle, quebracho, Spanish chestnut (tannin)
Lipstick	jojoba, castor bean, carnauba palm, soybean, coconut
Medicines	foxglove (digitalis), cinchona (quinine), yew (taxol), opium poppy (morphine, codeine), yam (cortisone), aloe, ipecac, ginseng, ginkgo, guarana, purple coneflower, kudzu, saw palmetto
Miscellaneous	cork oak (cork), incense cedar (pencil shafts), trees (disposable baby diapers and cellulose acetate plastic), kapok (life preserver stuffing), rosary pea (bead necklaces), water hyacinth (water purification), lignum vitae (submarine engine bearings)
Musical instruments	ebony (black piano keys), maple (violins), reed (woodwind reeds), African blackwood (woodwinds)
Ornamentals	shade trees, shrubs, lawns, cut flowers, Christmas trees, houseplants
Paints	flax (linseed oil), tung-oil tree, soybean, pine (turpentine)
Paper/cardboard	trees, cotton, flax, hemp, bamboo, papyrus
Perfumes	rose, orange, lavender, orchids, sandalwood, lilac, jasmine, lily of the valley, pine
Pesticides/repellents	tobacco (nicotine sulfate), derris (rotenone), chrysanthemum (pyrethrum), citronella grass, garlic, citrus
Rope	hemp, agave (sisal)
Rubber	rubber tree, guayule
Shampoo	palm oil, coconut, jojoba, aloe, trees, herbs, fruits
Soaps	coconut, palm oil, cacao, lavender, herbs, fruits
Sports equipment	balata (golf balls), persimmon (golf club heads), ash (baseball bats), ebony and ash (pool cues)
Toothpaste	mint, wheat, palm oil, coconut
Tourist attractions	redwoods, giant sequoias, saguaro cactuses, fall foliage, Holland flower bulbs
Waxes	carnauba palm, cauassu, candelilla, bayberry

Fuels

Most of the energy we use for heat, electricity, and machine fuel comes from fossil fuels—coal, oil, and natural gas. Fossil fuels are composed of stored photosynthetic energy from millions of years ago. In developing nations, much of the fuel comes from wood or other plant materials. For example, grains can be fermented into alcohol and mixed with gasoline to make **gasohol.** Gasohol, which is made of about 10 percent alcohol, is an alternative fuel for automobiles.

FIGURE 29-6

The redwood trees that grow along the West Coast of the United States are a majestic sight. Redwoods usually grow 60–84 m (200–275 ft) high. The bark is very thick, making the trees resistant to fires.



Other Uses of Plants

Ornamental trees, shrubs, and other plants outside our homes do much more than provide beauty. Besides their decorative function, they improve the environment by preventing soil erosion, reducing noise, providing habitats for wild animals, acting as windbreaks, providing shade, and moderating temperatures, which, in turn, reduces home heating and cooling costs. Scientists have also found that ornamental plants improve our mental well-being. Gardening has long been a popular hobby in the United States, and it is an important form of exercise for millions of people.

Many plants have become major tourist attractions, such as the California redwoods shown in Figure 29-6. Every fall, people visit the forests of the northeastern United States to view the spectacular leaf colors.

Plants are essential to our survival because they produce virtually all of our food, and they enhance our lives in many ways. Growing cut flowers is now a multibillion-dollar-a-year industry, and it is only a small part of the huge business of growing and using plants. Plants can also provide the inspiration to develop innovative products. The cocklebur plant provided the idea for hook and loop fasteners when the hooked fruit was caught in the inventor's clothing. Plants have made our lives better in numerous ways, and they undoubtedly will continue to do so in the future.

SECTION 29-1 REVIEW

1. **Describe ways that people use plants.**
2. **Distinguish between cereals, root crops, legumes, fruits, and vegetables.**
3. **List three plants that are widely used as medicines.**
4. **List several personal grooming products that use ingredients from plants.**
5. **Explain three environmental benefits of having ornamental trees around a house.**
6. **CRITICAL THINKING How might transferring specific genes from legumes into rice plants help reduce malnutrition?**

George Washington Carver: Healer of the Soil

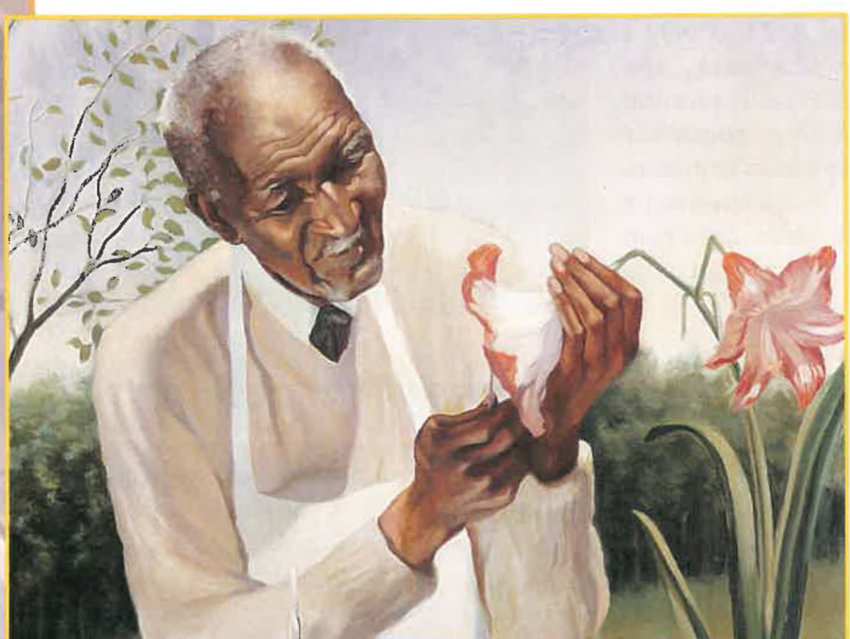
HISTORICAL PERSPECTIVE

Throughout the 1800s, cotton was the main cash crop and was called king of the South. As the century drew to a close, few people saw any reason for change. One man who did, however, was George Washington Carver. In 1896, Carver came to Alabama to teach scientific agriculture and direct the research department at Tuskegee Institute. But he had greater goals—to free African Americans from the ignorance and poverty left by slavery and to free the South of its dependence on cotton.

Scientific Agriculture

After the Civil War, the South remained an agricultural economy, with its recovery dependent on its farmers. Former slaves and masters devoted themselves to raising cotton to sell to eager markets. But George Washington Carver spent his life teaching another, better way.

All his life, Carver was intrigued by plants. He collected them, carried them around, identified and studied them, and even drew them. Like his teachers at Iowa State College of Agriculture (now Iowa State University), Carver believed American agriculture could be transformed by applying scientific principles.



George Washington Carver

After Carver earned a master's degree in agriculture and botany in 1896, Booker T. Washington, the founder of Tuskegee Institute (now Tuskegee University), invited him to head the school's agriculture department. Carver knew he had found a place where he could carry on his research.

Better Soil, Bigger Crops

When Carver saw the desolate fields around Tuskegee, he understood the problem. Planting the same crop in the same soil year after year had taken its toll. Great forests had been felled to make room for cotton, and without tree roots to hold the soil, millions of tons had washed away, along with valuable plant nutrients.

Carver and his students started a 20-acre school "farm." Later Carver said,

> *They told me it was the worst soil in Alabama, and I believed them. But it was the only soil I had. I could either sit down and cry over it or I could improve it.*

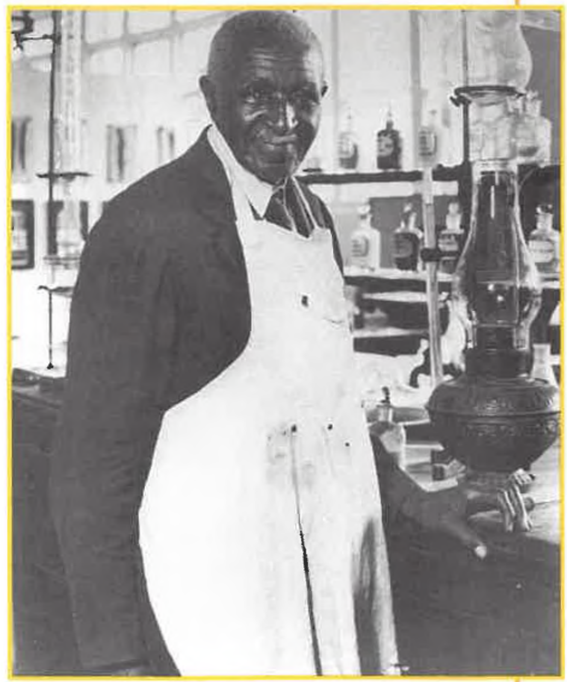
The first year, the soil yielded five bales of cotton, 120 bushels of sweet potatoes, and a net loss of $16.50. Each year thereafter, the soil and the harvest improved as Carver and his students made compost, spread fertilizer, planted various crops, and rotated the crops from year to year. After a few growing seasons, some cotton bushes bore as many as 275 giant white bolls.

The farm demonstrated what Carver had told his students: each plant needs certain things, the soil carries certain things, and it's up to the farmer to make any necessary changes to the soil. The depleted soil lacked nitrogen because cotton is a voracious nitrogen consumer, but legumes, such as cowpeas, peanuts, and soybeans, extract nitrogen from air and return it to the soil. The roots of legumes make nitrogen in the air available in a form that plants can use, and thereby enrich the soil with nitrogen.

From Shampoo to Axle Grease

Carver's contributions to southern farming were many, but he is best known for the many new uses he found for the peanut. Peanuts, he said, restore the soil's nitrogen and are easy to plant, grow, and harvest. Carver traveled throughout the Southern states, trying to promote the growing of peanuts.

At one point, Carver wondered if he had made a mistake. Farmers were growing a surplus of peanuts, but was there a market? Farmers would continue to plant peanuts only if they could sell them. Carver returned to his laboratory, where he created more than 300 peanut products. By 1950, the soil-enriching peanut was the second largest crop in the South. Carver experimented with other plants, including soybeans and sweet potatoes. Over 100 products were developed from the sweet potato plant by Carver. In fact, the Center for Sweet Potato Research is located on the Tuskegee University campus.



Working in his laboratory, George Washington Carver developed more than 300 products using peanuts. He also developed flour, molasses, rubber, and postage stamp glue from sweet potatoes.

Presidential Praises

Carver answered hundreds of letters, wrote a series of farm bulletins, displayed his products at fairs, and met with agriculture secretaries of the United States—and even the president. President Theodore Roosevelt once told him, "There is no more-important work than what you are doing." In 1930, the Roosevelt Medal was given to Carver for his contributions to science. Carver spent his life leading African Americans forward. In the process, he paved the way for a better life for an entire region.

Another reason to appreciate Carver's work is that he taught conservation long before that word became popular. He showed that certain "weeds" could make useful products, reminding us that seemingly useless plants may someday serve humanity as vital medicines and food products. Carver once said, "We can learn to synthesize materials for every human need from the things that grow."

In 1951, a national monument was established to honor George Washington Carver. This tribute to his extraordinary life in science is located on a Missouri farm—where he was born.

SECTION

29-2

OBJECTIVES

▲ Define *plant ecology.*

● Give two examples of how plants recycle elements in the environment, and explain why this recycling is essential to humans.

■ Explain how plants benefit from interactions with animals.

◆ Explain the beneficial interactions between plants, fungi, and bacteria.

▲ Describe how people have damaged wild plant populations.

PLANTS AND THE ENVIRONMENT

Based solely on weight, algae and photosynthetic bacteria are dominant organisms in the oceans, and plants are dominant on land. Photosynthetic plants are called producers because they make food for other living things. Organisms that eat other organisms, like animals, are called consumers and depend on plants for a source of organic compounds.

PLANT ECOLOGY

The study of the interactions between plants and the environment is called **plant ecology.** The most important interaction involves the ability of plants to capture solar energy through photosynthesis. In photosynthesis, plants absorb carbon dioxide from the air, produce sugar and starch, and break apart water, releasing oxygen into the air. Consumers use sugar and oxygen in aerobic respiration and produce carbon dioxide and water. Organic compounds from plants provide consumers with energy, building blocks, and essential molecules like vitamins and fiber.

Plants also provide organisms with inorganic nutrients. Plant roots are very efficient at mining the soil for inorganic nutrients, such as nitrogen, phosphorus, potassium, iron, and magnesium. Plants use these inorganic nutrients in the organic compounds they make. Consumers ingest these organic compounds and incorporate the inorganic nutrients into their own bodies. Eventually, these same

FIGURE 29-7

About half of the world's species of plants and animals live in tropical rain forests. Scientists are very concerned about the destruction of rain forests because many plant species have yet to be researched, and some may have medicinal properties.

inorganic nutrients are returned to the soil when the consumer's waste material or dead body is decomposed by bacteria and fungi. Plants thus play a major role in the continuous cycling of the Earth's water, oxygen, carbon dioxide, and inorganic nutrients.

Plants are also responsible for the formation and maintenance of soil. Roots bind soil particles together, leaves reduce the soil-eroding impact of wind and rain, and dead plant parts add organic matter to the soil.

Plant-Animal Interactions

Plants interact with animals in many fascinating ways. Many flowering plants attract pollinators, animals that carry pollen from one plant to another. Usually the pollinator gets a reward for its efforts in the form of food from nectar. The size, shape, color, and odor of many flowers make them attractive to their pollinators. For example, Figure 29-8 shows that in some orchid species, the flowers have evolved to look and smell like the female of their wasp or bee pollinators. A male wasp or bee lands on a flower believing he has located a mate. The pollen he touches sticks to his body and is transferred to the next orchid he visits. In this case, the flower lures the pollinator with the promise of a mate, but fools the insect into picking up pollen without receiving a reward.

FIGURE 29-8

Some orchid species have evolved to resemble their wasp or bee pollinators.

Plant-Microbe Interactions

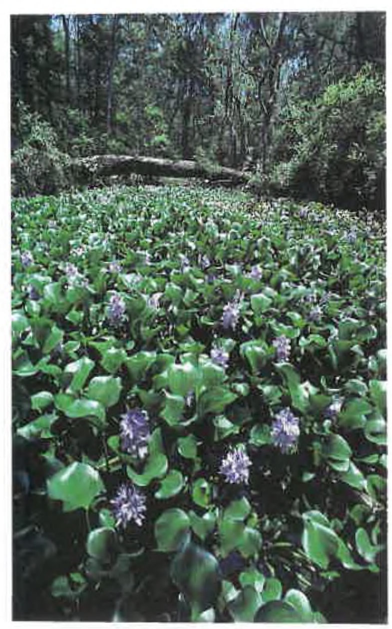
Two important aspects of plant ecology are plant interactions with fungi and with bacteria. Plant-microbe interactions may be harmful to plants, as in the case of fungal and bacterial diseases. Diseases often cause major crop losses. However, bacteria and fungi also form important beneficial relationships with plants.

The majority of plant species form mycorrhizae, which are symbiotic relationships between fungi and the roots of a plant. A mycorrhizal fungus infects a root, often changing the root structure. However, the fungus does not harm the root. Instead, it greatly increases the root's ability to absorb water and other inorganic nutrients, such as phosphorus and potassium. In return, the root supplies the fungus with energy.

The roots of many plant species also form beneficial associations with bacteria. Some bacteria can take nitrogen gas from the air and "fix" it, or convert it to a form that plants can use. Plants of the legume family, such as peas, beans, and peanuts commonly host bacteria that fix nitrogen.

FIGURE 29-9

The water hyacinth has become a weed that clogs waterways in the southeastern United States.



Protecting Native Plants

We protect and care for many plants that provide us with food, clothing, shelter, and other products. However, humans have drastically changed natural plant populations by introducing foreign plant species, diseases, and animals. Introduced plants, like the water hyacinth shown in Figure 29-9, kudzu, crabgrass, and dandelion have become widespread weeds. **Weeds** are undesirable plants that often crowd out crop plants or native plant species. For example, water hyacinths float on lakes and rivers, growing so fast and dense that they impede boats and shade underwater plants. The introduction of a fungal disease, chestnut blight, in 1904 virtually wiped out the American chestnut as a dominant forest tree in the eastern United States. Government inspectors now carefully screen plant materials entering the country to prevent the introduction of new plant pests.

HARMFUL PLANTS

Despite the many benefits plants provide, some plants can also cause harm. Many deaths are caused by addictive plant products, such as tobacco, cocaine, opium, and alcohol. Some plant species are poisonous when eaten or touched. Poison ivy and poison oak give an itchy rash to millions of Americans each year. Children are often poisoned, though usually not fatally, when they eat the leaves or colorful berries of house or garden plants. Despite widespread reports to the contrary, the popular Christmas plant poinsettia is not deadly, but its sap may cause skin irritation. However, holly berries and all parts of American mistletoe are poisonous.

Tens of millions of people suffer from pollen allergies, one cause of hay fever. **Hay fever** is an allergic reaction that results in sneezing, a runny nose, and watering eyes. Pollen allergies occur at three seasons. In early spring, deciduous trees, such as oak, ash, birch, and sycamore release pollen. In late spring or early summer, it is mainly wild and pasture grasses that cause allergy problems. Of the cereal crops, only rye pollen seems to be an important cause of allergies. In late summer and fall, the highly allergenic pollen of ragweeds, shown in Figure 29-10, affects people. Contrary to popular belief, large, colorful flowers do not cause hay fever. Pollen that causes allergies comes from small, drab flowers that are wind-pollinated.

FIGURE 29-10

Giant ragweed, which can grow to more than 4 m (13 ft.) tall, produces massive amounts of pollen that is a major cause of hay fever. The small, dull flowers indicate that it is wind-pollinated.

SECTION 29-2 REVIEW

1. What is plant ecology?
2. How do plants continuously recycle the Earth's inorganic nutrients?
3. How do plants benefit from their interactions with animals?
4. How do plants benefit from their interactions with fungi and bacteria?
5. How do plants harm people?
6. CRITICAL THINKING Explain how people have damaged wild plant populations by introducing foreign organisms.

CHAPTER 29 REVIEW

SUMMARY/VOCABULARY

29-1

- The branch of biology that studies plants is called botany. The practical applications of botany are evident in agriculture, which is the raising of crops and livestock for food or other uses.
- Humans have cultivated plants for at least 11,000 years and have changed many plant species so much, via selection, that these plants can no longer survive in the wild.
- There are several hundred thousand plant cultivars, or cultivated varieties, that are given names, such as McIntosh apple.
- Food crops can be classified in many ways, including by their usage and by their taxonomic classification.
- The major part of the human diet is provided by a few cereal crops in the grass family, especially corn, wheat, and rice.
- The identification of fruits and vegetables is sometimes confusing because everyday definitions are different from botanical definitions. Many of our common vegetables, such as green beans, tomatoes, squash, and pumpkins, are actually fruits. Botanically speaking, a fruit is the part of a flowering plant that usually contains seeds.
- Plants provide many important medicines, such as digitalis, quinine, morphine, and cancer drugs.
- Several factors have increased food production, including the use of fertilizers and pesticides. As land is cultivated to produce an adequate food supply, the health of the environment is compromised by soil erosion, depleted water supplies, and pollution.
- Plants provide thousands of nonfood products, including clothing, fabric dye, lumber, paper, cosmetics, fuel, cork, rubber, turpentine, and pesticides.
- Ornamental plants improve the human environment in many important ways: they provide shade, minimize soil erosion, reduce noise, and lower home energy costs.

Vocabulary

agriculture (561)	cultivar (561)	herb (563)	quinine (563)
aspirin (564)	fertilizer (564)	legume (563)	root crop (563)
botany (561)	fruit (563)	nut (563)	spice (563)
cereal (562)	gasohol (567)	pesticide (564)	vegetable (563)

29-2

- Based on weight, plants are the dominant organisms on land.
- Photosynthetic plants are producers, and animals are consumers.
- Plants play a major role in recycling the Earth's water, oxygen, carbon dioxide, and inorganic nutrients.
- Plants provide animals with inorganic nutrients as well as organic nutrients.
- Most plant roots are infected with beneficial mycorrhizal fungi, which greatly increase the roots' ability to absorb inorganic nutrients.
- Most nitrogen in living organisms must first be fixed by bacteria, which may live in association with plant roots, especially the roots of legumes.
- Plants associate with animals in many mutually beneficial ways, such as providing food to animals that protect them or carry their pollen.
- People have negatively affected wild plant populations by introducing foreign species of plants, animals, and disease organisms.
- Hay fever, or pollen allergies, is caused by the small flowers of certain wind-pollinated plants, not by ornamental flowers.

Vocabulary

hay fever (572)	plant ecology (570)	weed (571)

REVIEW

Vocabulary

1. Distinguish between botany and agriculture.
2. Define *cultivar*, and give two examples of popular cultivars.
3. List three cereals.
4. List three medicinal plants.
5. What are mycorrhizae, and how do they benefit a plant?

Multiple Choice

6. Plants provide us with (a) energy (b) oxygen (c) inorganic elements (d) all of the above.
7. Some plants attract pollinators by producing (a) spines (b) grains (c) toxic chemicals (d) modified flowers.
8. Organisms that use plants as food are referred to as (a) predators (b) consumers (c) producers (d) pollinators.
9. The cultivation of plants by humans probably began in (a) the Middle East (b) South America (c) North America (d) Northern Europe.
10. The foxglove plant aids in the treatment of heart disease because it is the source of a medication called (a) quinine (b) morphine (c) digitalis (d) taxol.
11. Edible underground structures that store nutrients are called (a) root crops (b) legumes (c) forage crops (d) grains.
12. Legumes can produce seeds that are protein-rich even in unfertilized soil because of their associations with bacteria that (a) break down carbohydrates (b) absorb oxygen (c) fix nitrogen (d) produce carbon.
13. Plants that are the major source of food for the world today are called (a) spices (b) root crops (c) legumes (d) cereals.
14. Pollen allergies most likely would be caused by pollen from (a) a bee-pollinated flower (b) a large colorful flower (c) a wind-pollinated flower (d) a fragrant flower.
15. During photosynthesis, plants produce (a) carbon dioxide (b) quinine (c) oxygen (d) water.

Short Answer

16. Distinguish between a fruit and a vegetable.
17. List three nonfood, nonmedicinal uses of plants.
18. Why can't people survive solely on a diet of cereals?
19. Why are pharmaceutical companies and health care providers sometimes skeptical of herbal remedies?
20. Explain how plants and microbes interact in mutually beneficial ways.
21. Describe how people act as selecting agents in the evolution of food plants.
22. List several grooming products that use ingredients from plants.
23. What adaptive advantage might colorful flowers have for plants?
24. Name three addictive plant products.
25. Describe how ornamental trees improve the environment.

CRITICAL THINKING

1. Native American farmers often grow corn, pole beans, and squash together. The drawing below shows how the pole beans climbed the corn while the squash carpeted the ground around the corn. What advantage might each plant gain from this arrangement? What advantage is this to the human diet?

2. One explanation for the sudden extinction of dinosaurs is that they starved after an asteroid hit the Earth. The impact created huge dust clouds that blocked out the sunlight and prevented photosynthesis. How would people obtain food and oxygen if the same thing were to happen today?
3. If all animals disappeared from the Earth, what effects, positive and negative, would this have on plants?
4. During the rainy season in the Brazilian rain forest, the rivers flood the land. Many fish from these rivers then swim among the land plants and eat their fruit. How might this intermingling of fish and plants help the plants?
5. Suppose a friend asks you why corn, which he or she considers to be a vegetable, is listed as a cereal crop in the encyclopedia. To answer this question, write a paragraph that explains why corn is a cereal crop, agriculturally, and why it is also a fruit, botanically. Include other examples of foods that are classified as vegetables or grains, but are also fruits.
6. How did artificial selection by humans play a role in the origin of agricultural crops? How is artificial selection similar to natural selection?
7. Many athletes consume carbohydrates before a competition to increase their endurance. The table below shows a variety of legumes and grains that can be purchased at a grocery store. Compare their prices and nutritional backgrounds. Determine which food is the least expensive source of carbohydrates.

Common Legumes and Grains

				Per serving			
Food	**Package size**	**Price**	**Serving (g)**	**Calories**	**Total fat (g)**	**Total carbohydrate (g)**	**Total protein (g)**
Navy beans	454 g	.69	45	80	0	23	8
Rice	907 g	.79	45	150	0	35	3
Barley	454 g	.49	45	100	0	24	3
Soybeans	454 g	.89	45	170	8	14	15
Spaghetti	907 g	.79	45	200	1	34	6

EXTENSION

1. Examine the labels of some processed foods, such as ice cream, yogurt, crackers, and margarine. Determine the types of plants that were used in their preparation.
2. Read "The Bromeliads of the Atlantic Forest" in *Scientific American,* March 2000, on page 86. Describe at least one interaction between bromeliads and an animal of the forest. How are these plants endangered?
3. Read "Redwoods in the Mist" in *National Wildlife,* April/May 1999, on page 8. Discuss how Todd Dawson of Cornell University explains why tall redwood trees might not have to transport water all the way from their roots to their tops. What role does fog play in the process?
4. Using field guides from a library, determine which plants in your school grounds or in a nearby park are native and which are foreign. For foreign species, list the continent of origin.

Comparing Soil-Grown Plants with Hydroponic Plants

OBJECTIVES

- Compare hydroponic plant-cultivation techniques with conventional plant-cultivation techniques.
- Observe the germination of wheat seeds over a two-week period.

PROCESS SKILLS

- analyzing data
- measuring
- comparing and contrasting

MATERIALS

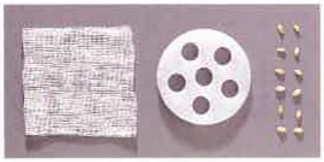
- 2 clear plastic cups
- plastic-foam floater with 6 holes in it
- 50 mL of potting soil
- cheesecloth (must be large enough to cover the plastic-foam floater)
- 12 wheat seeds
- 50 mL of complete nutrient solution
- plastic dropper
- labeling tape
- marking pen
- 50 mL graduated cylinder
- metric ruler

Background

1. Hydroponic cultivation is a technique for growing plants in a solution that contains all of the inorganic nutrients the plant needs. Plants that are grown hydroponically do not require soil.
2. The beginning of growth in a seed is called *germination.*

PART A Day 1

1. Using the marking pen and the labeling tape, label one clear plastic cup "Soil Cultivated," and label the other plastic cup "Hydroponically Cultivated."
2. Fill the cup labeled "Soil Cultivated" halfway with moist potting soil. Place six wheat seeds on the surface of the soil; use the distance between the holes in the foam floater as a guide to determine the spacing of the wheat seeds. (Do not place the floater on the soil.)
3. Press the seeds into the soil until they are approximately 0.5 cm below the surface. Cover the seeds with soil, and press down firmly.
4. Water the seeds with 10 mL of distilled water.
5. Add 50 mL of complete nutrient solution to the cup labeled "Hydroponically Cultivated," and place the plastic-foam floater on the surface of the solution, as shown in the figure below.
6. Place the cheesecloth on top of the floater, as illustrated in the figure. Press lightly at the location of the holes in the floater to moisten the cheesecloth.



7. Place the remaining six wheat seeds on top of the cheesecloth in the cup labeled "Hydroponically Cultivated." Position the seeds so that each one lies in an indentation formed by the cheesecloth in a hole in the floater. Press each seed lightly into the hole until the seed coat is moistened.
8. Place both cups in a warm, dry location. Water the soil-cultivated seeds as needed, monitoring the amount of water added. Aerate the roots of the hydroponic plants every day by using a clean plastic dropper to blow air into the nutrient solution.
9. In your lab report, prepare data tables similar to Table A and Table B. Write your observations of the seeds in your data tables.
10. Clean up your lab materials and wash your hands before leaving the lab.

TABLE A OBSERVATIONS OF SOIL-GROWN PLANTS

Day	Appearance of seedlings	Average height (mm)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

TABLE B OBSERVATIONS OF HYDROPONICALLY GROWN SEEDS

Day	Appearance of seedlings	Average height (mm)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

PART B Days 2–14

11. Compare the contents of each cup every day for two weeks, and record the appearance of the wheat seedlings in your data tables. If you are unable to observe your seedlings over the weekend, be sure to note in your data table that no observations were made on those days.
12. Each time that you observe the seedlings after they have begun to grow, measure their height and record the average height of the seedlings in each cup in your data tables. To find the average height for one cup, add the heights of each seedling in the cup together and divide by the number of seedlings (6).
13. After the seeds in the cup containing nutrient solution have germinated and formed roots, allow an air pocket to form between the floater and the surface of the nutrient solution. A portion of the roots should still be submerged in the nutrient solution. The air pocket allows the roots of the seeds to absorb the oxygen necessary for metabolic processes while continuing to absorb nutrients from the nutrient solution. Continue to observe and record the progress of the seedlings in each cup on a daily basis.
14. Clean up your lab materials and wash your hands before leaving the lab.

Analysis and Conclusions

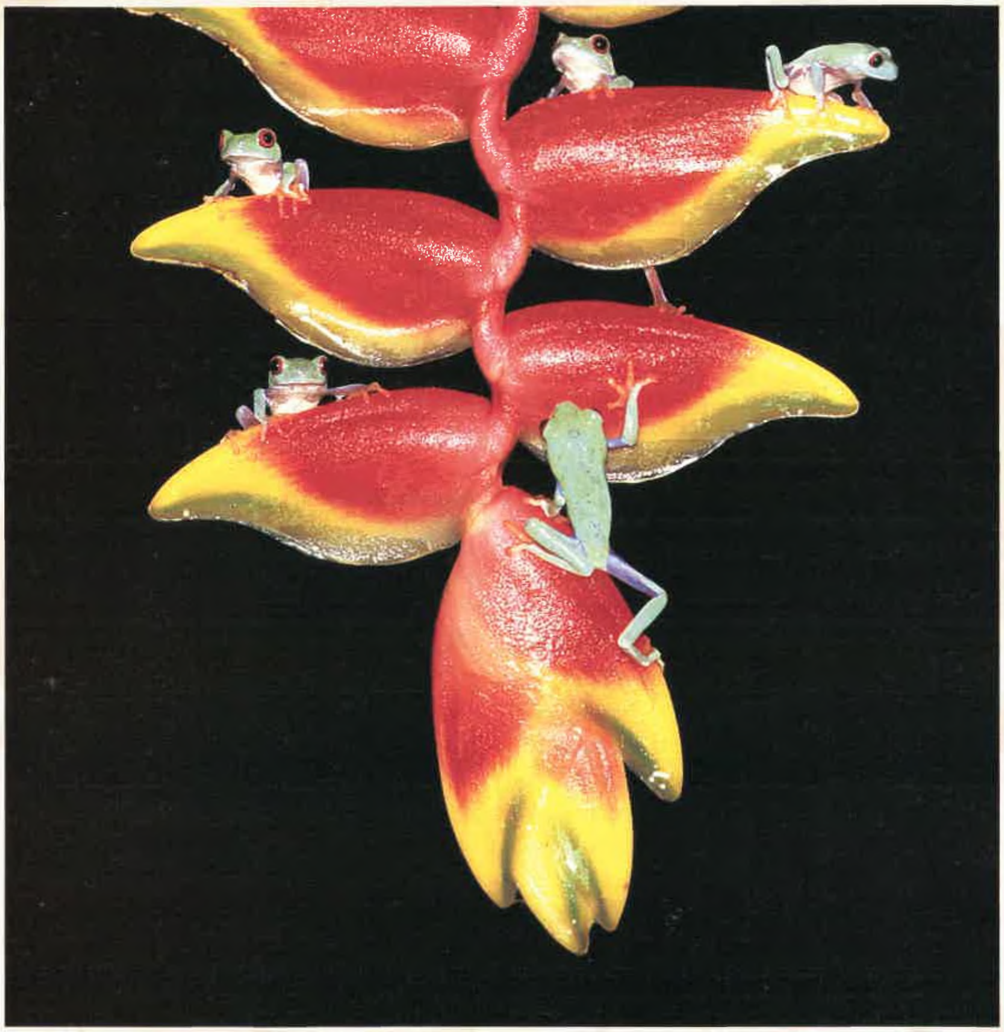
1. Based on the data you recorded, which seeds germinated more quickly? Which seeds attained the greatest height?
2. Compare your results with those of your classmates. Were the results the same for each group of students?
3. You planted six seeds in each cup. Why do you think the lab had you do this instead of having you plant a single seed in each cup? Why is the use of more than one sample important?
4. How could hydroponic growing techniques be useful to countries that have either a growing season that is too short to grow a variety of crops or soil that does not support most agricultural crops?

Further Inquiry

The nutrient solution you used in this investigation should have provided all of the inorganic nutrients that the wheat seeds needed for proper growth. How could you determine exactly which inorganic nutrients a plant requires by using hydroponic cultivation?

CHAPTER 30

PLANT EVOLUTION AND CLASSIFICATION



Red-eyed tree frogs are climbing on this colorful Heliconia *flower. These organisms are from the tropical rain forest of Belize, a country in Central America. Worldwide, tropical rain forests are home to almost half the world's species of plants and animals.*

FOCUS CONCEPT: *Evolution*

As you read, look for the characteristics that reveal how plants have adapted to conditions on land.

OVERVIEW OF PLANTS

SECTION

30-1

OBJECTIVES

▲ Compare and contrast green algae and plants.

● Name three adaptations plants have made to life on land.

■ Compare vascular plants with nonvascular plants.

◆ Define and describe alternation of generations.

Plants dominate the land and many bodies of water. Plants exhibit tremendous diversity. Some plants are less than 1 mm (0.04 in.) in width, and some plants grow to more than 100 m (328 ft) in height. The 12 phyla, or divisions, of kingdom Plantae include more than 270,000 species. Some plants complete their life cycle in a few weeks, while others may live nearly 5,000 years.

ADAPTING TO LAND

Although life had flourished in the oceans for more than 3 billion years, no organisms lived on land until about 430 million years ago, when a layer of ozone formed. The ozone protected organisms from the sun's ultraviolet radiation. Eventually, small club-shaped plants began to grow in the mud at the water's edge.

Preventing Water Loss

The move from water to land offered some organisms distinct advantages, including more exposure to sunlight for photosynthesis, increased carbon dioxide levels, and a greater supply of inorganic nutrients. However, the land environment also presented challenges. Plants on land are susceptible to drying out through evaporation.

One early adaptation to life on land was the **cuticle** (KYOOT-ih-kuhl), a waxy protective covering on plant surfaces that prevents water loss. Although the cuticle protects a plant by keeping water in the plant, it also keeps out carbon dioxide. Plants that had small openings in their surfaces, called stomata, were able to survive. Stomata allow the exchange of carbon dioxide and oxygen.

Reproducing by Spores and Seeds

Successful land plants also developed structures, such as spores and seeds, that helped protect reproductive cells from drying out. A **spore** is a haploid reproductive cell surrounded by a hard outer wall. Spores allowed the widespread dispersal of plant species. Eventually, most plants developed seeds. A **seed** is an embryo surrounded by a protective coat. Seeds also contain **endosperm,** a tissue that provides nourishment for the developing plant. Figure 30-1 shows the unusual seed adaptation of the sugar maple tree; the winged seeds get caught in the wind and twirl to the ground. Seeds are more effective at dispersal than spores are.

FIGURE 30-1

The leaves of a sugar maple tree are covered with a waxy cuticle that prevents water loss. The seeds are found inside a winged fruit. The wings help the seeds disperse away from the parent tree, usually twirling down to the ground.

Word Roots and Origins

vascular

from the Latin *vasculum*, meaning "small vessel"

Transporting Materials Throughout the Plant

Certain species of plants evolved **vascular** (VAS-kyu-luhr) **tissue,** a type of tissue that transports water and dissolved substances from one part of the plant to another. Two types of specialized tissue make up vascular tissue. **Xylem** (ZIE-luhm) carries water and inorganic nutrients in one direction, from the roots to the stems and leaves. **Phloem** (FLOH-uhm) carries organic compounds, such as carbohydrates, and some inorganic nutrients in any direction, depending on the plant's needs. Vascular tissue also helps support the plant, which is an important function for land plants. Aquatic plants are mainly supported by the water around them.

Some plants developed woody tissue and grew to great heights, giving them an advantage in gathering light. **Woody tissue** is formed from several layers of xylem, usually concentrated in the center of the stem. Woody stems are usually brown and rigid. Nonwoody plants are usually called **herbaceous** because they have soft, usually green stems. Because the vascular tissue is not surrounded by rigid sclerenchyma cells, the stems of herbaceous plants are flexible.

CLASSIFYING PLANTS

Study the classification of plants in Table 30-1. The 12 phyla of plants, formerly referred to as *divisions,* can be divided into two groups based on the presence of vascular tissue. The three phyla of

TABLE 30-1 ***The 12 Phyla of the Plant Kingdom***

Type of plant	Phylum	Common name	Approximate number of species
Nonvascular	Bryophyta	mosses	10,000
	Hepatophyta	liverworts	6,500
	Anthocerophyta	hornworts	100
Vascular, seedless	Psilotophyta	whisk ferns	10–13
	Lycophyta	club mosses	1,000
	Sphenophyta	horsetails	15
	Pterophyta	ferns	12,000
Vascular, seed			
Gymnosperms	Cycadophyta	cycads	100
	Ginkgophyta	ginkgoes	1
	Coniferophyta	conifers	550
	Gnetophyta	gnetophytes	70
Angiosperms	Anthophyta	flowering plants	240,000
	class Monocotyledones	monocots	70,000
	class Dicotyledones	dicots	170,000

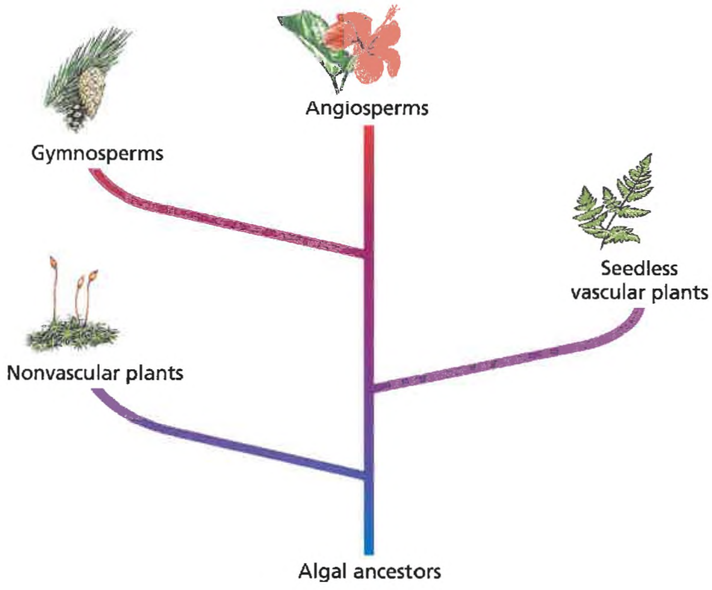


FIGURE 30-2

This phylogenetic tree shows how plants evolved from green algae. The earliest plants were nonvascular and radiated into more-complex forms of vascular plants.

nonvascular plants have neither true vascular tissue nor true roots, stems, or leaves. Most members of the nine phyla of **vascular plants** have vascular tissue and true roots, stems, and leaves.

Notice in Table 30-1 that vascular plants can be further divided into two groups, seedless plants and seed plants. Seedless plants include the phylum of ferns and three phyla made up of plants closely associated with ferns. **Seed plants**—plants that produce seeds for reproduction—include four phyla of gymnosperms and one phylum of angiosperms. **Gymnosperms** (JIM-nuh-SPUHRMZ), which include pine trees, produce seeds that are not enclosed in fruits. **Angiosperms** (AN-jee-uh-SPUHRMZ), also known as flowering plants, produce seeds within a protective fruit. Examples are apple and orange trees.

The Fossil Record of Plants

Figure 30-2 shows the origins of major plant groups. Much of what we know about plant phylogeny has come from studying the fossil record. The fossil record is incomplete, but scientists think that plants evolved from an ancestor of green alga. The strongest evidence supporting this hypothesis lies in the similarities between modern green algae and plants. Both have the same photosynthetic pigments—chlorophylls *a* and *b*, both store energy as starch, and both have cell walls made of cellulose.

Alternating Life Cycles

All plants have a life cycle that involves two phases. The first phase consists of a diploid ($2n$) **sporophyte** (SPOR-uh-FIET) plant that produces spores. The second phase consists of a haploid ($1n$) **gametophyte** (guh-MEET-uh-FIET) plant that produces eggs and sperm. The two plant phases are named for the type of reproductive cells they produce. This type of life cycle, which alternates between the gametophyte phase and sporophyte phase, is called **alternation of generations.**

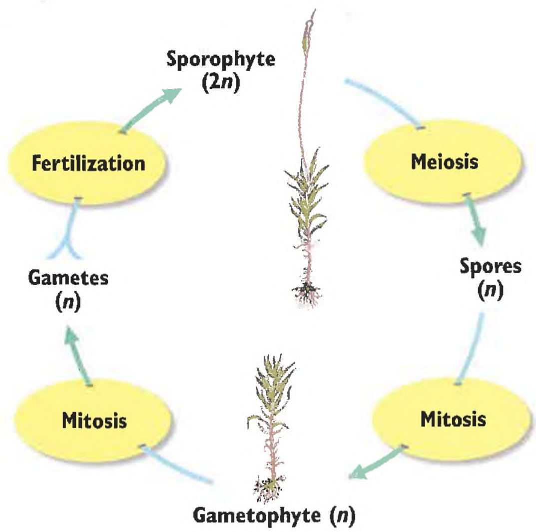
Eco Connection

Reforestation Efforts

The process of replacing trees that have died or been cut down is called reforestation. Natural reforestation occurs when seeds grow into new seedlings. Throughout the world, many governments and private landowners do not replace trees after land has been cleared to produce timber, build roads, and construct buildings.

Deforestation is occurring at a rate of several hundred thousand square miles per year. Although this rate seems overwhelming and daunting, people can help reforestation efforts by planting seeds or seedlings in their own community. Trees can be planted in yards, in pots on patios or balconies, and along streets. It's best to choose trees that are well adapted to your area.

Many neighborhoods and local organizations sponsor tree-planting programs. Besides providing beautification, these programs can help educate people about the importance of trees. For more information, call your local or state parks department, the U.S. Forest Service, a county extension agent, or a nearby college forestry department.



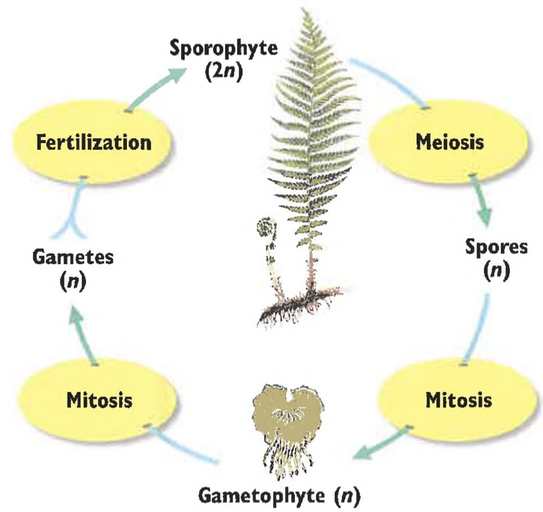


FIGURE 30-3

In the life cycle of a plant, there is an alternation of the haploid gametophyte generation and the diploid sporophyte generation. (a) The life cycle of a nonvascular plant, such as a moss, is characterized by a gametophyte that is larger than the sporophyte. (b) The life cycle of a vascular plant, such as a fern, is characterized by a large sporophyte and a very small gametophyte.

Figure 30-3 shows the life cycles of a nonvascular plant and a vascular plant. In alternation of generations, the gametophyte ($1n$) produces structures that form gametes—eggs and sperm—by mitosis. Once an egg is fertilized by a sperm and produces a zygote, the plant begins the diploid phase of its life cycle. The zygote divides by mitosis to form a sporophyte plant. The sporophyte ($2n$) produces structures that undergo meiosis to form haploid spores. These spores are released by most seedless plants but are retained by seed plants. The life cycle begins again when spores divide by mitosis to form new gametophytes.

In nonvascular plants, the gametophyte is the dominant phase. In contrast, the sporophyte is the dominant phase of vascular plants. Oak trees are large sporophytes that dominate some parts of our landscape. In seedless vascular plants, the gametophyte is usually a separate small organism quite different from the sporophyte. In seed plants, the gametophyte is a very small parasite of the sporophyte. For example, gametophytes of flowering plants are microscopic parts of their flowers.

SECTION 30-1 REVIEW

1. What are the similarities between today's plants and green algae?
2. How does the cuticle represent an adaptive advantage for early land plants?
3. How has the evolution of spores contributed to the chances of success for land plants?
4. What is the main difference between vascular plants and nonvascular plants?
5. Describe alternation of generations, and explain how it differs in vascular plants and nonvascular plants.
6. **CRITICAL THINKING** Why are vascular plants the most successful land plants?

SECTION

30-2

OBJECTIVES

▲ Name three types of plants that make up the bryophytes.

● List distinguishing characteristics shared by nonvascular plants.

■ Compare sporophytes in bryophytes with gametophytes in bryophytes.

◆ Describe the environmental importance of bryophytes.

▲ Name the main ways people use *Sphagnum* moss.

NONVASCULAR PLANTS

The three phyla of nonvascular plants are collectively called ***bryophytes.*** *Botanists have identified 16,600 species of bryophytes. They lack vascular tissue and do not form true roots, stems, and leaves. These plants usually grow on land near streams and rivers.*

CLASSIFYING BRYOPHYTES

Bryophytes are the most primitive type of plants. Overall, their characteristics are more closely related to plants than to algae. Bryophytes are mostly terrestrial and have an alternation-of-generations life cycle. Bryophytes are seedless, and they produce spores. Because they do not have vascular tissue, they are very small, usually 1–2 cm (less than 1 in.) in height.

Bryophytes need water to reproduce sexually because the sperm must swim through water to an egg. In dry areas, bryophytes can reproduce sexually only when adequate moisture is available. The asexual production of haploid spores does not require water.

Phylum Bryophyta

Almost every land environment is home to at least one species of moss in the phylum Bryophyta (brie-AHF-uh-tuh). The thick green carpets of moss you see on shady forest floors actually consist of thousands of tiny moss gametophytes. Each gametophyte is attached to the soil by rootlike structures called **rhizoids** (RIE-zoidz). Unlike roots, rhizoids do not have vascular tissue. But rhizoids do function like roots by anchoring the moss and by absorbing water and inorganic nutrients.

Moss gametophytes are usually less than 3 cm (1 in.) tall, as shown in Figure 30-4. The moss sporophyte is attached to and dependent on the larger gametophyte. Gametophytes may be male, female, or contain both male and female reproductive parts.

Mosses are called *pioneer plants* because they are often the first species to inhabit a barren area. This is an important environmental function because mosses gradually accumulate inorganic and organic matter on the surface of rocks, creating a layer of soil in which other plants can grow. In areas devastated by fire, volcanic action, or human activity, pioneering mosses can help trigger the development of new biological communities. They also help prevent soil erosion by covering the soil surface and absorbing water.

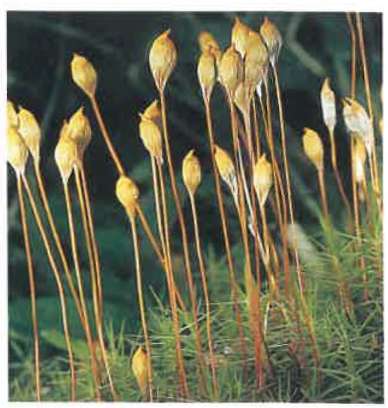
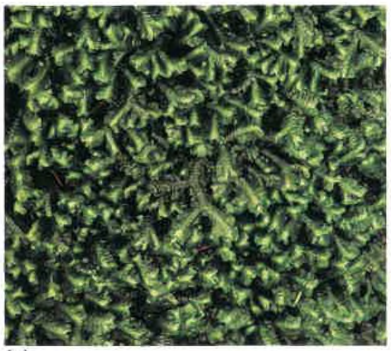


FIGURE 30-4

The leafy carpet of moss gametophytes is topped by sporophytes. Mature sporophytes release their spores, which can then grow into a new generation of gametophytes.

FIGURE 30-5

(a) A leafy liverwort has two rows of leaves growing on a stem. (b) A thalloid liverwort has very flat, thin leaves.


(a)


(b)

Sphagnum (SFAG-nuhm), or peat moss, is a genus of moss that is a major component of peat bogs in northern parts of the world. Peat moss consists of partially decomposed plant matter. In many northern European and Asian countries, peat moss is mined and dried for use as fuel. Sphagnum produces an acid that slows down decomposition in the swamplike bogs. Sphagnum is widely used to enhance the water-retaining ability of potting and gardening soils. Sphagnum is also used by florists to pack bulbs and flowers for shipping.

FIGURE 30-6

Hornworts grow in warm, moist, shaded habitats. Look for hornworts growing along roads or near streams.

Phyla Hepatophyta and Anthocerophyta

Phylum Hepatophyta (HEP-uh-TAHF-uh-tuh) includes the liverworts, unusual-looking plants that grow in moist, shady areas. Most liverworts have thin, transparent leaflike structures arranged along a stemlike axis, as shown in Figure 30-5a. Some liverworts have a **thalloid** (THAL-oid) form—that is, a flat body with distinguishable upper and lower surfaces, as shown in Figure 30-5b. All liverworts lie close to the ground. This is an adaptation that allows them to absorb water readily. In some species, the gametophyte is topped by an umbrella-shaped structure that holds the reproductive cells.

Phylum Anthocerophyta (AN-thoh-suh-RAHF-uh-tuh) includes the hornworts, which resemble liverworts, as shown in Figure 30-6. They grow in moist, shaded areas. They share an unusual characteristic with algae: each cell usually has a single large chloroplast rather than numerous small ones.

SECTION 30-2 REVIEW

1. What advantage do bryophyte gametophytes that are either male or female have over bryophyte gametophytes that have both male and female structures?
2. List two characteristics shared by all bryophytes.
3. What role do mosses play in the early development of biological communities?
4. What are the main uses of sphagnum moss?
5. Why are bryophytes classified with plants instead of with algae?
6. CRITICAL THINKING Why can't sphagnum moss grow as large as maple or oak trees?

Literature & Life

Earth's Green Mantle

This excerpt is from Rachel Carson's book *Silent Spring.*

The earth's vegetation is part of a web of life in which there are intimate and essential relations between plants and the earth, between plants and other plants, between plants and animals. Sometimes we have no choice but to disturb these relationships, but we should do so thoughtfully, with full awareness that what we do may have consequences remote in time and place. But no such humility marks the booming "weed killer" business of the present day, in which soaring sales and expanding uses mark the production of plant-killing chemicals.

One of the most tragic examples of our unthinking bludgeoning of the landscape is to be seen in the sagebrush lands of the West, where a vast campaign is on to destroy the sage and to substitute grasslands. If ever an enterprise needed to be illuminated with a sense of the history and meaning of the landscape, it is this. For here the natural landscape is eloquent of the interplay of forces that have created it. It is spread before us like the pages of an open book in which we can read why the land is what it is, and why we should preserve its integrity. But the pages lie unread.

The land of the sage is the land of the high western plains and the lower slopes of the mountains that rise above them, a land born of the great uplift of the Rocky Mountain system many millions of years ago. It is a place of harsh extremes of climate: of long winters when blizzards drive down from the mountains and snow lies deep on the plains, of summers whose heat is relieved by only scanty rains, with drought biting deep into the soil, and drying winds stealing moisture from leaf and stem.

As the landscape evolved, there must have been a long period of trial and error in which plants attempted the colonization of this high and windswept land. One after another must have failed. At last one group of plants evolved which combined all qualities needed to survive. The sage—low-growing and shrubby—could hold its place on the mountain slopes and on the plains, and within its small gray leaves it could hold moisture enough to defy the thieving winds. It was no accident, but rather the result of long ages of experimentation by nature, that the great plains of the West became the land of the sage. . . .

So in a land which nature found suited to grass growing mixed with and under the shelter of sage, it is now proposed to eliminate the sage and create unbroken grassland. Few seem to have asked whether grasslands are a stable and desirable goal in this region. Certainly nature's own answer was otherwise. The annual precipitation in this land where the rains seldom fall is not enough to support good sod-forming grass; it favors rather the perennial bunchgrass that grows in the shelter of the sage.

Reading for Meaning

In this passage, Carson asserts that altering the natural plant life of a region may be a change for the worse. What facts does she use to support her argument?

Read Further

Carson's book *Silent Spring* describes how human activities, including the use of pesticides, endanger our environment. What are some questions we should ask before we disturb the relationships between ourselves and the plants and animals with whom we share Earth?

SECTION

30-3

OBJECTIVES

▲ List two main characteristics of vascular plants.

● Distinguish between seedless plants and seed plants.

■ Distinguish between gymnosperms and angiosperms.

◆ Summarize the adaptive advantages of seeds.

▲ Distinguish between monocots and dicots.

VASCULAR PLANTS

Vascular plants contain specialized conducting tissues (xylem and phloem) that transport water and dissolved substances from one part of the plant to another. Vascular plants can grow larger and live in more environments than nonvascular plants. The strong stems of vascular plants allow the plants to grow tall, enabling them to rise above other plants and receive more sunlight than shorter plants do.

SEEDLESS VASCULAR PLANTS

Seedless vascular plants dominated the Earth until about 200 million years ago. Characteristics of the four phyla of seedless vascular plants are summarized in Table 30-2. The first three phyla are called fern allies, while members of the last phylum are ferns. Spores are the mobile sexual reproductive parts of all seedless plants.

Phylum Psilotophyta

The phylum Psilotophyta (sie-lah-TAHF-uh-tuh) is represented by whisk ferns, illustrated in Figure 30-7. Despite their name, whisk ferns are not ferns at all. They have no roots or leaves and produce spores on the ends of short branches. These features suggest that whisk ferns resemble early land plants. Whisk ferns are epiphytes, which means they grow on other plants, but they are not considered parasites.

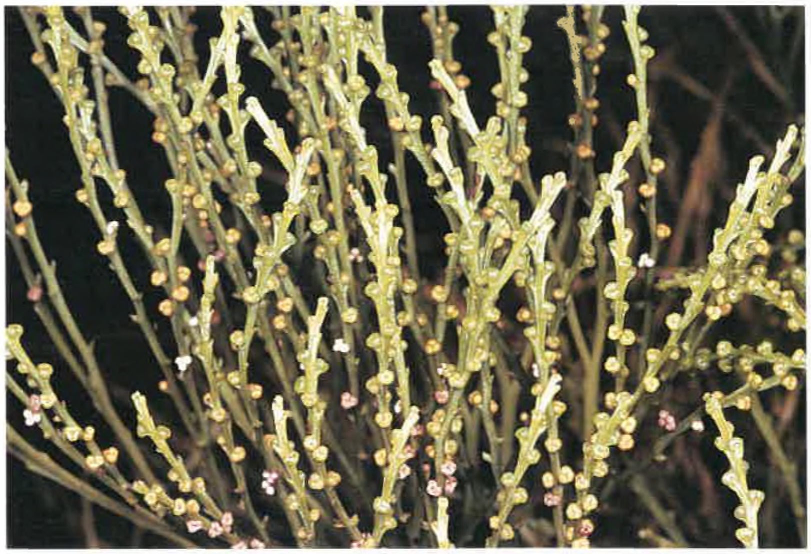


FIGURE 30-7
The whisk fern has branched stem tips. These rare plants are found in tropical and subtropical regions.

TABLE 30-2 *Seedless Vascular Plants*

Example plant	Phylum	Features	Size	Location
Whisk ferns	Psilotophyta	• produce reproductive structures on the ends of forked branches • no roots or leaves	• about 30 cm (1 ft) tall	• tropical and temperate regions, as far north as South Carolina
Club mosses	Lycophyta	• evergreens that produce spores in cones • have roots	• about 5 cm (2 in.) tall	• tropical and temperate regions, on forest floors, in swamps, or as epiphytes
Horsetails	Sphenophyta	• jointed stems • outer cells of stems contain silica, the major component of sand	• about 60–90 cm (2–3 ft) tall	• tropical and temperate regions, usually in moist soil
Ferns	Pterophyta	• leaves • most have an underground stem • most produce spores on the underside of their leaves	• range from less than 1 cm (0.4 in.) to 25 m (82 ft) tall	• all climates, on forest floors, as epiphytes, some in full sun, some aquatic

Phylum Lycophyta

The phylum Lycophyta (lie-KAHF-uh-tuh) contains the club mosses, shown in Figure 30-8. Because they look like miniature pine trees, club mosses are also called ground pines. They produce a **strobilus** (STROH-bi-luhs), or cone, which is a cluster of sporangia-bearing modified leaves. Club mosses were once widely collected as Christmas decorations.

Another member of phylum Lycophyta is a spike moss called *Selaginella lepidophylla,* native to the American Southwest. *Selaginella* turns brown and curls up in a ball during drought. However, when moistened, the plant uncurls and turns green again after a few hours.

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FIGURE 30-8

The club moss, sometimes known as a ground pine, is a member of the phylum Lycophyta. The tips of the aerial stems contain conelike structures.

FIGURE 30-9

The horsetail, *Equisetum,* has hollow, jointed stems that contain silica. About 300 million years ago, *Equisetum* was a large tree, growing with large club moss trees and ferns in steaming swamps. Over millions of years, the trees and other plant life in the swamps died, became buried, and turned into coal.

Phylum Sphenophyta

The phylum Sphenophyta (sfee-NAHF-uh-tuh) includes horsetails, or *Equisetum.* Horsetails have jointed photosynthetic stems that contain silica, with scalelike leaves at each joint. American pioneers used horsetails to scrub pots and pans; hence, they are frequently called scouring rushes. As you can see in Figure 30-9, the shoots are often highly branched and remind some people of a horsetail.

Phylum Pterophyta

Ferns probably originated over 350 million years ago. Ferns belong to the phylum Pterophyta (tuhr-AHF-uh-tuh) and represent a diverse group. Some are floating plants that are less than 1 cm (0.4 in.) across. Ferns also grow above the Arctic Circle and in desert regions. The largest living ferns are tree ferns, shown in Figure 30-10. These ferns can reach 25 m (82 ft) in height, and some have leaves 5 m (16 ft) long.

Most ferns have an underground stem called a **rhizome** (RIE-zohm). The fibrous rhizomes of some ferns are commonly used as a growing medium for orchids. The tightly coiled new leaves of ferns are called **fiddleheads.** The young fiddleheads of some species are eaten by humans as a vegetable. Fiddleheads uncoil and develop into mature leaves called **fronds.**

FIGURE 30-10

Tree ferns, such as the *Dicksonia antarctica* shown here, look like palm trees but are actually the largest living ferns. Sometimes epiphytic ferns grow on the trunk of tree ferns. Orchids are often cultivated on sections of trunk cut from tree ferns. Tree ferns live in the tropics and subtropics.

VASCULAR SEED PLANTS

The mobile sexual reproductive part of seed plants is the multicellular seed. Seeds are an evolutionary success story. Plants with seeds have a greater chance of reproductive success than seedless plants. Inside the tough, protective outer coat of a seed is an embryo and a nutrient supply. When conditions are too hot or too cold, or too wet or too dry, the seed remains inactive. When conditions favor growth, the seed sprouts, or **germinates**—that is, the embryo begins to grow into a young plant, called a **seedling.**

There are two main groups of seed-bearing vascular plants, gymnosperms and angiosperms. The four phyla of gymnosperms produce naked seeds, which means the seeds are not enclosed and protected in fruits. Most gymnosperms are evergreen and bear their seeds in cones. A **cone** is a reproductive structure composed of hard scales. The seeds of a conifer lie open on the surface of the scales. The one phylum of angiosperms produces seeds that are enclosed and protected in fruits. Angiosperms are commonly referred to as flowering plants. Cones serve some of the same functions for gymnosperms that flowers serve for angiosperms.

Phylum Cycadophyta

Cycads (SIE-KADZ) are gymnosperms of the phylum Cycadophyta. Although cycads flourished during the age of the dinosaurs, only about 100 species survive today. Most are native to the tropics and

FIGURE 30-11

The cycad is a gymnosperm that looks like a palm or fern. Cycads can sometimes grow to 18 m (60 ft) in height. Some cycads live for almost a thousand years.

grow slowly. Many are endangered because of habitat loss, overcollection, and their slow growth. Most cycads have fernlike, leathery leaves at the top of a short, thick trunk. Cycad plants are either male or female, and they bear large cones like those shown in Figure 30-11. Cycads are mostly used as ornamental plants.

Phylum Ginkgophyta

Like cycads, ginkgoes (GINK-ohz) flourished during the time of the dinosaurs. The only species existing today is *Ginkgo biloba,* which is native to China. It is called a living fossil because it closely resembles fossil ginkgoes that are 125 million years old. The ginkgo tree has fan-shaped leaves that fall from the tree at the end of each growing season—an unusual characteristic for a gymnosperm. Trees that lose their leaves at the end of the growing season, like the ginkgo, are called **deciduous.** Most gymnosperms are evergreens and retain their leaves year-round.

Ginkgoes are tolerant of air pollution, making them good plants for urban settings. Ginkgo seeds are considered a delicacy in China and Japan. Notice the plum-shaped, fleshy seeds on the ginkgo shown in Figure 30-12. They are often mistakenly called berries or fruits.

Phylum Coniferophyta

The conifers (KOHN-uh-fuhrz), which are gymnosperms of the phylum Coniferophyta, include pine, cedar, redwood, fir, spruce, juniper, cypress, and bald cypress trees. They are very important sources of wood, paper, turpentine, resin, ornamental plants, and Christmas trees. Gin is flavored with juniper seeds. Amber is yellow or brownish yellow fossilized resin that once flowed from ancient conifers. Prehistoric insects are often preserved in amber, a fact that figured prominently in the plot of the novel *Jurassic Park,* by Michael Crichton.

Quick Lab

Examining Ferns

Materials disposable gloves, lab apron, potted fern, hand lens, water

Procedure

1. Put on your disposable gloves and lab apron.
2. Choose a frond of the fern, and examine its underside for the structures that contain spores.
3. Wash the soil from the underground structures. Examine the fern's horizontal stems and roots.

Analysis How do ferns differ from nonvascular plants? What enables ferns to surpass nonvascular plants in height and size? From what part of the fern do the fronds grow?

FIGURE 30-12

The ginkgo, *Ginkgo biloba,* has unusual fan-shaped leaves and large seeds. This gymnosperm tree can reach heights of 24 m (80 ft).

(a) Fir needles and cones

(b) Pine needles and cones

(c) Yew needles and seeds

FIGURE 30-13

The needles and cones of conifers come in many shapes and sizes. (a) The fir tree displays its female cones. Its needle-shaped leaves grow evenly all around the branch. (b) The pine tree shows its small male and larger female cones. Some pines reach heights of 60 m (200 ft). (c) The seed of the yew tree is surrounded by a red covering that looks like a berry. Its leaves are flat, pointed needles that are dark green on top and pale green underneath.

Conifers are woody plants, and most have needle or scalelike leaves, as shown in Figure 30-13. A conifer usually bears both male and female cones. Small male cones typically grow in clusters. Male cones release clouds of dustlike pollen, and then the cones fall from the branches. The pollen falls or blows into the larger female cones, where the egg cells are attached to the scales of the cone. After pollination, the female cone closes up tightly. This protects the developing seeds, which mature after one or two years. The mature seeds are released when the female cone opens.

Redwoods and giant sequoia trees provide a majestic forest setting along the West Coast of the United States. These conifers are the Earth's tallest and most massive living organisms. The tallest living coastal redwood, *Sequoia sempervirens,* is about 110 m (360 ft) tall, the height of a 30-story building. The most massive tree is a giant sequoia, *Sequoiadendron giganteum,* estimated to weigh 5,600 megagrams (6,200 tons).

Phylum Gnetophyta

An odd group of cone-bearing gymnosperms called gnetophytes (NEE-tuh-FIETS) have vascular systems that more closely resemble those of angiosperms. As Figure 30-14 shows, *Ephedra* (ih-FED-ruh) is a genus of desert shrubs with jointed stems that look like horsetails. It is the source of the drug **ephedrine,** which is used as a decongestant.

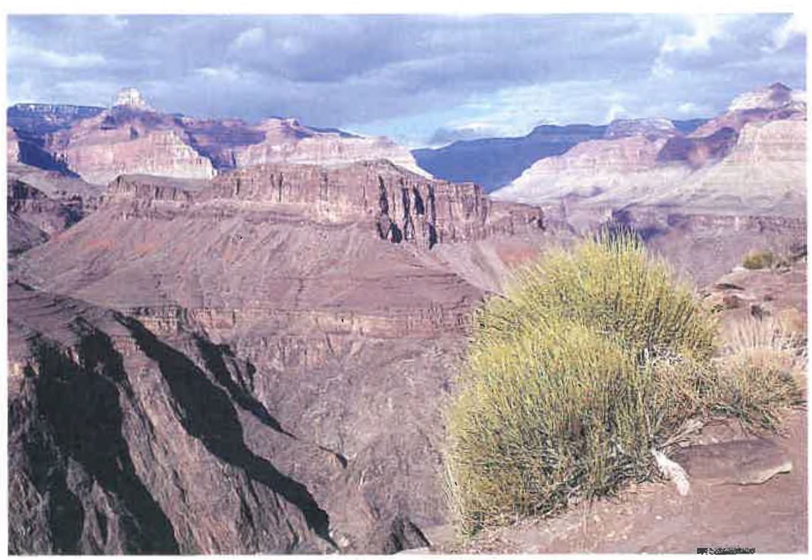

FIGURE 30-14

Ephedra viridis, called Mormon tea, grows on the rim of the Grand Canyon. This highly branched shrub has small, scale-like leaves. It is the source of the medicine ephedrine and is brewed to make a tea.

Figure 30-15 shows the unique *Welwitschia mirabilis* plant. The plant's stem is only a few centimeters tall but can grow to 1 m (3.3 ft) in diameter. Two leaves grow from the stem. The leaves elongate from their base and then become tattered and split lengthwise by the wind. A mature leaf may be nearly 1 m (3.3 ft) wide and 3 m (10 ft) long. *Welwitschia* grows in the Namib Desert of southwestern Africa. The Namib Desert lies near the Atlantic Ocean, so a thick night fog often rolls in over the desert. *Welwitschia* apparently gets most of its water from the dew that condenses from the fog.

FIGURE 30-15

Welwitschia mirabilis has a short, wide stem and twisting leaves. The female plants of this unusual gymnosperm bear large seed cones that are bright scarlet in color.

Phylum Anthophyta

The largest phylum of plants, Anthophyta (an-THAHF-uh-tuh), includes over 240,000 species of flowering plants. Angiosperms, or the flowering plants, are seed plants characterized by the presence of a flower and fruit. You may recall from Chapter 29 that botanists define a fruit as a ripened ovary that surrounds the seeds of angiosperms. The **ovary** is the female part of the flower that encloses the egg(s).

Angiosperms grow in many forms and occupy diverse habitats. Some are herbaceous plants with showy flowers, such as violets and impatiens. Others, such as rose bushes, are shrubs. Some angiosperms are vines, like grape and ivy plants. Oak, aspen, and birch trees are all flowering plants that have woody stems, although you may never have noticed their small flowers. Grasses are also angiosperms, but you must look closely to see their small, highly modified flowers. The world's largest flower, which can grow to 1 m (3.3 ft) in diameter, is produced by *Rafflesia,* shown in Figure 30-16.

FIGURE 30-16

The stinking-corpse lily, *Rafflesia arnoldii,* has the world's largest flowers but no leaves or stems. The flowers can be male or female, and they are pollinated by flies. The plant lacks chlorophyll and is parasitic on a woody vine native to Southeast Asia.

The Evolution of Angiosperms

Angiosperms first appeared in the fossil record about 135 million years ago. By about 90 million years ago, angiosperms had probably begun to outnumber gymnosperms. What led to the success of this new kind of plant? Several factors were probably involved. In many angiosperms, seeds germinate and produce mature plants, which in turn produce new seeds, all in one growing season. This is a tremendous advantage over gymnosperms, which often take 10 or more years to reach maturity and produce seeds. Also, the fruits of flowering plants protect seeds and aid in their dispersal. Angiosperms also have a more efficient vascular system and are more likely to be associated with mycorrhizae than gymnosperms are. Angiosperms also may gain an advantage by using animal pollination rather than the less-efficient wind pollination method used by gymnosperms. However, wind pollination is used by many successful angiosperms, such as the grasses and many deciduous trees. Finally, angiosperms are more diverse than gymnospems, so they occupy more niches, such as in aquatic, epiphytic, and parasitic environments.

TABLE 30-3 Comparing Monocots and Dicots

Plant type	Embryos	Leaves	Stems	Flower parts	Examples
Monocots	One cotyledon 	Parallel venation 	Scattered vascular bundles 	Usually occur in threes 	lilies, irises, orchids, palms, tulips, bananas, pineapples, onions, bamboo, coconut, wheat, corn, rice, oats, barley, sugarcane
Dicots	Two cotyledons 	Net venation 	Radially arranged vascular bundles 	Usually occur in fours or fives 	beans, lettuce, oaks, maples, elms, roses, carnations, cactuses, most broad-leaved forest trees

Monocots and Dicots

The flowering plants classified under phylum Anthophyta are divided into two classes—Monocotyledones (monocots) and Dicotyledones (dicots). The primary feature that distinguishes these two groups is the number of **cotyledons** (KAHT-e-LEE-duhnz), or seed leaves, in a plant embryo. **Monocots** (MAHN-uh-KAHTS) usually have one cotyledon in their embryo, while **dicots** (DIE-KAHTS) typically have two. By comparison, gymnosperms usually have two or more cotyledons.

Characteristics used to identify monocots and dicots are shown in Table 30-3. Most mature monocot leaves have several main **veins,** or bundles of vascular tissue, running roughly parallel to each other. This is called **parallel venation.** Most dicots have one or more non-parallel main veins that branch repeatedly, forming an interconnected network. This is called **net venation.** When viewed in cross section under a microscope, most monocot stems have scattered vascular bundles, while the vascular bundles of dicot stems are arranged in a circle. It is best to use more than one characteristic to determine whether a species is a monocot or a dicot.

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SECTION 30-3 REVIEW

1. What are the two main tissues of all vascular plants?
2. What are the main differences between gymnosperms and angiosperms?
3. How do male cones differ from female cones?
4. What are three characteristics that distinguish monocots from dicots?
5. What reproductive advantages do seed plants have over seedless vascular plants and nonvascular plants?
6. CRITICAL THINKING How do humans use seedless vascular plants and seed plants?

CHAPTER 30 REVIEW

SUMMARY/VOCABULARY

30-1

- All plants are multicellular, most live on land, and almost all are photosynthetic.
- There are 12 phyla and over 270,000 species of living plants. Three phyla are nonvascular plants, and the rest are vascular plants.
- Plants originated about 430 million years ago, when a green algae adapted to land.
- The evolution of spores and seeds helped plants colonize land.
- The main function of xylem is to carry water and inorganic nutrients. Phloem carries organic compounds and some inorganic nutrients.
- All plants have a life cycle known as alternation of generations. In alternation of generations, a haploid gametophyte produces gametes, which unite and give rise to a diploid sporophyte. Through meiosis, the sporophyte produces haploid spores, which develop into gametophytes.
- The gametophyte is the dominant phase in nonvascular plants, while the sporophyte is dominant in vascular plants.

Vocabulary

alternation of generations (581)
angiosperm (581)
cuticle (579)
endosperm (579)
gametophyte (581)
gymnosperm (581)
herbaceous (580)
nonvascular plant (581)
phloem (580)
seed (579)
seed plant (581)
spore (579)
sporophyte (581)
vascular plant (581)
vascular tissue (580)
woody tissue (580)
xylem (580)

30-2

- The three phyla of nonvascular plants are called bryophytes. These plants do not have true roots, stems, or leaves. They are very small and often live in moist areas.
- Sphagnum moss, found in peat bogs, is an important bryophyte because of its acidity and moisture-holding capacity.

Vocabulary

bryophyte (583)
rhizoid (583)
sphagnum (584)
thalloid (584)

30-3

- All nine phyla of vascular plants contain vascular tissue, xylem, and phloem. The sporophyte generation is dominant in the life cycle of all vascular plants.
- Whisk ferns have no true roots or leaves.
- Ferns are the dominant phylum of seedless plants, and they have sporangia on their leaves.
- Seed plants are either gymnosperms, which are characterized by naked seeds and no flowers, or angiosperms, which have flowers and seeds enclosed by a fruit.
- Conifers, the dominant living gymnosperms, form vast forests in the Northern Hemisphere.
- Various species of flowering plants have numerous adaptations that give them an advantage over gymnosperms.
- Angiosperms, or flowering plants, are the dominant phylum today, with over 240,000 species.
- Dicots are distinguished from monocots on the basis of several characteristics: cotyledon number, leaf venation, arrangement of stem vascular tissue, and number of flower parts.

Vocabulary

cone (588)
cotyledon (592)
deciduous (589)
dicot (592)
ephedrine (590)
fiddlehead (588)
frond (588)
germinate (588)
monocot (592)
net venation (592)
ovary (591)
parallel venation (592)
rhizome (588)
seedling (588)
strobilus (587)
vein (592)

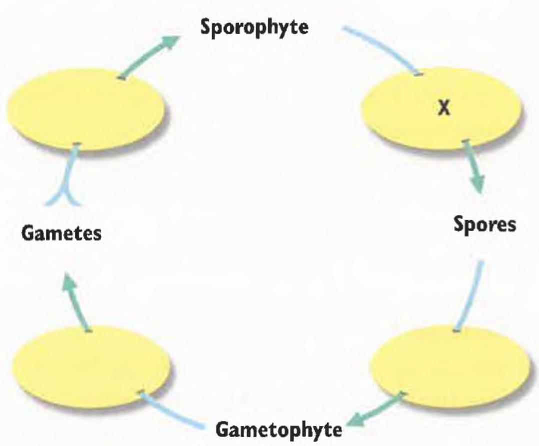
REVIEW

Vocabulary

1. Explain the difference between a gametophyte and a sporophyte.
2. Explain the difference between angiosperms and gymnosperms.
3. List two ways that monocots and dicots differ.
4. Describe the functions of xylem and phloem.
5. Compare and contrast spores and seeds.

Multiple Choice

6. The phylum Bryophyta includes (a) mosses and club mosses (b) hornworts and liverworts (c) liverworts and cycads (d) conifers and ginkgoes.
7. Mosses help start new biological communities by (a) detecting air pollution (b) forming new soil (c) producing spores (d) slowing decomposition.
8. Look at the diagram of the plant life cycle below. The process that occurs at *X* is (a) fertilization (b) meiosis (c) mitosis (d) meiosis and mitosis.



9. The presence of silica in the outer cells of the plant is a characteristic of (a) ferns (b) mosses (c) horsetails (d) club mosses.
10. Flowering plants are in the phylum (a) Psilotophyta (b) Anthophyta (c) Gnetophyta (d) Sphenophyta.
11. Seedless vascular plants include all of the following *except* (a) ferns (b) horsetails (c) cycads (d) club mosses.
12. Gymnosperms include all of the following *except* (a) cycads (b) gnetophytes (c) ginkgoes (d) horsetails.
13. The great success of angiosperms is due in part to (a) a highly efficient vascular system (b) seeds protected by fruits (c) animal dispersion of pollen, fruits, and seeds (d) all of the above.
14. A monocot has (a) parallel leaf venation (b) two seed leaves (c) four-part flowers (d) five-part flowers.
15. The distinguishing feature of all plants is the presence of (a) vascular tissue (b) pollen grains (c) a cuticle (d) rhizoids.

Short Answer

16. When did the first land plants probably develop?
17. Why did it take about 3 billion years after life developed in the oceans for plants to first appear on land?
18. Which phylum of organisms is believed to represent the ancestors of land plants? Why?
19. What is the genetic difference between the gametophyte and the sporophyte?
20. How does alternation of generations in nonvascular plants differ from that in vascular plants?
21. What factor limits the size of nonvascular plants?
22. Why do nonvascular plants usually live in moist environments?
23. What is the principal distinguishing feature of vascular plants?
24. What are the structural features found in vascular plants that are lacking in nonvascular plants?
25. Why are ferns and flowering plants placed in different phyla?

Critical Thinking

1. Steven Spielberg has hired you to landscape his new $110 million Jurassic Park theme ride with living plants similar to those that grew during the Jurassic period. What plant phyla could you use? Give examples of specific plants that you would use as shade trees, shrubs, and low-growing ground cover.
2. Fossil trees are easier to find than fossils of small plants. Give two possible explanations.
3. The water lily, shown below, is an aquatic vascular plant. Do you think its cuticle would be thicker on the upper surface of the leaf or on the lower surface? Explain.

4. Luminous moss, *Schistostega pennata,* has cells shaped like lenses, with chloroplasts spread out behind the curving cell membrane. In what sort of environment would you expect to find this moss?
5. Cactuses are vascular plants that are adapted to dry environments. What specific adaptations might have been selected for during evolution?
6. In the chart below, indicate which groups of plants have vascular tissue. Also indicate which groups of plants have a dominant sporophyte as part of their life cycle.

Plant Evolution

Phylum	Has vascular tissue	Has dominant sporophyte
Anthophyta		
Bryophyta		
Coniferophyta		
Hepatophyta		
Pterophyta		

Extension

1. Read "Tasty Brazil Nuts Stun Harvesters and Scientists" in *Smithsonian,* April 1999, on page 38. Describe a Brazil nut pod, and compare it to the familiar Brazil nuts we find in the grocery store. How are the nuts harvested? Explain the role of the agouti in the survival of the Brazil nut.
2. Go to your local garden center and get a handful of sphagnum moss. Let it air-dry. Determine the mass of the moss to the nearest 0.1 g. Then submerge the moss in water, and let it sit overnight. Remove the moss, let the excess water drain off, and determine the mass of the moss again. Calculate the percentage of increase in mass.
3. Collect one or more fern fronds with mature but unopened sporangia, and place them in an envelope to dry. Soak a clean 7.5 cm diameter clay flowerpot in distilled water or rainwater overnight. Fill the pot with wet sphagnum moss, and place it upside down in a pan of distilled water. Sprinkle the fern spores from the envelope on the flowerpot's upturned surface, and cover the pot with a bell jar or clear 2 L plastic soda bottle with its base cut off. Place the setup in indirect light, and keep it watered. Watch for the development of fern gametophytes in a week or two.

Observing Plant Diversity

OBJECTIVES

- Compare similarities and differences among phyla of living plants.
- Relate structural adaptations to the evolution of plants.

PROCESS SKILLS

- observing
- comparing and contrasting
- classifying
- relating structure and function

MATERIALS

- live and preserved specimens representing four plant phyla
- stereomicroscope or hand lens
- compound light microscope
- prepared slides of male and female gametophytes of mosses and ferns

Background

1. How do plants you commonly see compare with their ancestors, the green algae?
2. What are the differences between nonvascular plants and vascular plants? How do these differences relate to the size of a plant?
3. What is alternation of generations? Is it found in all plants?
4. Do all plants produce spores? Do all plants produce seeds? What are the advantages of producing seeds?
5. What do you think was the evolutionary pressure that resulted in colorful flowers?

Procedure

1. CAUTION **Keep your hands away from your face while handling plants.** You will travel to four stations to observe plants that are representatives of four phyla of plants. Record the answers to the questions in your lab report.

STATION 1 Mosses

2. Use a stereomicroscope or a hand lens to examine the samples of mosses, which are bryophytes. Which part of the moss is the gametophyte? Which part of the moss is the sporophyte? Make a sketch of your observations in your lab report. In your drawing, label the gametophyte and sporophyte portions of the moss plant and indicate whether each is haploid or diploid.
3. Use a compound microscope to look at the prepared slides of male and female gametophytes. What kinds of reproductive cells are produced in each of these structures? Draw the cells in your lab report.
4. Do mosses have roots? How do mosses obtain water and nutrients from the soil?

STATION 2 Ferns

5. Look at the examples of ferns at this station. The fern leaf is called a frond. Use the hand lens to examine the fronds.
   a. How does water travel throughout a fern? List observations supporting your answer.
   b. Make a drawing of the fern plant in your lab report.

Indicate whether the leafy green frond in your drawing is haploid or diploid.

c. Search the underside of the fern fronds for evidence of reproductive structures. Make a drawing of your findings in your lab report. What kind of reproductive cells are produced by these structures?

6. Examine the examples of fern gametophytes.
   a. Locate and identify the reproductive organs found on the gametophytes. In your lab report, sketch and label these organs and identify the reproductive cells produced by each.
   b. Are the gametophytes haploid or diploid?
7. In what ways are ferns like bryophytes? In what ways are they different?

STATION 3 Conifers

8. The gymnosperms most familiar to us are conifers. Look at the samples of conifers at this station.
   a. When you look at the limb of a pine tree, which portion (gametophyte or sporophyte) of the plant life cycle are you seeing?
   b. In what part of the conifer would you find reproductive structures?
9. Name an evolutionary advancement found in gymnosperms but lacking in ferns.

STATION 4 Angiosperms

10. Draw one of the representative angiosperms at this station in your lab report. Label the representative angiosperm as a monocot or a dicot, and list at least two characteristics you used to identify it.
11. Name an evolutionary development that is present in both gymnosperms and angiosperms but absent in bryophytes and ferns.

12. How do the seeds of angiosperms differ from those of gymnosperms?
13. Examine the fruits found at this station. How have fruits benefited angiosperms?
14. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. In bryophytes, how do the sperm travel from the male gametophyte to the female gametophyte?
2. In angiosperms, how do the sperm get to the part of the flower containing the egg?
3. Which portion of the plant life cycle is dominant in bryophytes? Which portion is dominant in ferns, gymnosperms, and angiosperms?
4. What is a seed? Why is the seed a helpful adaptation for terrestrial plants?
5. Why are gymnosperms referred to as *naked* seed plants?
6. Which group of plants is the most successful and diverse today? What are some adaptations found among members of this group?

Further Inquiry

1. Find out how the geographic distribution of the phyla of living plants relates to their structures.
2. Research the deforestation of tropical rain forests. How are the different groups of plants affected by deforestation?

CHAPTER 31

PLANT STRUCTURE AND FUNCTION

This Dahlia *"flower" is really a cluster of small, individual flowers.* Dahlia *is a member of the family of plants called the composites, which also includes sunflowers and daisies.*

FOCUS CONCEPT: *Cell Structure and Function*

As you read, notice how the roots, stems, and leaves perform different functions for a plant. Plant tissues are organized for specialized functions.

SECTION

31-1

PLANT CELLS AND TISSUES

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

SPECIALIZED PLANT CELLS

All organisms are composed of cells. Recall from Chapter 4 that plant cells have unique structures, including a central vacuole, plastids, and a thick cell wall that surrounds the cell membrane. These common features are found in the three types of specialized plant cells—parenchyma, collenchyma, and sclerenchyma—which are shown in Figure 31-1. Small changes in the structure of these plant cells help make different functions possible. The three types of plant cells are arranged differently in roots, stems, and leaves.

Parenchyma (puh-REN-kuh-muh) cells are usually loosely packed cube-shaped or elongated cells that contain a large central vacuole and have thin, flexible cell walls. Parenchyma cells are involved in many metabolic functions, including photosynthesis, storage of water and nutrients, and healing. These cells usually form the bulk of nonwoody plants. For example, the fleshy part of an apple is made up mostly of parenchyma cells.

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

OBJECTIVES

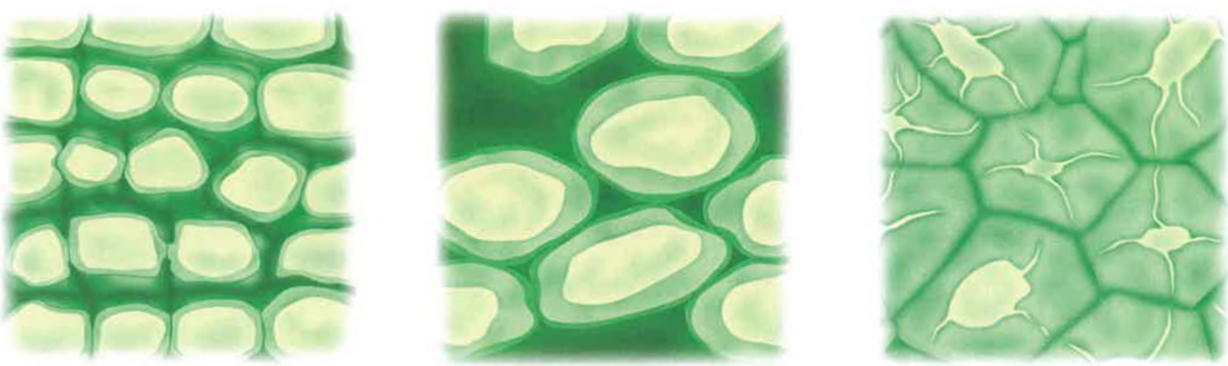
▲ Describe the three kinds of plant cells.

● Explain the differences between the three plant tissue systems.

■ Describe the main types of meristems.

◆ Differentiate between monocot and dicot meristems.

▲ Differentiate between primary and secondary growth.



(a) PARENCHYMA (b) COLLENCHYMA (c) SCLERENCHYMA

FIGURE 31-1

Plants are composed of three types of specialized cells. (a) Parenchyma cells are usually cube-shaped with thin walls. (b) Collenchyma cells are elongated with irregularly thickened cell walls. (c) Sclerenchyma cells are cube-shaped or elongated and have thick, rigid cell walls.

the plant. Collenchyma cells are usually grouped in strands. They are specialized for supporting regions of the plant that are still lengthening. Celery stalks contain a great amount of collenchyma cells.

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

TISSUE SYSTEMS

Cells that work together to perform a specific function form a tissue. Tissues are arranged into systems in plants, including the dermal system, ground system, and vascular system, which are summarized in Table 31-1. These systems are further organized into the three major plant organs—the roots, stems, and leaves. The organization of each organ reflects adaptations to the environment.

Dermal Tissue System

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

TABLE 31-1 ***Characteristics of Plant Tissue Systems***

Tissue system	Type of cells	Location	Function in roots	Function in stems	Function in leaves
Dermal tissue system	flat, living parenchyma (epidermal cells) in nonwoody parts; flat, dead parenchyma (cork cells) in woody parts	outermost layer(s) of cells	absorption, protection	gas exchange, protection	gas exchange, protection
Ground tissue system	mostly parenchyma, usually with some collenchyma and fewer sclerenchyma	between dermal and vascular in nonwoody plant parts	support, storage	support, storage	photosynthesis
Vascular tissue system	elongated cells—dead xylem and living phloem, also parenchyma and sclerenchyma (fibers)	tubes throughout plant	transport, support	transport, support	transport, support

Ground Tissue System

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

Vascular Tissue System

Ground tissue surrounds the **vascular tissue system,** which functions in transport and support. Recall from Chapter 30 that the term *vascular tissue* refers to both xylem and phloem. Xylem tissue conducts water and mineral nutrients primarily from roots upward in the plant. Xylem tissue also provides structural support for the plant. Phloem tissue conducts organic compounds and some mineral nutrients throughout the plant. Unlike xylem, phloem is alive at maturity.

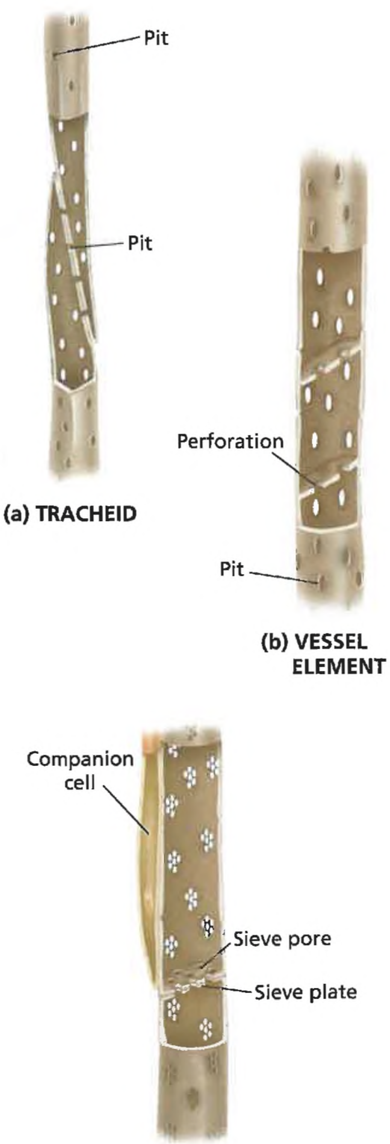
In angiosperms, xylem has two major components—tracheids and vessel elements. Both are dead cells at maturity. Look at Figure 31-2a. A **tracheid** (TRAY-kee-id) is a long, thick-walled sclerenchyma cell with tapering ends. Water moves from one tracheid to another through **pits,** which are thin, porous areas of the cell wall. A **vessel element**, shown in Figure 31-2b, is a sclerenchyma cell that has either large holes in the top and bottom walls or no end walls at all. Vessel elements are stacked to form long tubes called **vessels.** Water moves more easily in vessels than in tracheids. The xylem of most seedless vascular plants and most gymnosperms contains only tracheids, which are considered a primitive type of xylem cell. The vessel elements in angiosperms probably evolved from tracheids. Xylem also contains parenchyma cells and sclerenchyma cells.

The conducting parenchyma cell of angiosperm phloem is called a **sieve tube member.** Look at Figure 31-2c. Sieve tube members are stacked to form long **sieve tubes.** Compounds move from cell to cell through end walls called **sieve plates.** Each sieve tube member lies next to a specialized parenchyma cell, the **companion cell,** which assists in transport. Phloem also usually contains sclerenchyma cells called fibers. Commercially important hemp, flax, and jute fibers are phloem fibers.

Vascular tissue systems are also modified for environmental reasons. For example, xylem forms the wood of trees, providing the plants with strength while conducting water and mineral nutrients. In aquatic plants, such as duckweeds, xylem is not needed for support or water transport and may be nearly absent from the mature plant.

FIGURE 31-2

(a) Tracheids are long and thin, and they contain pits in their cell walls. (b) Vessel elements are shorter and wider than tracheids. Both tracheids and vessel elements transport water. (c) Sieve tube members are long and tubular, and they contain pores in their cell walls. Sugar is transported through sieve tube members and companion cells.



(a) TRACHEID

(b) VESSEL ELEMENT

(c) SIEVE TUBE MEMBER

TABLE 31-2 *Types of Meristems*

Type	Location	Function
Apical meristem	tips of stems and roots	growth; increase length at tips
Intercalary meristem	between the tip and base of stems and leaves	growth; increase length between nodes
Lateral meristem	sides of stems and roots	growth; increase diameter

GROWTH IN MERISTEMS

Plant growth originates mainly in **meristems** (MER-i-STEMZ), regions where cells continuously divide. Look at Table 31-2. Most plants grow in length through **apical** (AP-i-kuhl) **meristems** located at the tips of stems and roots. Some monocots have **intercalary** (in-TUHR-kah-ler-ee) **meristems** located above the bases of leaves and stems. Intercalary meristems allow grass leaves to quickly regrow after being grazed or mowed.

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

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

SECTION 31-1 REVIEW

1. What are the differences between tracheids and vessel elements? How does water travel through each structure?
2. What kinds of meristems do monocots and dicots have in common? What kinds do they not share?
3. Would you expect to find sclerenchyma cells near meristems? Why or why not?
4. Would you expect to find sclerenchyma and collenchyma cells in roots?
5. Distinguish between the primary growth and secondary growth in a tree.
6. CRITICAL THINKING Describe the factors that influence the transport of water through xylem tissue.

SECTION

31-2

ROOTS

Plants have three kinds of organs—roots, stems, and leaves. Roots are the structures that typically grow underground. Roots are important because they anchor the plant in the soil. They also absorb and transport water and mineral nutrients. The storage of water and organic compounds is provided by roots.

OBJECTIVES

▲ List the three major functions of roots.

● Explain the difference between a taproot system and a fibrous root system.

■ Distinguish between primary growth and secondary growth in roots.

◆ Describe primary root tissues.

TYPES OF ROOTS

When a seed sprouts, it produces a primary root. If this first root becomes the largest root, it is called a **taproot,** as illustrated in Figure 31-3a. Many plants, like carrots and certain trees, have taproots. Contrary to what you might think, even taproots rarely penetrate the ground more than a meter or two. A few species, such as cottonwoods, do have some roots that grow 50 m (164 ft) deep to tap into underground water supplies. However, tall trees rarely have roots as deep as their height aboveground.

In some plants, the primary root does not become large. Instead, numerous small roots develop and branch to produce a **fibrous root system,** like that shown in Figure 31-3b. Many monocots, such as grasses, have fibrous root systems. Fibrous roots of monocots often develop from the base of the stem rather than from other roots.

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TOPIC: Types of roots
GO TO: www.scilinks.org
KEYWORD: HM603

(a) TAPROOT SYSTEM

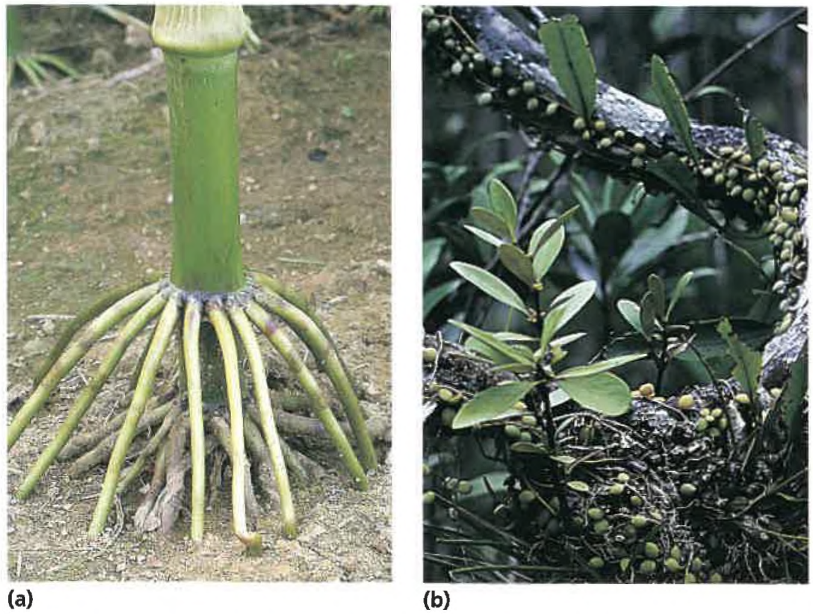
(b) FIBROUS ROOT SYSTEM

FIGURE 31-3

Plants can have either a taproot system or a fibrous root system. (a) Many dicots, including the radish, have a large central taproot with small lateral roots. (b) Most monocots, including grasses, have a highly branched fibrous root system.

FIGURE 31-4

Some plants grow adventitious roots from aboveground parts, including stems and leaves. (a) Corn plants grow prop roots at their base to provide additional stability. (b) This orchid displays another type of adventitious root, called an air root. These plants live on tree branches and absorb water and mineral nutrients from the surface of the tree and from the air.



Specialized roots that grow from stems and leaves are called **adventitious roots.** Figure 31-4a shows the prop roots of corn, which help keep the plant's stems upright. The air roots of an epiphytic orchid, shown in Figure 31-4b, obtain water and mineral nutrients from the air. Air roots on the stems of ivy and other vines enable them to climb walls and trees.

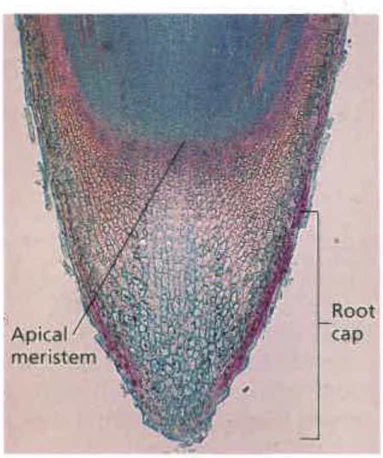
ROOT STRUCTURES

Study Figure 31-5. Notice that the root tip is covered by a protective **root cap,** which covers the apical meristem. The root cap produces a slimy substance that functions like lubricating oil, allowing the root to move more easily through the soil as it grows. Cells that are crushed or knocked off the root cap as the root moves through the soil are replaced by new cells produced in the apical meristem, where cells are continuously dividing. Look at Figure 31-6 on the next page. **Root hairs,** which are extensions of epidermal cells, increase the surface area of the root and thus increase the plant's ability to absorb water and mineral nutrients.

Root structures are adapted for several functions. Root hairs on the epidermis greatly increase the surface area available for absorption. Most roots also form partnerships with mycorrhizal fungi, whose threadlike hyphae also increase the surface area for absorption. The spreading, usually highly branched root system increases the amount of soil that the plant can "mine" for water and mineral nutrients and aids in anchoring the plant. The large amount of root parenchyma usually functions in storage and general metabolism. Roots are dependent on the shoots for their energy, so they must store starch to use as an energy source during periods of little or no photosynthesis, such as winter.

FIGURE 31-5

The root cap protects the apical meristem of a root tip. The primary growth of a root is caused by cell division occurring in the apical meristem.



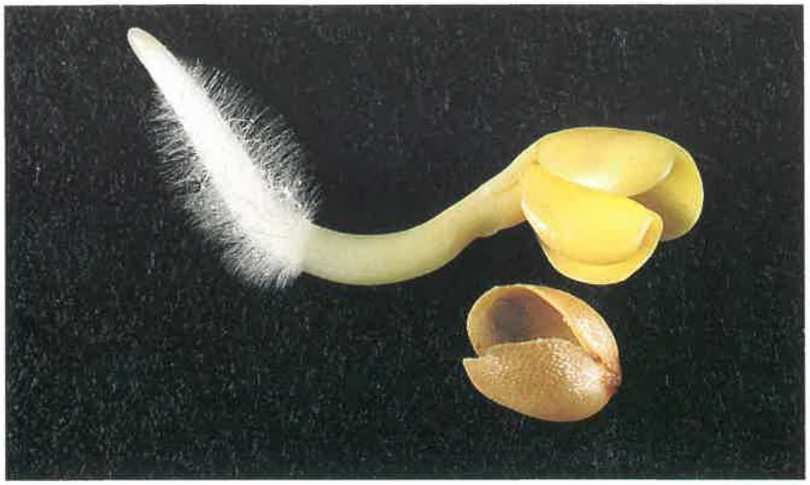


FIGURE 31-6

The root tip of this seedling has many root hairs, which help the plant absorb water and mineral nutrients from the soil. Root hairs grow from the outer layer of cells, called the epidermis.

Primary Growth in Roots

Roots increase in length through cell division, elongation, and maturation in the root tip. Dermal tissue matures to form the epidermis, the outermost cylinder of the root. Ground tissue in roots matures into two specialized regions: the cortex and the endodermis. The **cortex** is located just inside the epidermis, as you can see in Figure 31-7. This largest region of the primary root is made of loosely packed parenchyma cells.

The innermost cylinder of the cortex is the **endodermis** (EN-doh-DUHR-mis), also shown in Figure 31-7. Endodermal cell walls contain a narrow band of a waterproof substance that stops further movement of water through the cell walls. To enter farther into the root than the endodermis, water and dissolved substances must pass through the selectively permeable membrane of a root cell. Once inside the cell membrane, dissolved substances can move from cell to cell via small channels in cell walls that interconnect the cytoplasm of adjoining cells.

Vascular tissue in roots matures to form the innermost cylinder of the root. In most dicots and gymnosperms, xylem makes up the central core of the root, as shown in Figure 31-7b. Dicot root xylem

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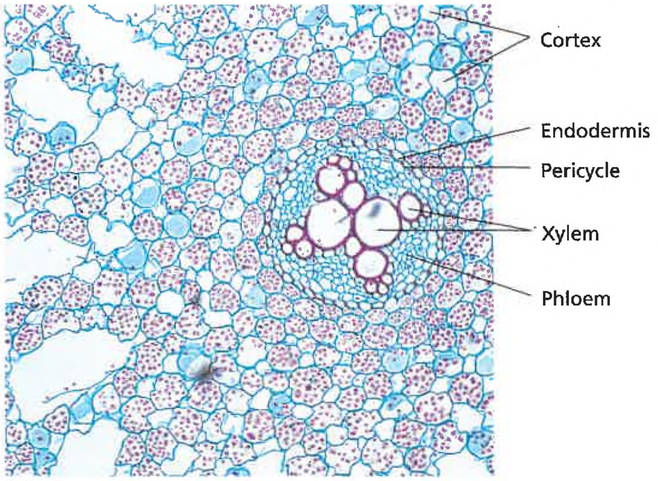
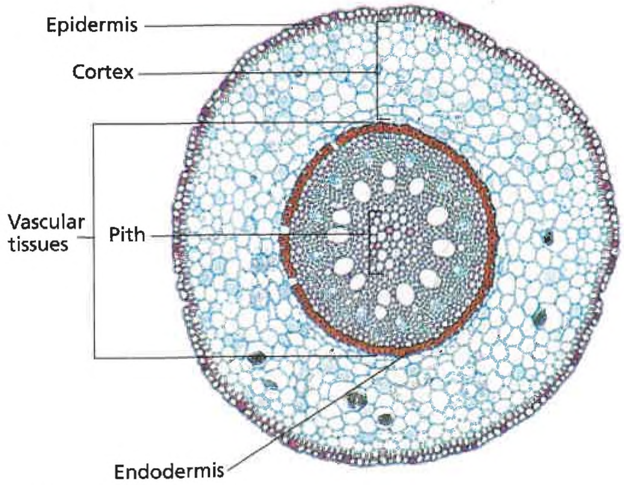
FIGURE 31-7

(a) This cross section of a dicot root shows the arrangement of vascular tissue and ground tissue. Note how the xylem tissue forms an X in the center. The cortex and the endodermis, which are composed of ground tissue, surround the vascular tissue. (b) This cross section of a monocot root shows a prominent endodermis, the innermost layer of the cortex. The center of the root, called the pith, is made up of parenchyma cells.



(a)



(b)

usually has a fluted structure with pockets of phloem between the xylem lobes. In monocots, the center of the root usually contains a pith of parenchyma cells, as Figure 31-7b shows. Monocot root xylem occurs in many patches that circle the pith. Small areas of phloem occur between the xylem patches.

The outermost layer or layers of the central vascular tissues is termed the **pericycle** (PER-i-SIE-kuhl). Lateral roots are formed by the division of pericycle cells. The developing lateral root connects its vascular tissues and endodermis to those of the parent root. Figure 31-8 shows how a lateral root grows out through the parent root's endodermis and cortex, finally emerging from the epidermis.

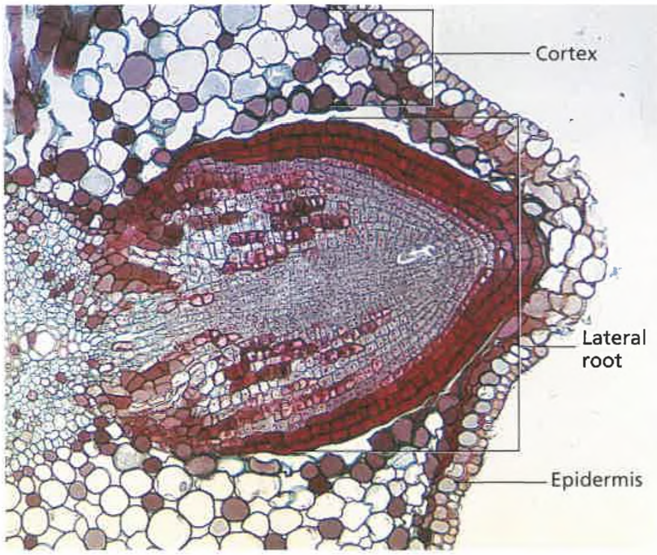


FIGURE 31-8

The vascular core of a primary root is surrounded by the pericycle, a tissue that produces lateral roots.

Secondary Growth in Roots

Dicot and gymnosperm roots often experience secondary growth. Secondary growth begins when a vascular cambium forms between primary xylem and primary phloem. Pericycle cells form the vascular cambium at the ends of the xylem lobes, where no phloem is located. The vascular cambium produces secondary xylem toward the inside of the root and secondary phloem toward the outside. The expansion of the vascular tissues in the center of the root crushes all the tissues external to the phloem, including the endodermis, cortex, and epidermis. A cork cambium develops in the pericycle to replace the crushed cells with cork.

ROOT FUNCTIONS

Besides anchoring a plant in the soil, roots serve two other primary functions. They absorb water and a variety of minerals or mineral nutrients that are dissolved in the soil. Roots are selective about which minerals they absorb. Roots absorb some minerals and exclude others. Table 31-2 lists the 13 minerals that are essential for all plants. They are absorbed mainly as ions. Carbon, hydrogen, and oxygen are not listed because they are absorbed as water and carbon dioxide.

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

Adequate amounts of all 13 mineral nutrients in Table 31-3 are required for normal growth. Plants with deficiencies show

Quick Lab

Observing Roots

Materials wilted radish seedlings, hand lens, Petri dish, water, pipet

Procedure

1. Place the wilted radish seedlings in a Petri dish. Observe them with the hand lens. Record your observations.
2. Using a pipet, cover only the roots with water. Observe the seedlings with the hand lens every 5 minutes for 15 minutes. Record each of your observations.
3. Use the hand lens to observe the roots. Draw and label what you see.

Analysis What happened to the wilted seedlings when you put them in water? How can you explain what happened? Describe two functions of a root.

TABLE 31-3 Essential Mineral Nutrients in Plants

Macronutrients

Element	Absorbed as	Use in plants
Nitrogen	NO_3^-, NH_4^+	part of proteins, nucleic acids, chlorophyll, ATP
Phosphorus	$H_2PO_4^-$	part of nucleic acids, ATP, phospholipids, coenzymes
Potassium	K^+	required for stomatal opening and closing, enzyme cofactor
Calcium	Ca^{2+}	part of cell walls and cell membranes
Magnesium	Mg^{2+}	part of chlorophyll
Sulfur	SO_4^{2-}	part of proteins

Micronutrients

Element	Absorbed as	Use in plants
Iron	Fe^{2+}	part of cytochromes in electron transport
Manganese	Mn^{2+}	required by many enzymes
Boron	$B(OH)_3$	thought to be involved in carbohydrate transport
Chlorine	Cl^-	required to split water in photosynthesis
Zinc	Zn^{2+}	essential part of many enzymes
Copper	Cu^{2+}	essential part of many enzymes
Molybdenum	MoO_4^{2-}	required for nitrogen metabolism

characteristic symptoms and reduced growth. Severe mineral deficiencies can kill a plant. Excess amounts of some essential mineral nutrients also can be toxic to a plant.

Roots are often adapted to store carbohydrates or water. Phloem tissue carries carbohydrates made in leaves to roots. Carbohydrates that roots do not immediately use for energy or building blocks are stored. In roots, these excess carbohydrates are usually converted to starch and stored in parenchyma cells. You are probably familiar with the storage roots of carrots, turnips, and sweet potatoes. The roots of some species in the pumpkin family store large amounts of water, which helps the plants survive during dry periods.

SECTION 31-2 REVIEW

1. What are the major functions of the root system?
2. What are the differences between a taproot system and a fibrous root system?
3. What is the difference between primary growth and secondary growth? What types of tissues are involved in each type of growth?
4. Explain how root hairs increase the ability of a plant to absorb water from the soil.
5. Name two areas of the root where you would probably find parenchyma cells.
6. **CRITICAL THINKING** Why might a taproot system be an advantage to some plants, while a fibrous root system might be an advantage to others?

SECTION

31-3

OBJECTIVES

▲ Describe the differences between monocot stems and dicot stems.

● List five differences and five similarities between the structure of roots and the structure of stems.

■ Explain how annual rings are formed.

◆ Describe the pressure-flow model for organic-compound movement in the phloem.

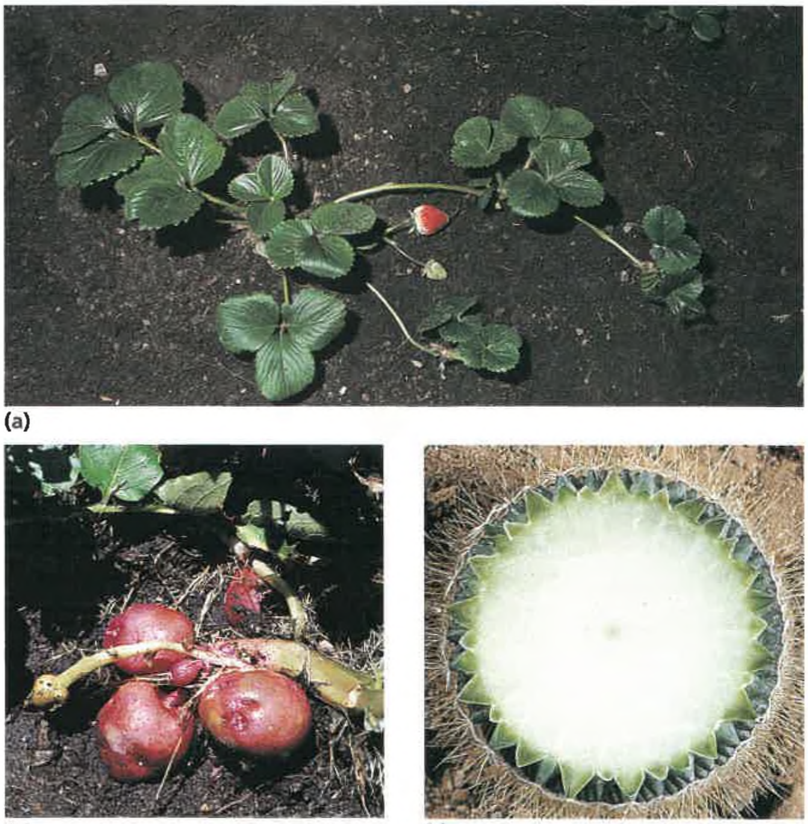
▲ Describe the cohesion-tension theory for water movement in the xylem.

STEMS

In contrast to roots, which are mainly adapted for absorption and anchoring, stems are usually adapted to support leaves. Whatever their sizes and shapes, stems also function in transporting materials and providing storage.

TYPES OF STEMS

The various differences in stem shape and growth represent adaptations to the environment. Several types of stems are shown in Figure 31-9. Strawberry runners grow along the soil surface and produce new plants at their nodes. Stems such as the edible white potato tuber are modified for storing energy as starch. Cactuses have green fleshy stems that both store water and carry on all the plant's photosynthesis. Stems of the black locust and the honeylocust develop sharp thorns to protect the plant from animals. These stem modifications are related to environmental adaptations.



(a) (b) (c)

FIGURE 31-9

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

STEM STRUCTURES

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

The surfaces of stems have several features that roots lack, as Figure 31-10 shows. Stems are divided into segments called **internodes.** At each end of an internode is a **node.** Initially, one or more leaves are attached at each node. At the point of attachment of each leaf, the stem bears a lateral bud. A **bud** is capable of developing into a new shoot. A bud contains an apical meristem and is enclosed by specialized leaves called **bud scales.** The tip of each stem usually has a terminal bud. When growth resumes in the spring, the terminal bud opens, and the bud scales fall off. The bud

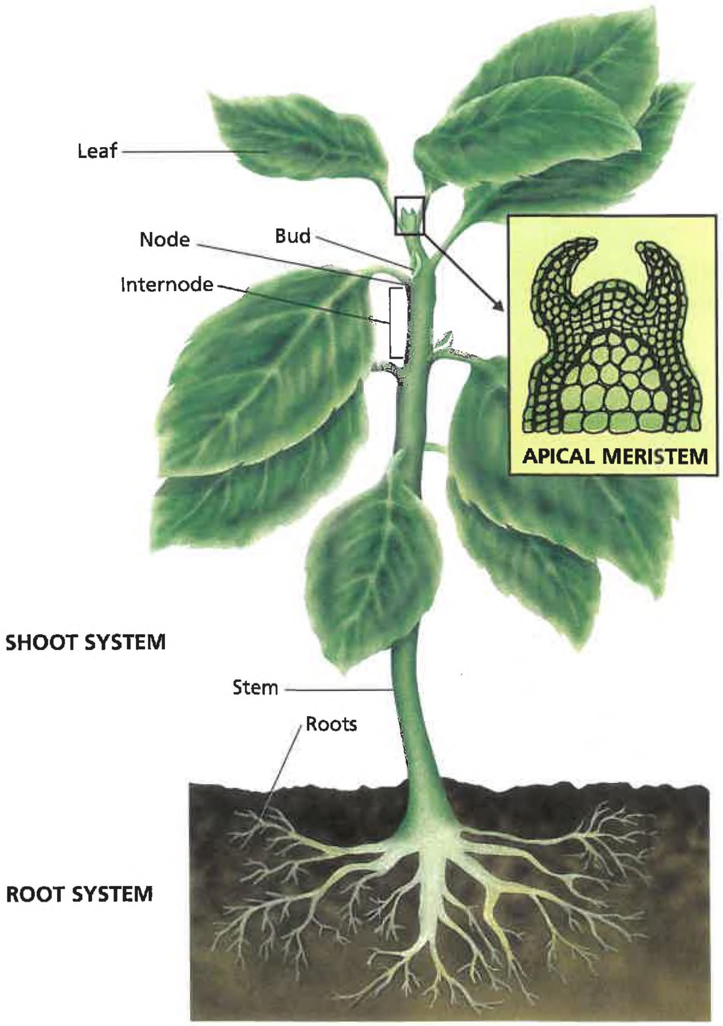


FIGURE 31-10

Apical meristems, responsible for the primary elongation of the plant body, are found in the shoot tips and root tips. Each leaf is attached to the stem at a node. The space between nodes, called the internode, is much larger in the older part of the stem. When the shoot tip is pinched off, the lateral buds begin to grow, resulting in a bushier plant.

Quick Lab

Observing Stems

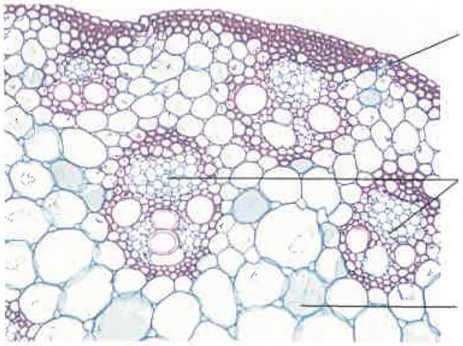
Materials winter twig, fresh stem with leaves, hand lens or dissecting microscope

Procedure

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

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

(a) MONOCOT STEM



(b) DICOT STEM

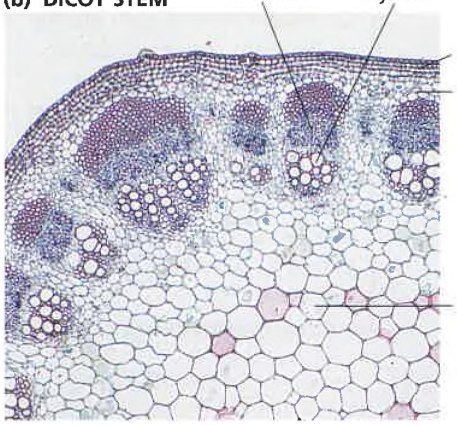


FIGURE 31-11

Compare the two basic types of stems. (a) The cross section of a herbaceous stem of corn, a monocot, shows the vascular bundles scattered throughout the ground tissue. (b) In the sunflower, a dicot, the vascular tissues appear as a single ring of bundles between the cortex and the pith.

scales leave scars on the stem surface. Trees and shrubs often are identified in winter by these twig characteristics.

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

Primary Growth in Stems

As in roots, apical meristems of stems give rise to the dermal, ground, and vascular tissues. Locate each of these tissues in Figure 31-11. As you can see, the dermal tissue is represented by the epidermis, or the outer layer of the stem. Its main functions are to protect the plant and to reduce the loss of water to the atmosphere while still allowing gas exchange through stomata.

In gymnosperm and dicot stems, ground tissue usually forms a cortex and a pith. The cortex lies just inside the epidermis, as it does in the root. The cortex frequently contains flexible collenchyma cells. The **pith** is located in the center of the stem. The ground tissue of monocot stems is usually not clearly separated into pith and cortex.

Vascular tissue formed near the apical meristem occurs in bundles—long strands that are embedded in the cortex. Look at the vascular bundles in Figure 31-11. Each bundle contains xylem tissue and phloem tissue. Xylem is usually located toward the inside of the stem, while phloem is usually located toward the outside.

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

Secondary Growth in Stems

Stems increase in thickness due to the division of cells in the vascular cambium. The vascular cambium in dicot and gymnosperm stems first arises between the xylem and phloem in a vascular bundle. Eventually the vascular cambium forms a cylinder. The vascular cambium produces secondary xylem to the inside and secondary phloem to the outside. It usually produces much more secondary xylem than it does secondary phloem. Secondary xylem is called **wood.** Occasionally, the vascular cambium produces new cambium cells, which increase its diameter.

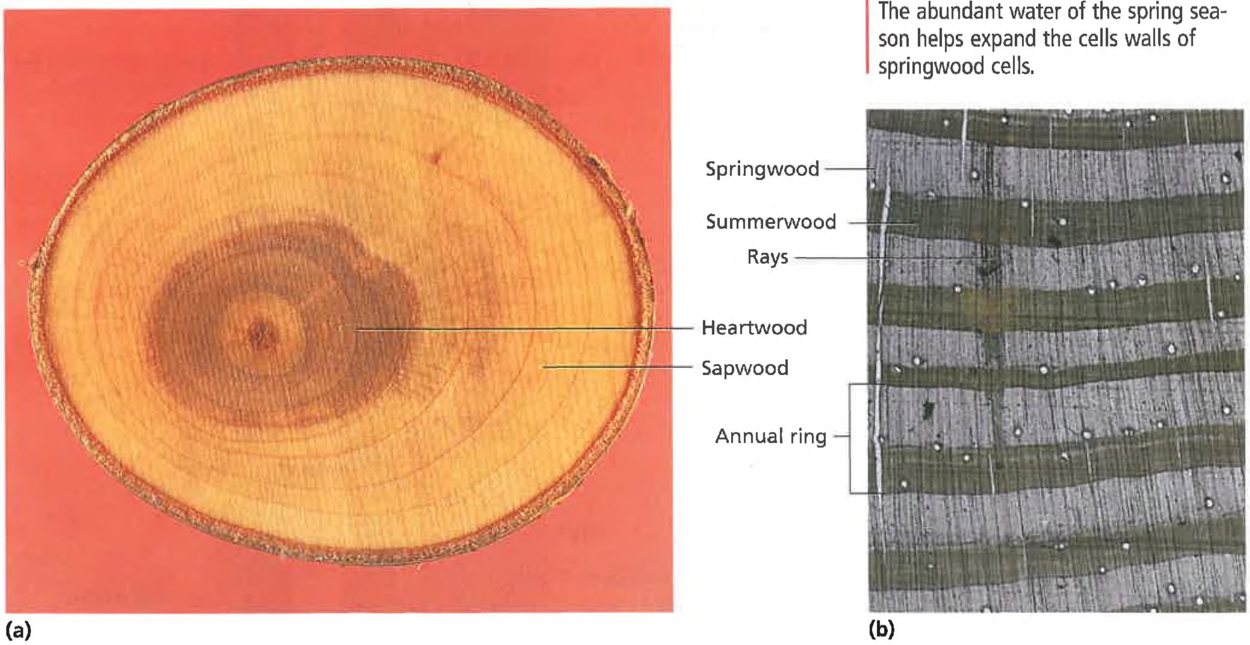
Older portions of the xylem eventually stop transporting water. They often become darker than the newer xylem due to the accumulation of resins and other organic compounds produced by the few live cells remaining in the xylem. This darker wood in the center of a tree is called **heartwood,** as shown in Figure 31-12a. The functional, often lighter-colored wood nearer the outside of the trunk is **sapwood.** In a large-diameter tree, the heartwood keeps getting wider while the sapwood remains about the same thickness.

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

During spring, when water is plentiful, the vascular cambium forms new xylem tissue with cells that are wide and thin walled. This wood is called **springwood.** In summer, when water is more limited, the vascular cambium produces **summerwood,** which has smaller cells with thicker walls. In a stem cross section, the abrupt change between small summerwood cells and the following year's large springwood cells produces an **annual ring.** The circles that look like rings on a target in Figure 31-12 are the annual rings of the stem. Because one ring is usually formed each year, you can estimate the age of the stem by counting its annual rings. Annual rings also form in dicot and gymnosperm roots, but they are often less pronounced because the root environment is more uniform. Annual rings often do not occur in tropical trees because of their uniform year-round environment.

FIGURE 31-12

(a) This cross section of a mature woody stem shows secondary growth, which results in a thicker stem. Wood consists of secondary xylem. The dark-colored wood is called heartwood and the light-colored wood is called sapwood. (b) You can see the annual rings produced by alternating springwood cells and summerwood cells. The abundant water of the spring season helps expand the cells walls of springwood cells.



STEM FUNCTIONS

Stems function in the transportation and storage of nutrients and water, and they support the leaves. Carbohydrates, some plant hormones, and other organic compounds are transported in the phloem. The movement of carbohydrates occurs from where the carbohydrates are made or have been stored, called a **source,** to where they are stored or used, called a **sink.** Botanists use the term **translocation** to refer to the movement of carbohydrates through the plant. For example, in most plants, carbohydrates move from the leaves to the roots, to the shoot apical meristems, and to the developing flowers or fruits. Carbohydrates may be newly made in photosynthetic cells or may have been stored as starch in roots or stems.

Movement in the phloem is explained by the **pressure-flow hypothesis,** which states that carbohydrates are actively transported into sieve tubes. Look at Figure 31-13. As carbohydrates enter the sieve tubes, water is also transported in by osmosis. Thus, a positive pressure builds up at the source end of the sieve tube. This is the pressure part of the hypothesis.

At the sink end of the sieve tube, this process is reversed. Carbohydrates are actively transported out, water leaves the sieve tube by osmosis, and pressure is reduced at the sink. The difference

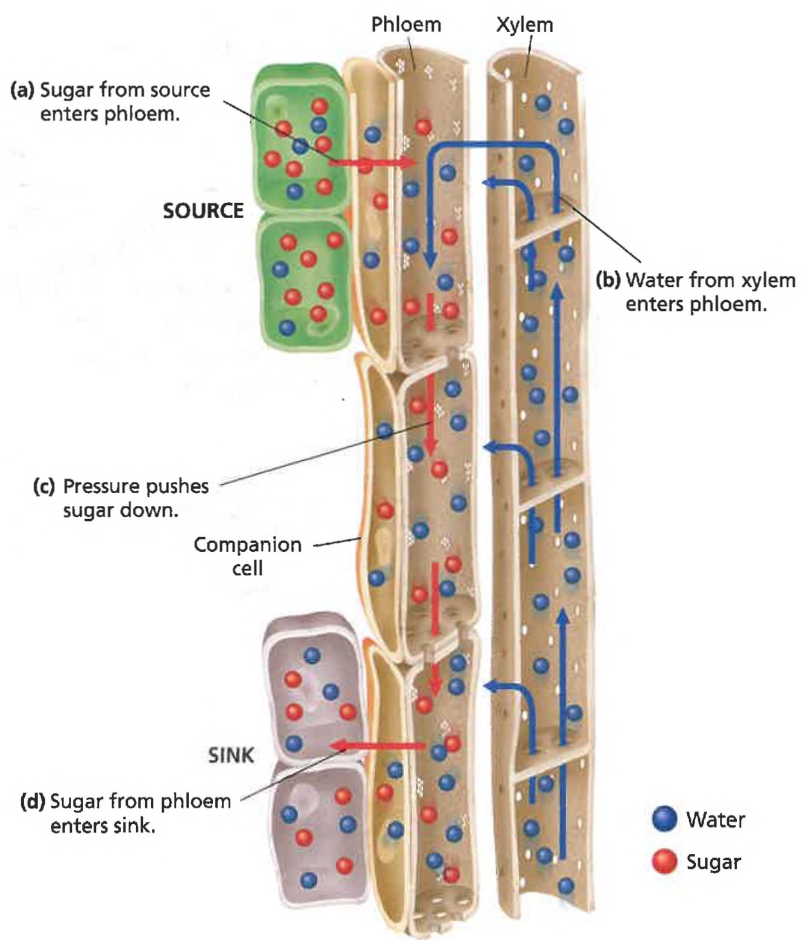


FIGURE 31-13

In the pressure-flow model, carbohydrates are pushed through the phloem by the pressure that results from the movement of water into the phloem by osmosis. The blue arrows indicate water movement, and the red arrows indicate carbohydrate movement.

in pressure causes water to flow from source to sink—carrying dissolved substances with it. Transport in the phloem can occur in different directions at different times.

Transport of Water

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

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

Word Roots and Origins

transpiration

from the Latin *trans,* meaning "across," and the Latin *spirare,* meaning "to breathe"

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TOPIC: Transpiration
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Storing Water and Nutrients

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

SECTION 31-3 REVIEW

1. How does the arrangement of vascular tissues in a stem differ between monocots and dicots?
2. Describe five differences and five similarities between the structure of roots and the structure of stems.
3. Explain the difference between summerwood and springwood and tell how they form annual rings.
4. Describe how water moves through xylem tissue.
5. Describe the movement of carbohydrates within phloem tissue.
6. CRITICAL THINKING Some squirrels damage trees by stripping off portions of the bark. Why would a squirrel eat bark?

Research Notes

Nature's Chemical Arsenal

Plants depend heavily on chemical compounds for their survival because they are unable to otherwise escape herbivores. Such defensive compounds are called secondary compounds because they have no known function in plant growth. Secondary compounds are the active ingredients in many familiar medicines, including aspirin and taxol.

Secondary compounds are unique not only to each plant species but often to specific parts of a plant. For example, the chemicals found in a plant's flowers are likely to attract pollinators, while the chemicals found in the same plant's leaves may be toxic. With so many plants and plant parts in existence, scientists have a multitude of chemical compounds to study in their search for new medicines.

Eloy Rodriguez, a plant chemist at Cornell University, has found a surprising way to track down secondary compounds that are likely to be helpful to humans—by studying how animals may medicate themselves in the wild with plants. He named this new discipline zoopharmacognosy.

Rodriguez and his colleagues found that non-human primates, which suffer from many of the same illnesses as humans, tend to eat only one kind of plant, or even one part of one kind of plant, when they have a particular illness. For example, Richard Wrangham, a Harvard University primatologist, observed that East African chimpanzees suffering from parasitic infections eat *Aspilia* leaves. When Rodriguez analyzed the chemistry of *Aspilia*, he identified one of the chemicals extracted from the plant's leaves as thiarubrine-A. Rodriguez's experiments on thiarubrine-A demonstrated that the chemical has antibiotic effects on bacteria, fungi, and intestinal parasites.

Plant researcher Eloy Rodriguez shows students in his lab some of the chemicals extracted from plant leaves.

Another plant eaten by chimpanzees is *Rubia cordifolia.* Several chemicals collected from this plant, grouped together as cyclic hexapeptides, are being investigated by the National Institutes of Health as a possible therapeutic agent against cancer. Laboratory tests with mice have shown that at the dosages ingested by chimpanzees, these chemicals have low toxicity. So if further research documents the chemicals' effectiveness as a weapon against cancer, they may provide the benefits of chemotherapy with less serious side effects.

After Rodriguez's research team began presenting its results on zoopharmacognosy, animal behaviorists began reporting similar observations of other animals. In 1996, Andrew Dobson, a professor at Princeton University, suggested that the diet of the African green monkey should be studied by researchers looking for new compounds to combat AIDS because the virus is thought to have originated in green monkeys.

Meanwhile, Rodriguez is concerned that he and other plant researchers face a race against time. Potentially life-saving plants found in tropical areas of the world are becoming extinct as the rain forests rapidly disappear. Rodriguez urges other researchers to join him in investigating the animals and plants that have coexisted in this region, using the innovative approaches that he pioneered.

LEAVES

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

SECTION

31-4

OBJECTIVES

▲ Identify the difference between a simple leaf and a compound leaf.

● Describe the tissues that make up the internal structure of a leaf.

■ Describe adaptations of leaves for special purposes.

◆ Explain the importance of stomata.

TYPES OF LEAVES

Look at the leaves in Figure 31-14a. The coiled structure is a **tendril,** a specialized leaf found in many vines, such as peas and pumpkins. It wraps around objects to support the climbing vine. In some species, like grape, tendrils are specialized stems.

An unusual leaf modification occurs in carnivorous plants such as the pitcher plant, shown in Figure 31-14b. In carnivorous plants, leaves function as food traps. These plants grow in soil that is poor in several mineral nutrients, especially nitrogen. The plant receives substantial amounts of mineral nutrients when it traps and digests insects and other small animals.

Leaves, or parts of leaves, are often modified into spines that protect the plant from being eaten by animals, as shown in Figure 31-14c. Because spines are small and nonphotosynthetic, they greatly reduce transpiration in desert species such as cactuses.

FIGURE 31-14

Many plants have developed leaf adaptations. (a) The pea plant has tendrils that climb. (b) The pitcher plant has tubular leaves that trap insects. (c) The barberry has spines that protect against herbivores.

(a) (b) (c)

(a) SIMPLE LEAF

(b) COMPOUND LEAF

(c) DOUBLY COMPOUND LEAF

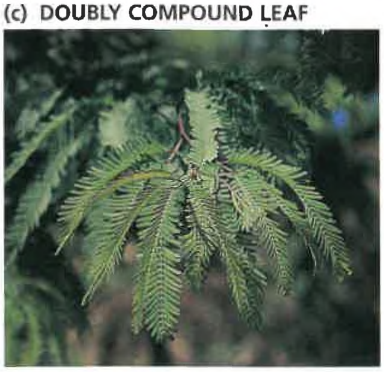


FIGURE 31-15

(a) A sugar-maple leaf is called a simple leaf because it has only one blade. (b) A white clover leaf is called a compound leaf because the leaf blade is divided into distinct leaflets. (c) The honeylocust has a doubly compound leaf because each leaflet is subdivided into smaller leaflets.

LEAF STRUCTURES

Leaves come in a wide variety of shapes and sizes and are an important feature used for plant identification. Leaves can be round, straplike, needlelike, or heart-shaped. The broad, flat portion of a leaf, called the **blade,** is the site of most photosynthesis. The blade is usually attached to the stem by a stalklike **petiole.** The maple leaf shown in Figure 31-15a is a **simple leaf;** it has a single blade. In **compound leaves,** such as the white clover in Figure 31-15b, the blade is divided into **leaflets.** In some species, the leaflets themselves are divided. The result is a doubly compound leaf, such as that of the honeylocust shown in Figure 31-15c.

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

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

In most plants, photosynthesis occurs in the leaf **mesophyll** (MEZ-oh-FIL), a ground tissue composed of chloroplast-rich parenchyma cells. In most plants, the mesophyll is organized into two layers, which are shown in Figure 31-16. The **palisade mesophyll** layer occurs directly beneath the upper epidermis and is the site of most photosynthesis. Palisade cells are columnar and appear to be packed tightly together in one or two layers. However, there are air spaces between the long side walls of palisade cells. Beneath the palisade layer is the **spongy mesophyll.** It consists of irregularly shaped cells surrounded by large air spaces, which allow oxygen, carbon dioxide, and water to diffuse into and out of the leaf.

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

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

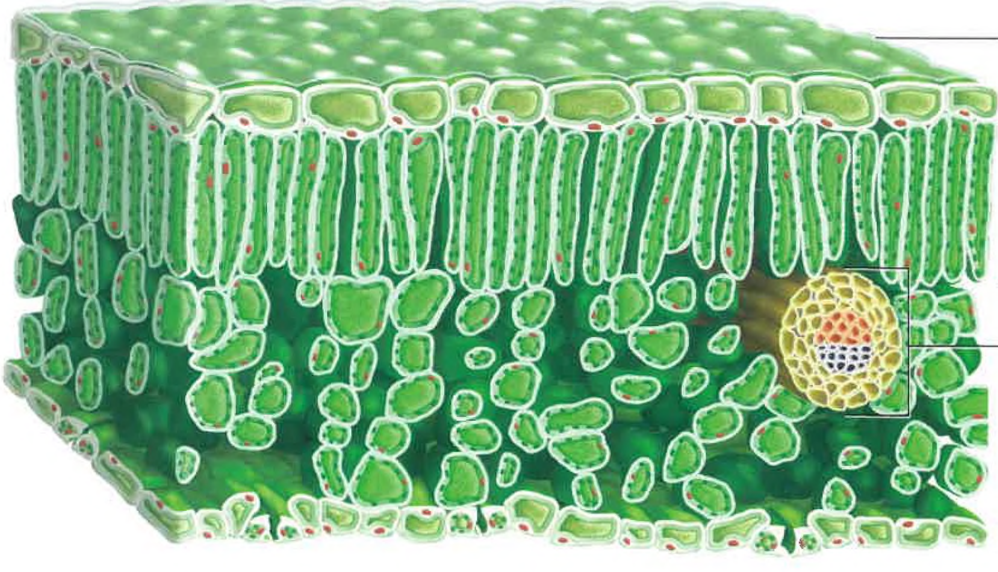


FIGURE 31-16

Cells from all three tissue systems are represented in the internal structure of a leaf. The epidermis is part of the dermal system, and the vascular bundle is part of the vascular system. The mesophyll is ground tissue made of parenchyma cells, and it generally contains chloroplasts. Note that the palisade mesophyll layer is more dense than the spongy mesophyll layer.

LEAF FUNCTIONS

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

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

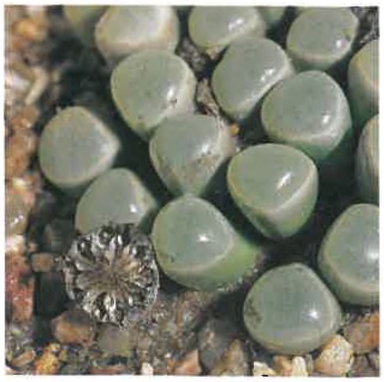
Modifications for Capturing Light

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

In dry environments, plants often receive more light than they can use. These plants often have structures that reduce the amount of light absorbed. For example, many desert plants have evolved dense coatings of hairs that reduce light absorption. The window plant shown in Figure 31-17 protects itself from its dry environment by growing underground. Only its transparent leaf tips protrude above the soil to gather light for photosynthesis.

FIGURE 31-17

The unusual transparent leaf tips of this window plant channel light to the plant's buried leaves.



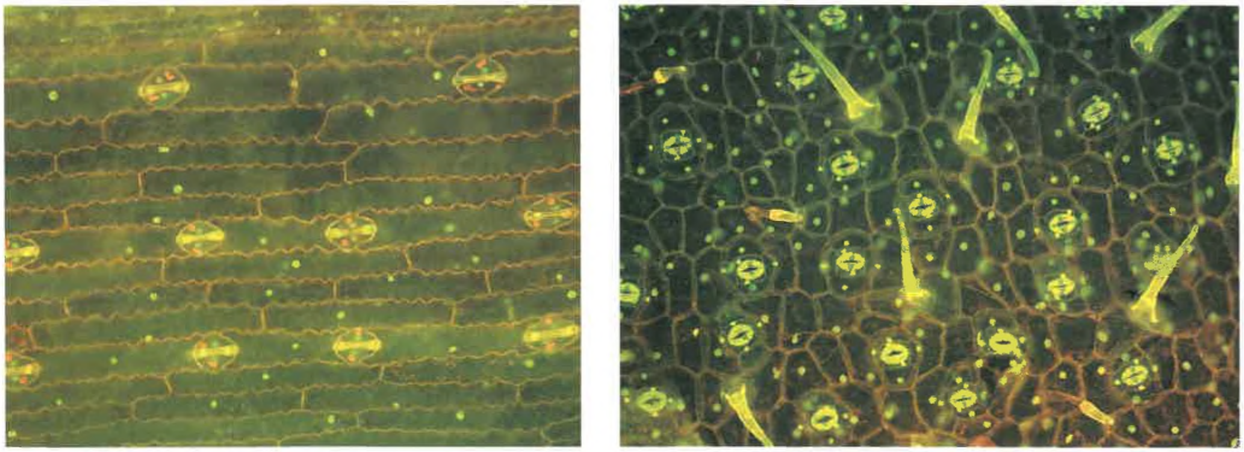


FIGURE 31-18

Scanning electron micrographs of monocot and dicot leaves show how the arrangement of stomata in each is different. (a) In the corn leaf, the stomata are in a parallel arrangement, which is typical of monocots. (b) In the potato leaf, the stomata are in a random arrangement, which is typical of dicots. For both monocots and dicots, the movement of water in the guard cells of each stoma is regulated by potassium ions (K^+).

Gas Exchange

Plants obtain carbon dioxide for photosynthesis from the air. Plants must balance their need to open their stomata to receive carbon dioxide and release oxygen with their need to close their stomata to prevent water loss through transpiration. A stoma is bordered by two kidney-shaped guard cells. **Guard cells** are modified cells found on the leaf epidermis that regulate gas and water exchange. Figure 31-18 shows how the stomata are arranged differently in monocots and dicots.

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

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

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SECTION 31-4 REVIEW

1. What is the difference between a simple leaf and a compound leaf?
2. Describe the basic function of each of the three leaf tissues.
3. What are three types of specialized leaves?
4. Explain the function of the guard cells in regulating stomatal opening and closing.
5. Why do plants grown in greenhouses in winter rarely grow as fast as the same type of plant grown outside in the summer even if the temperatures are the same in both locations?
6. CRITICAL THINKING Why is it an advantage for a plant to have most of its stomata on the underside of a horizontal leaf?

CHAPTER 31 REVIEW

SUMMARY/VOCABULARY

31-1

- Plants consist of three types of cells—parenchyma, sclerenchyma, and collenchyma.
- The dermal system consists of the epidermis, or the outermost layer of cells; it functions in absorption and protection in the roots and in gas exchange and protection in stems and leaves.
- The bulk of leaves, nonwoody stems, and nonwoody roots is ground tissue, which functions in storage, metabolism, and support.
- Vascular tissue consists of xylem, which carries water and mineral nutrients, and phloem, which transports organic compounds and some mineral nutrients.
- An increase in length, called primary growth, occurs mainly at the tips of stems and roots in the apical meristems.
- In secondary growth, the stems and roots increase in diameter in the lateral meristems.

Vocabulary

apical meristem (602)
collenchyma (599)
companion cell (601)
cork (602)
cork cambium (602)
cuticle (600)
dermal tissue system (600)
epidermis (600)
ground tissue system (601)
intercalary meristem (602)
lateral meristem (602)
meristem (602)
parenchyma (599)
pit (601)
primary growth (602)
sclerenchyma (600)
secondary growth (602)
sieve plate (601)
sieve tube (601)
sieve tube member (601)
tracheid (601)
vascular cambium (602)
vascular tissue system (601)
vessel (601)
vessel element (601)

31-2

- Roots anchor the plant and store and absorb water and mineral nutrients from the soil.
- A taproot system has a large primary root, and a fibrous root system has many small branching roots.
- Young roots produce root hairs, which are extensions of epidermal cells that increase the surface area for absorption.
- The root endodermis prevents substances from entering or leaving the root vascular tissue without passing through a cell membrane.

Vocabulary

adventitious root (604)
cortex (605)
endodermis (605)
fibrous root system (603)
macronutrients (606)
micronutrients (606)
pericycle (606)
root cap (604)
root hair (604)
taproot (603)

31-3

- Stems function in the transportation and storage of nutrients and water.
- The stems of monocots usually have scattered vascular bundles and usually lack secondary growth.
- Dicot stems have vascular bundles arranged in a ring and often produce abundant secondary growth.
- Secondary growth consists primarily of secondary xylem, called wood.
- In nontropical areas, secondary xylem in stems forms one annual ring each year.
- The outer bark of trees consists of cork produced by the cork cambium.
- The cohesion-tension theory describes the process of how water is pulled up through the xylem tissue.
- The pressure-flow hypothesis describes the process of how organic compounds are transported in the phloem tissue.

Vocabulary

annual ring (611)
bark (611)
bud (609)
bud scale (609)
cohesion-tension theory (612)
heartwood (611)
internode (609)
node (609)
pith (610)
pressure-flow hypothesis (613)
sapwood (611)
sink (613)
source (613)
springwood (611)
summerwood (611)
translocation (612)
transpiration (613)
wood (611)

31-4
- The identification of plants is based on the shape, size, and arrangement of leaf blades. Plants with simple leaves or compound leaves are common.
- Photosynthesis occurs mostly in the palisade mesophyll, which consists of rows of closely packed cells, and the loosely packed spongy mesophyll.
- Gas exchange in leaves is controlled by stomata, or small openings in the leaf.
- Most of the water absorbed by a plant evaporates from the stomata during transpiration.
- Two guard cells surround each stoma. When the guard cells gain water, the stoma opens. When the guard cells lose water, the stoma closes.

Vocabulary

blade (616)
compound leaf (616)
guard cell (618)
leaflet (616)
mesophyll (616)
net venation (616)
palisade mesophyll (616)
parallel venation (616)
petiole (616)
simple leaf (616)
spongy mesophyll (616)
tendril (615)
vein (616)
venation (616)

REVIEW

Vocabulary

In each of the following sets, choose the term that does not belong and explain why.

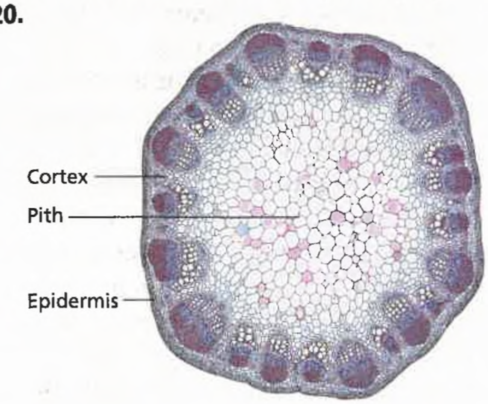
1. wood, bark, epidermis, cork
2. sieve tube member, mesophyll, tracheid, vessel element
3. apical meristem, primary xylem, vascular cambium, endodermis
4. root hair, transpiration, vessel element, collenchyma
5. blade, cork, petiole, vein

Multiple Choice

6. Nonfunctional xylem in the center of a tree trunk is (a) summerwood (b) sapwood (c) heartwood (d) springwood.
7. Mesophyll is the site of (a) water absorption (b) storage (c) photosynthesis (d) secondary growth.
8. Water moves between tracheids through (a) end walls (b) stomata (c) vessel elements (d) pits.
9. Stomata open and close due to water pressure changes in the (a) guard cells (b) sieve tube member (c) root hairs (d) cortex.
10. The root apical meristem is protected by the (a) bud scales (b) cuticle (c) root cap (d) cortex.
11. Collenchyma and sclerenchyma function mainly in (a) storage (b) photosynthesis (c) support (d) transport.
12. Most monocots do not have (a) primary growth (b) secondary growth (c) xylem (d) phloem.
13. A waterproof substance occurs in cell walls of (a) cortex (b) endodermal cells (c) palisade mesophyll cells (d) vessel elements.
14. The main site of photosynthesis in cactuses is the (a) root (b) leaf (c) flower (d) stem.
15. A structure found in stems but not in roots is (a) epidermis (b) vascular tissue (c) node (d) cortex.

Short Answer

16. What causes a plant stem or root to grow in diameter?
17. Explain the difference between heartwood and sapwood.
18. Describe the different arrangements of vascular bundles in the stems and leaves of monocots and dicots.
19. What substances are transported through the tissue shown in the photograph below?
20.



Distinguish between woody plants and nonwoody plants, and give an example of each.

21. Explain the difference between primary growth and secondary growth.
22. Briefly describe the cohesion-tension theory of water movement in the xylem.
23. List three modified types of leaves.
24. How are a sweet potato and a white potato different? How are they similar?
25. Explain how guard cells regulate the opening and closing of stomata.

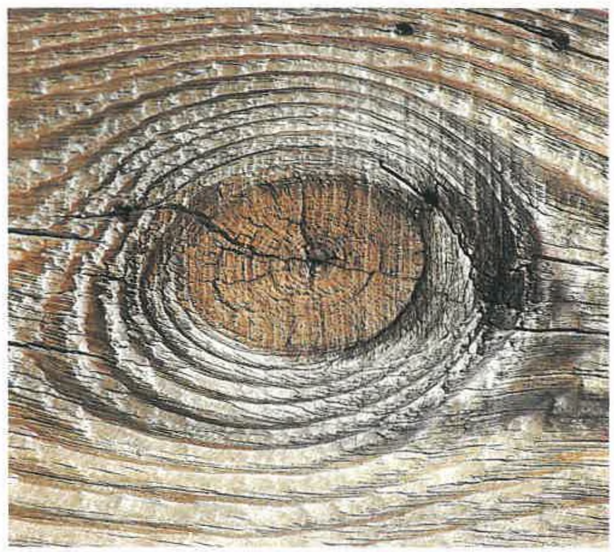
CRITICAL THINKING

1. Copy the chart shown below on a sheet of paper. Fill in the plant structures corresponding to the human structures listed in the chart.

Common Structural Functions

Function	Human structure	Plant structure
Gas exchange	lungs	a.
Circulation	blood vessels	b.
Water intake	mouth	c.
Energy intake	mouth	d.
Protective covering	skin	e.
Internal support	skeleton	f.
Energy storage	fat cells	g.

2. When transplanting a plant, it is important that you not remove any more soil than necessary from around the roots. From your knowledge of the function of roots and root hairs, why do you think is this so important?
3. Suppose you examine a tree stump and notice that the annual rings are thinner and closer together 50 rings in from the edge. What would you conclude about the climate in the area 50 years ago?
4. Girdling is the removal of a narrow strip of bark all the way around a tree trunk. What effects might girdling have on a plant's shoots and roots?
5. What causes a knot in a board, like that shown in the photograph below?



EXTENSION

1. Read "Why Tulips Can't Dance" in *Science News*, February 5, 2000, on page 95. Describe how the stem structures of tulips and daffodils compare. How does the stem structure of daffodils contribute to the plants' ability to bend in gusty winds?
2. Measure transpiration in a common nonwoody plant. Buy two small flowering plants or tomato plants from a local nursery. Get plants as identical in size as possible. Make sure the plants are well watered, and then cover the pots with a plastic bag. Tie the bag shut around the base of the plant's stem without injuring the stem. Weigh each pot to the nearest gram and record the mass. Place one plant in the dark and one plant in bright light. Weigh the pots again after two hours, and calculate the amount of transpiration in grams as follows: transpiration = initial mass − final mass. If there is no difference in transpiration, extend the length of the experiment. Which treatment resulted in the most transpiration? Why?

CHAPTER 31 INVESTIGATION

Observing Roots, Stems, and Leaves

OBJECTIVES

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

PROCESS SKILLS

- observing
- identifying
- relating structure and function

MATERIALS

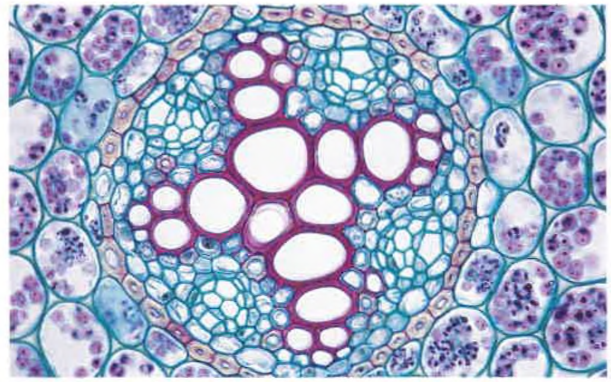
- prepared slides of the following tissues:
  - *Allium* root tip longitudinal section
  - *Syringa* leaf cross section
  - *Ranunculus* root cross section
  - *Ranunculus* stem cross section
  - *Zea mays* stem cross section
- compound light microscope

Background

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

PART A Roots

1. CAUTION **Glass slides may break and cut you.** Observe the prepared slide of the *Allium* root tip under low power. Locate the root cap and the root tip meristematic cells. You may look at the photograph on page 604 for help. Note the long root hairs in the area above the root tip.
2. In your lab report, draw the root tip that you observe, and label the root cap, meristem, and root hairs in your drawings.

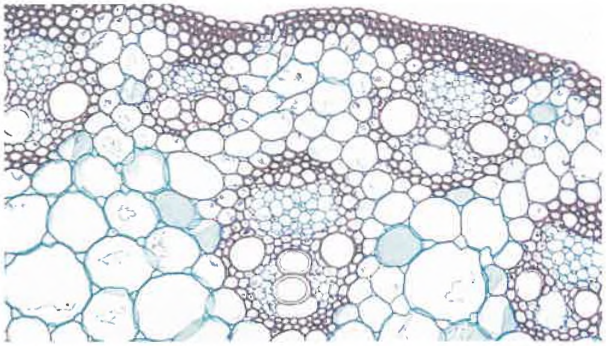


Ranunculus *root (275×)—a dicot*

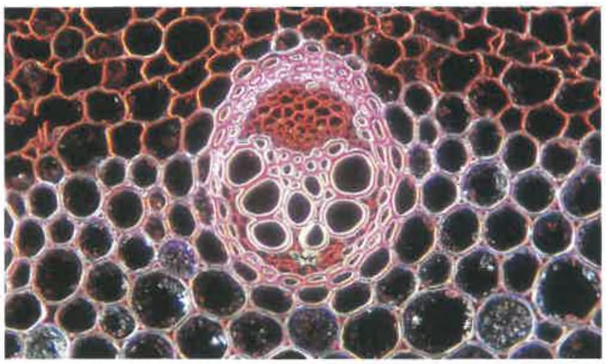
3. Change slides to the root cross section of the dicot *Ranunculus.* This slide should look similar to the photograph shown above. The inner core is the vascular tissue, which is surrounded by the endodermis. This area of the tissue is involved in the transport of water, mineral nutrients, and organic compounds. Look for the star-shaped xylem and the smaller phloem cells surrounding the xylem.
4. In your lab report, draw what you see, and identify the xylem tissue and the phloem tissue in your drawing.
5. Locate the cortex, where starch is stored, which surrounds the vascular cylinder. Outside the cortex, find the epidermal cells and their root hairs. Draw a one-quarter section of the root tissues. Label all the tissues in your lab report.

PART B Stems

6. Observe a prepared slide of the stem of *Zea mays,* a monocot, and find the epidermis and the photosynthetic layer. It should look like the photograph on the next page. In the center, look for the vascular bundles made up of xylem and phloem. Draw a diagram showing the location of the vascular bundles and the epidermis layer as they appear when viewed under low power.
7. Switch to high power, and observe a vascular bundle. Draw the vascular bundle, and label the tissues.
8. Observe a cross section of *Ranunculus,* a herbaceous dicot stem. Compare your slide with the photograph of



Zea mays *stem (130×)—a monocot*



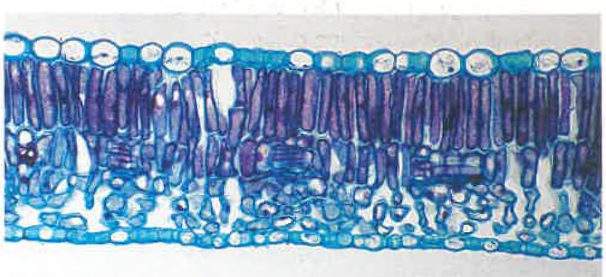
Ranunculus *stem (151×)—a dicot*

Ranunculus shown above. Look for the epidermis and cortex layers. Notice that in a dicot, the stem is more complex than the root. Note the arrangement of the vascular bundles. In your lab report, draw what you observe. Label the epidermis, cortex, and individual vascular bundles.

9. Focus on a vascular bundle under high power. Draw and label a diagram of a vascular bundle in your lab report.

PART C Leaves

10. Observe a prepared slide of a lilac leaf, *Syringa*, shown below, under low power, and find the lower epidermis.



Syringa *leaf (530×)*

11. Identify the stomata on the lower epidermis of the lilac leaf. Find the guard cells that open and close a particular stoma. Locate an open stoma and a closed stoma. Draw and label diagrams of the stomata and the guard cells in your lab report.

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

13. Clean up your materials before leaving the lab.

Analysis and Conclusions

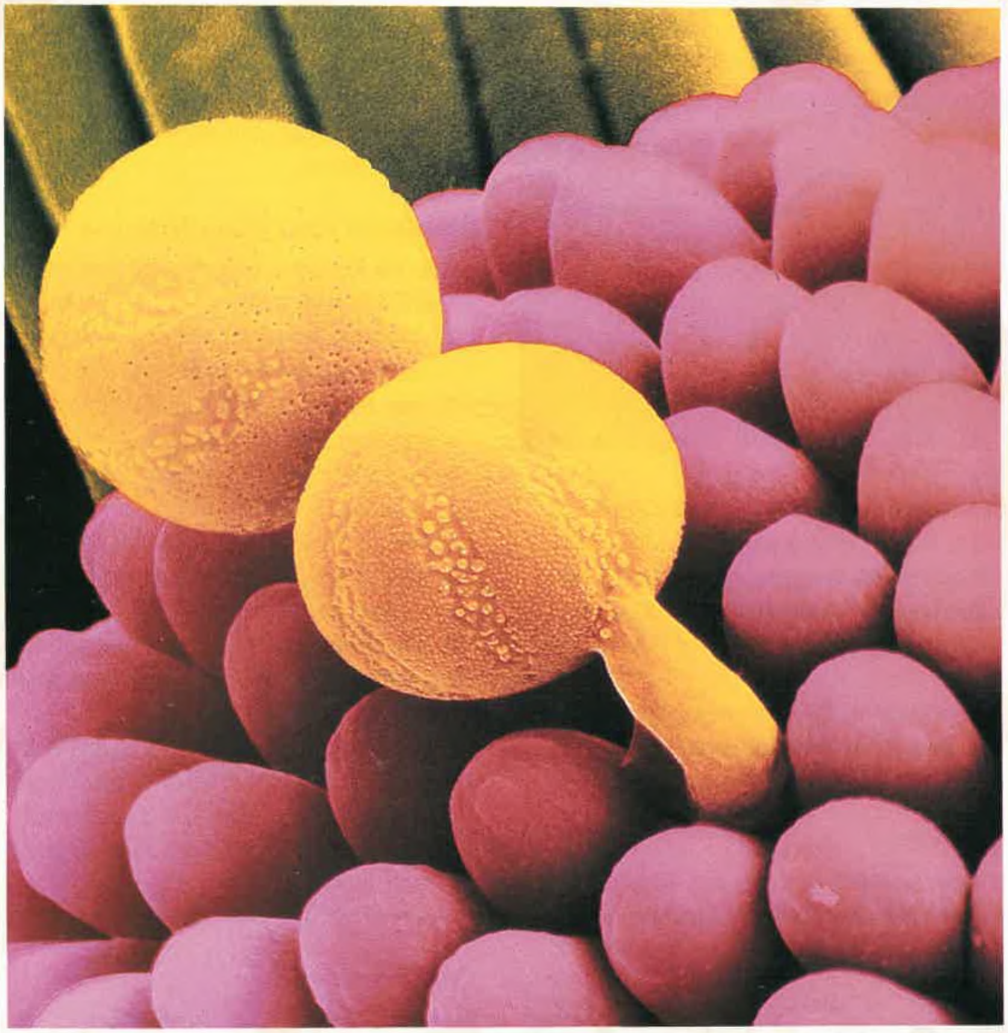
1. In the dicot root that you observed, where are phloem and xylem located?
2. Where are the xylem and phloem found in the herbaceous stem that you observed?
3. How are the vascular bundles different in the monocot and dicot stems that you observed?
4. How are the root cap cells different from the root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

Further Inquiry

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

CHAPTER 32

PLANT REPRODUCTION



Two pollen grains are on the stigma of a flower of goose grass, Galium aparine. *A pollen tube, seen growing out of one of these pollen grains, will travel toward the ovary.*

FOCUS CONCEPT: *Evolution*

As you read, note the many plant adaptations that help ensure the successful reproduction, protection, and dispersal of offspring.

SECTION

32-1

PLANT LIFE CYCLES

A life cycle includes all of the stages of an organism's growth and development. Recall from Chapter 30 that a plant's life cycle involves two alternating multicellular stages—a diploid (2n) sporophyte stage and a haploid (1n) gametophyte stage. This type of life cycle is called alternation of generations. Also recall that the size of gametophytes and sporophytes varies among the plant groups.

OBJECTIVES

▲ Describe the life cycle of a moss.

● Describe the life cycle of a typical fern.

■ Describe the life cycle of a gymnosperm.

◆ Compare and contrast homospory and heterospory.

THE LIFE CYCLE OF MOSSES

The dominant form of a moss is a clump of leafy green gametophytes. Look at the moss life cycle illustrated in Figure 32-1. Moss gametophytes produce gametes in two types of reproductive structures—antheridia and archegonia. An **antheridium** (AN-thuhr-ID-ee-uhm) is a male reproductive structure that produces hundreds of flagellated sperm by mitosis. An **archegonium** (AWR-kuh-GOH-nee-uhm) is a female reproductive structure that produces a single egg by mitosis. During moist periods, sperm break out of the antheridia and swim to the archegonia. One sperm fertilizes the egg at the base of an archegonium, forming a diploid zygote. Through repeated mitotic divisions, the zygote forms an embryo and develops into a sporophyte.

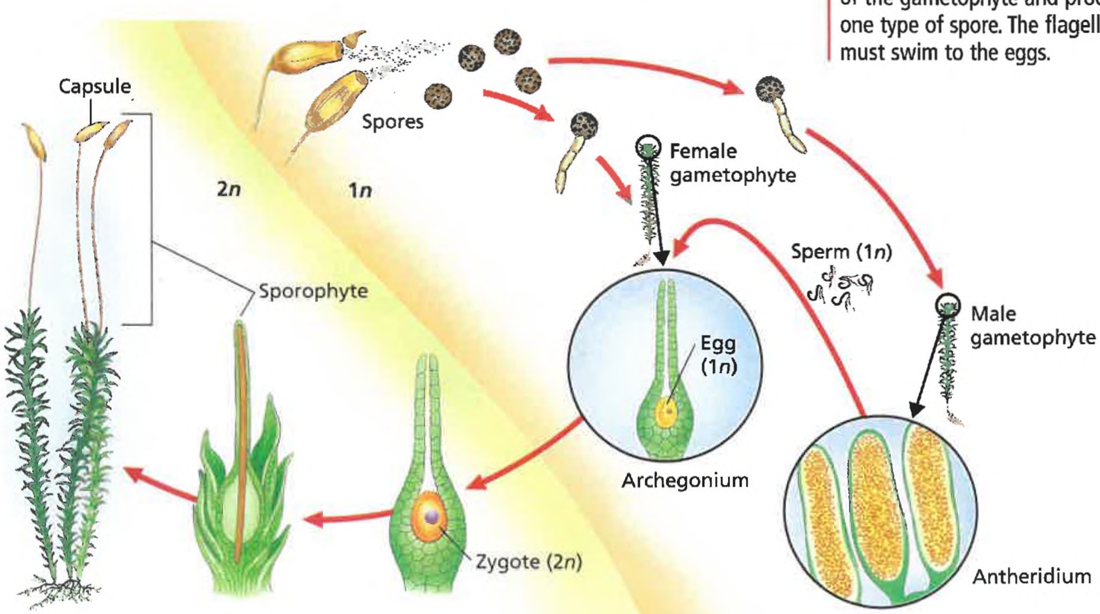


FIGURE 32-1
The life cycle of a moss includes a relatively large, leafy green gametophyte, which produces gametes, and a smaller sporophyte, which grows from the tip of the gametophyte and produces only one type of spore. The flagellated sperm must swim to the eggs.

A moss sporophyte begins as a thin stalk that grows from the tip of a gametophyte. The sporophyte remains attached to the gametophyte and depends on it for nourishment. Soon, cells at the tip of a stalk form a sporangium, called the capsule. Cells in the capsule undergo meiosis to form haploid spores, which are all the same. The production of one type of spore is called **homospory** (hoh-MAHS-puh-ree). Therefore, the life cycle of mosses is called *homosporous* (hoh-MAHS-puh-ruhs) *alternation of generations.* When the spores are mature, the capsule splits open, and the spores are carried away by the wind. Spores that land in favorable environments grow into new gametophytes.

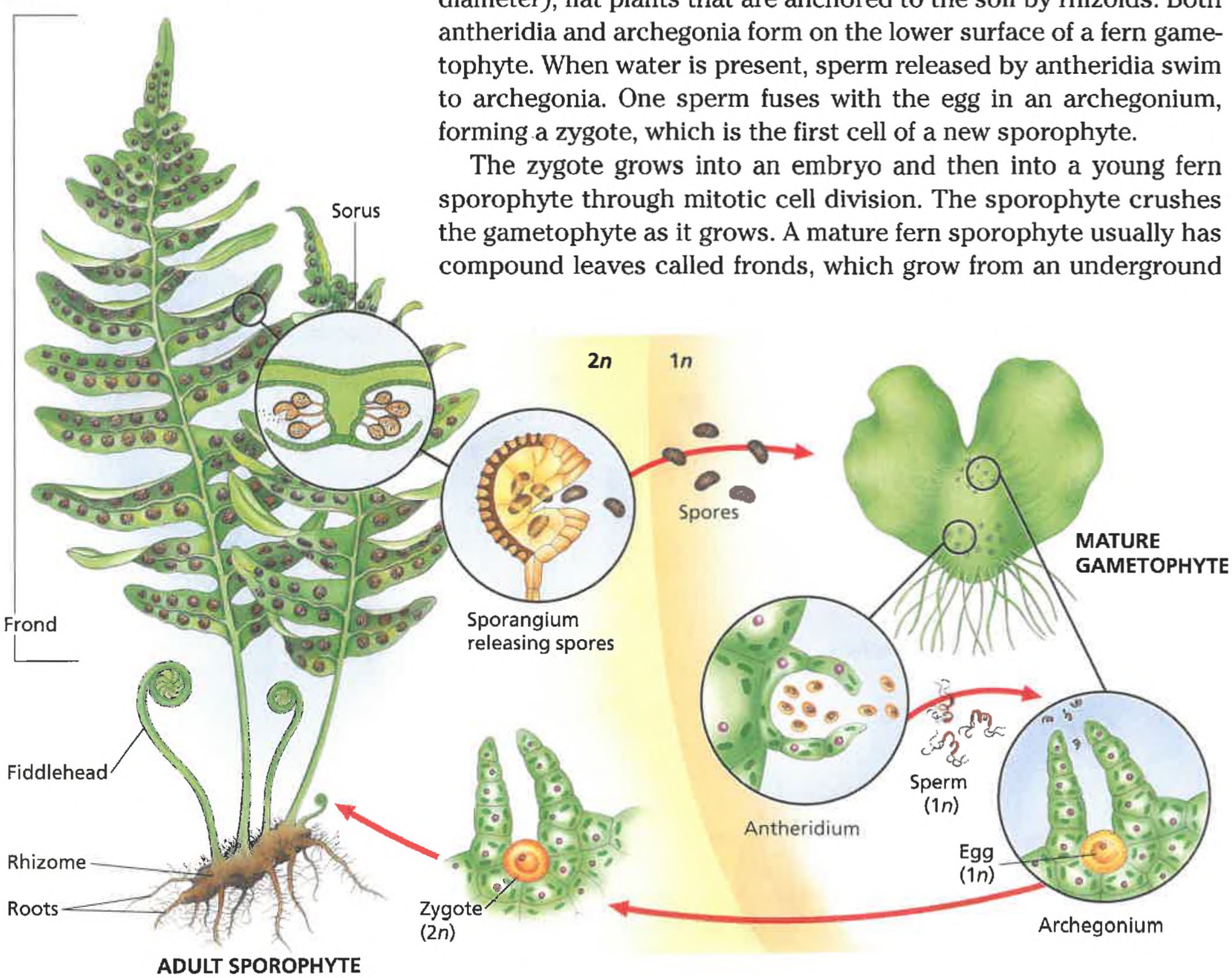
THE LIFE CYCLE OF FERNS

The life cycle of a fern, shown in Figure 32-2, is similar to the moss life cycle. Like mosses, most ferns are homosporous. And as in mosses, the fern sporophyte grows from the gametophyte. But in the fern life cycle, the sporophyte, not the gametophyte, is the dominant generation. Fern gametophytes are tiny (about 10 mm, or 0.5 in., in diameter), flat plants that are anchored to the soil by rhizoids. Both antheridia and archegonia form on the lower surface of a fern gametophyte. When water is present, sperm released by antheridia swim to archegonia. One sperm fuses with the egg in an archegonium, forming a zygote, which is the first cell of a new sporophyte.

The zygote grows into an embryo and then into a young fern sporophyte through mitotic cell division. The sporophyte crushes the gametophyte as it grows. A mature fern sporophyte usually has compound leaves called fronds, which grow from an underground

FIGURE 32-2

The life cycle of most ferns includes a large sporophyte, which produces only one type of spore, and a small gametophyte, which produces gametes. Both the eggs and sperm are produced on the same gametophyte. The flagellated sperm must swim to the eggs.



stem, or rhizome. In most ferns, certain cells on the underside of the fronds develop into sporangia. In many ferns, the sporangia are grouped together in clusters called **sori** (SOH-ree). Cells inside a sporangium undergo meiosis, forming haploid spores. At maturity, the sporangium opens and the spores are catapulted 1 cm (0.4 in.) or more and are then carried away by air currents. When the spores land, and if conditions are right, they grow into new gametophytes.

THE LIFE CYCLE OF CONIFERS

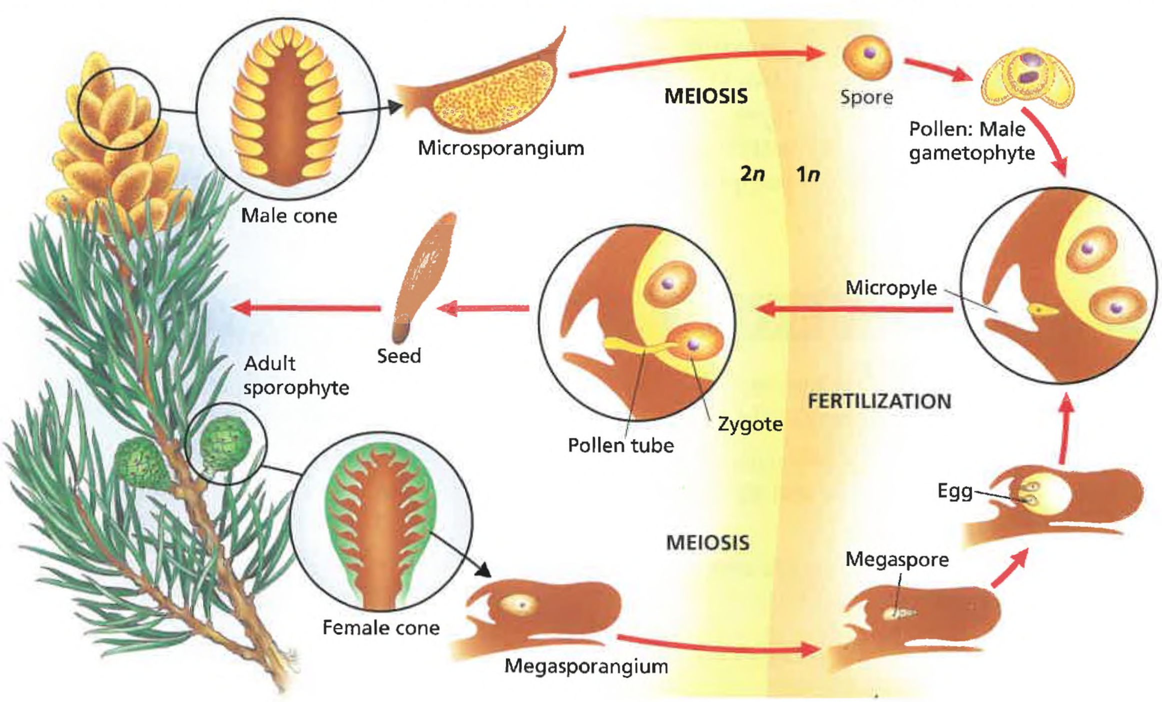
Unlike mosses and most ferns, gymnosperms produce two types of spores—male **microspores** and female **megaspores.** Microspores grow into male gametophytes, while megaspores grow into female gametophytes. The production of different types of spores is called **heterospory** (HET-uhr-AHS-puh-ree). Thus, the gymnosperm life cycle is called *heterosporous* (HET-uhr-AHS-puh-ruhs) *alternation of generations.* All seed plants, spike mosses, quillworts, and a few fern species also have heterospory, which ensures that a sperm will fertilize an egg from a different gametophyte and increases the chance that new combinations of genes will occur among the offspring.

Figure 32-3 shows the life cycle of a pine, which is a conifer, the most common kind of gymnosperm. The conifer life cycle illustrates how seed plants reproduce without water for sperm to swim through. The familiar pine tree is a sporophyte. Like humans, pines cannot sexually reproduce until they are mature. Depending on the species, pines take from 3 to more than 30 years to reach adulthood.

In pines, sexual reproduction takes more than two years. During the first summer, a mature pine tree produces separate male and

FIGURE 32-3

The life cycle of a gymnosperm includes a large sporophyte, which produces two types of spores, and microscopic gametophytes, which produce gametes. Female gametophytes produce eggs, and male gametophytes produce sperm. The nonflagellated sperm reach the eggs through a pollen tube.



female cones. The male cones produce microsporangia, while the female cones produce megasporangia. The following spring, cells in all sporangia undergo meiosis and divide to produce haploid spores. These spores never leave the parent to develop independently. **Megasporangia** produce megaspores, which develop into **megagametophytes,** or female gametophytes. A thick layer of cells called an **integument** (in-TEG-yoo-muhnt) surrounds each megasporangium. The integument has a small opening called the **micropyle** (MIE-kroh-PIEL). Together, a megasporangium and its integument form a structure called an **ovule** (AHV-yool). Two ovules develop on each scale of a female cone. **Microsporangia** produce microspores, which develop into **microgametophytes,** or male gametophytes. A **pollen grain** is a microgametophyte of a seed plant.

The male cones of a pine release huge numbers of pollen grains, as seen in Figure 32-4. Pine pollen travels on the wind, and only a few grains may land on a female cone. The pollen grains drift between the cone scales until they reach the ovules. The arrival of a pollen grain at the micropyle of a pine ovule is called pollination. A drop of fluid at the micropyle captures the pollen grain. As the fluid dries, the pollen grain is drawn into the micropyle. After pollination, the female gametophyte within the ovule produces archegonia and eggs.

After pollination, the pollen grain begins to grow a **pollen tube,** a slender extension of the pollen grain that enables sperm to reach an egg. Unlike the sperm of seedless plants, pine sperm do not have flagella and they do not swim to an egg. The pollen tube takes about a year to reach an egg only a few millimeters away. During this time, two sperm develop in the pollen tube. When the pollen tube reaches an archegonium, one sperm unites with an egg to form a zygote. The other sperm and the pollen tube die. Over the next few months, the zygote develops into an embryo as the ovule matures into a seed.

Seed plants benefit from having a life cycle with microscopic gametophytes. The microscopic gametophytes are enclosed in structures produced by the much larger sporophyte. These structures provide a way for the sperm to fertilize the eggs without water. Sexual reproduction in seed plants can therefore take place independent of seasonal rains or other periods of moisture.

FIGURE 32-4

The male cones (pollen cones) of pines produce millions of pollen grains. The male cones then die. Wind-pollinated species typically produce large amounts of pollen. Large numbers of pollen grains increase the odds that female cones (seed cones) will be pollinated.

SECTION 32-1 REVIEW

1. **Distinguish between an antheridium and an archegonium, and state the function of each.**
2. **Draw a generalized diagram of alternation of generations showing the haploid and diploid phases of the moss life cycle.**
3. **List three differences between the life cycle of a fern and that of a pine.**
4. **How are the spores of seed plants different from the spores of bryophytes and most ferns?**
5. **In what way did the enclosure of the male gametophyte contribute to the great evolutionary success of seed plants?**
6. **CRITICAL THINKING Many mosses and ferns live in the desert. Why do you think this is so?**

SECTION

32-2

OBJECTIVES

▲ Identify the four main flower parts, and state the function of each.

● Describe ovule formation and pollen formation in angiosperms.

■ Relate flower structure to methods of pollination.

◆ Describe fertilization in flowering plants.

▲ Compare and contrast the gymnosperm and angiosperm life cycles.

SEXUAL REPRODUCTION IN FLOWERING PLANTS

You have probably admired flowers for their bright colors, attractive shapes, and pleasing aromas. These characteristics are adaptations that help ensure successful sexual reproduction by attracting animal pollinators. But some flowers are not colorful, large, or fragrant. Such flowers rely on wind or water for pollination.

PARTS OF A FLOWER

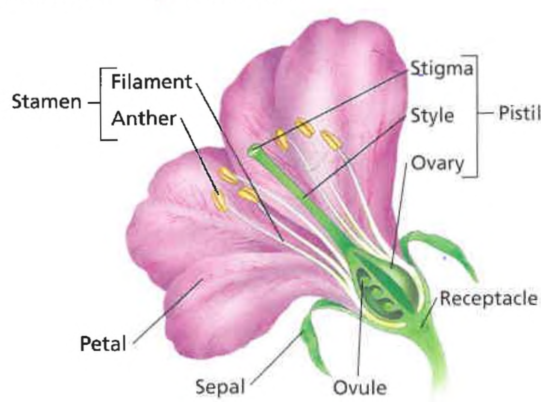
Recall from Chapter 30 that early land plants lacked leaves and roots and consisted only of stems. Leaves evolved from branches of stems. Botanists consider flowers to be highly specialized branches and the parts of a flower to be specialized leaves. All of these specialized leaves form on the swollen tip of a floral "branch," which is called the **receptacle.**

Flower parts are usually found in four concentric whorls, or rings. Figure 32-5 shows a classic flower with all of the flower parts. **Sepals** (SEE-puhlz) make up the outermost whorl of flower parts. They surround and protect the other parts of a developing flower before it opens. **Petals** make up the next whorl. Most animal-pollinated flowers have brightly colored petals. The petals and sepals of wind-pollinated plants are usually small or absent.

The two innermost whorls of flower parts contain the reproductive structures. The male reproductive structures are **stamens** (STAY-muhnz), each of which consists of an anther and a filament. An **anther** contains microsporangia, which produce microspores that develop into pollen grains. A stalklike **filament** supports an anther. The innermost whorl contains the female reproductive structures, which are called **carpels** (KAHR-puhlz). One or more carpels fused together make up the structure called a **pistil.** The enlarged base of a pistil is called the **ovary.** A **style,** which is usually stalklike, rises from the ovary. The tip of the style is called the **stigma.** Generally, a stigma is sticky or has hairs, enabling it to trap pollen grains. Most species of flowering plants have flowers with both stamens and pistils. However, some species have flowers with only stamens (male flowers) or pistils (female flowers).

FIGURE 32-5

This diagram shows a flower with all four whorls of flower parts—sepals, petals, stamens, and carpels. Many flowers lack one or more of these whorls.



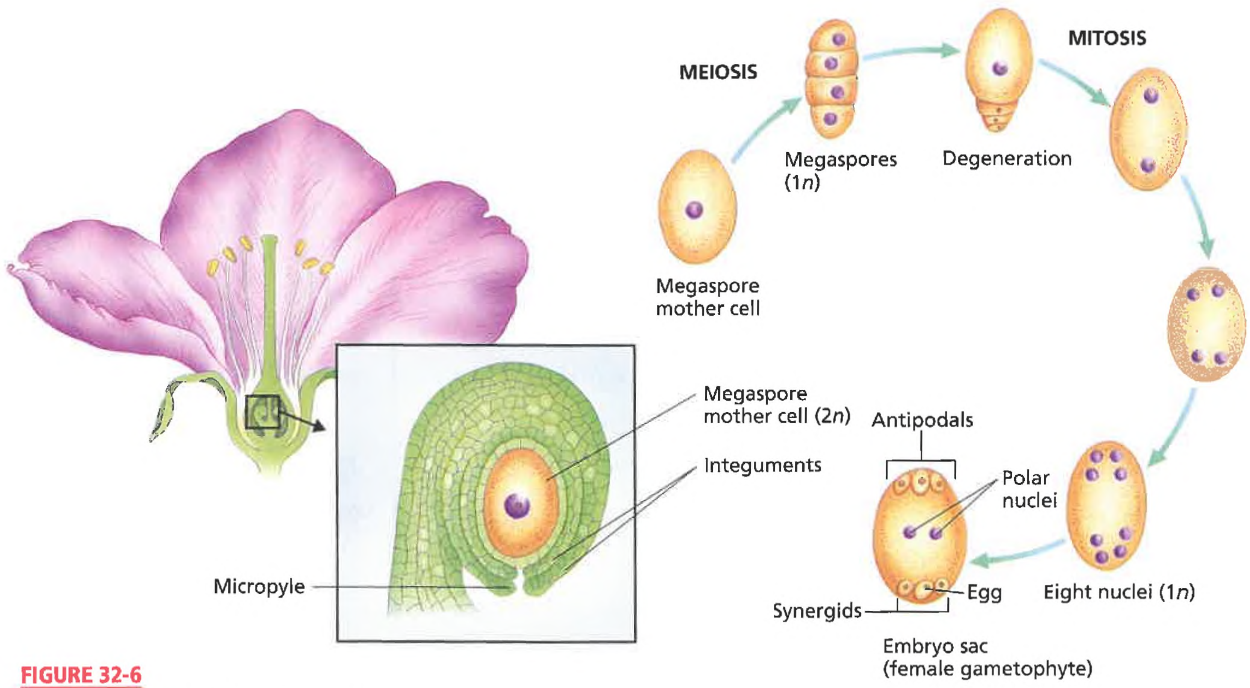


FIGURE 32-6

A cross section of an immature ovule from a flower reveals a single large cell, a megaspore mother cell. This cell undergoes meiosis and produces four megaspores. One of the megaspores undergoes a series of divisions that result in the formation of an embryo sac (a female gametophyte).

OVULE FORMATION

In flowering plants, ovules form in the ovary of a pistil. As Figure 32-6 shows, an angiosperm ovule consists of a megasporangium surrounded by two integuments. Like the integument of a pine ovule, these two integuments do not completely enclose the megasporangium. At one end of the ovule is the micropyle, through which a pollen tube can enter.

Initially, an ovule contains a large diploid cell called a megaspore mother cell. A **megaspore mother cell** undergoes meiosis and produces four haploid megaspores. Only one of the megaspores enlarges. The other three die and disappear. In most species, the remaining megaspore undergoes three consecutive mitotic divisions to produce eight haploid nuclei. These nuclei migrate to certain locations within the ovule. As you can see in Figure 32-6, the nuclei are initially arranged in two groups of four, with one group at each end of the cell. Here is what happens next:

- One nucleus from each group migrates to the center of the cell. These two nuclei are called **polar nuclei** because they came from the ends, or poles, of the cell.
- Cell walls form around each of the remaining six nuclei.
- One of the three cells nearest the micropyle enlarges and becomes the egg. The remaining five cells die after fertilization.

The resulting structure, which is microscopic and usually contains seven cells and eight nuclei, is called an **embryo sac.** The embryo sac is a mature female gametophyte, or megagametophyte. The embryo sac is another feature seen in angiosperms but not in gymnosperms.

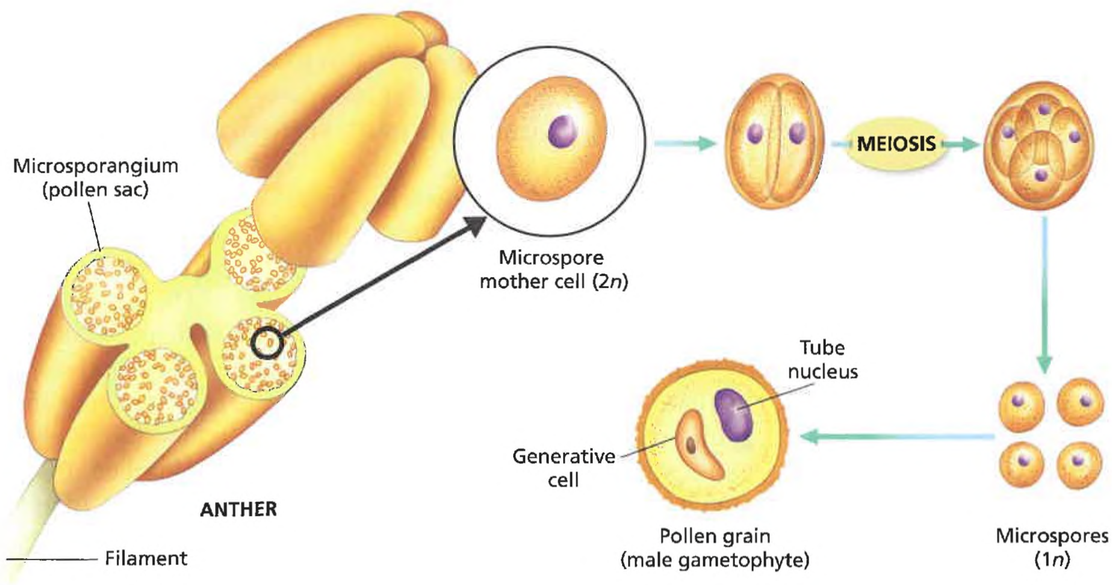


FIGURE 32-7

A cross section of the anther of a flower reveals four pollen sacs (microsporangia). Microspore mother cells within the microsporangia undergo meiosis and produce microspores. Each microspore then develops into a two-celled pollen grain (a male gametophyte).

POLLEN GRAIN FORMATION

In flowering plants, pollen grains form in the anthers of stamens. Figure 32-7 shows how pollen forms in anthers. An anther contains four microsporangia, or pollen sacs. Initially, the pollen sacs contain many diploid cells called **microspore mother cells.** Each of these cells undergoes meiosis and produces four haploid microspores. A microspore undergoes mitosis and divides into two haploid cells. A thick wall then develops around the microspore. The resulting two-celled structure is a pollen grain, which is the male gametophyte, or microgametophyte. The larger of the two cells is the **tube cell,** which contains the tube nucleus. When a pollen grain germinates, the tube nucleus causes the tube cell to grow through the style, forming a pollen tube. The smaller of the two cells is the **generative cell,** which divides by mitosis to form two sperm.

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POLLINATION

Before a sperm can fertilize the egg contained in an embryo sac, pollen must be transferred from an anther to a stigma. This process is called pollination. Recall from Chapter 9 that pollination involving the same flower, flowers on the same plant, or flowers from two genetically identical plants is called self-pollination. In contrast, pollination involving two genetically different plants is called cross-pollination. Plants produced by cross-pollination are called hybrids.

FIGURE 32-8

These long, tubular flowers are adapted for pollination by hummingbirds, which have long beaks adapted for reaching the nectar located deep in the flowers.

The type of pollination is of great concern to growers of many fruit crops. Some cultivars of fruit crops, such as apples and peaches, will produce fruit when they are self-pollinated. Others must be cross-pollinated in order to produce fruit. Date palms and kiwis produce male and female flowers on separate plants. Therefore, a few male plants must be grown to pollinate the mostly female crop.

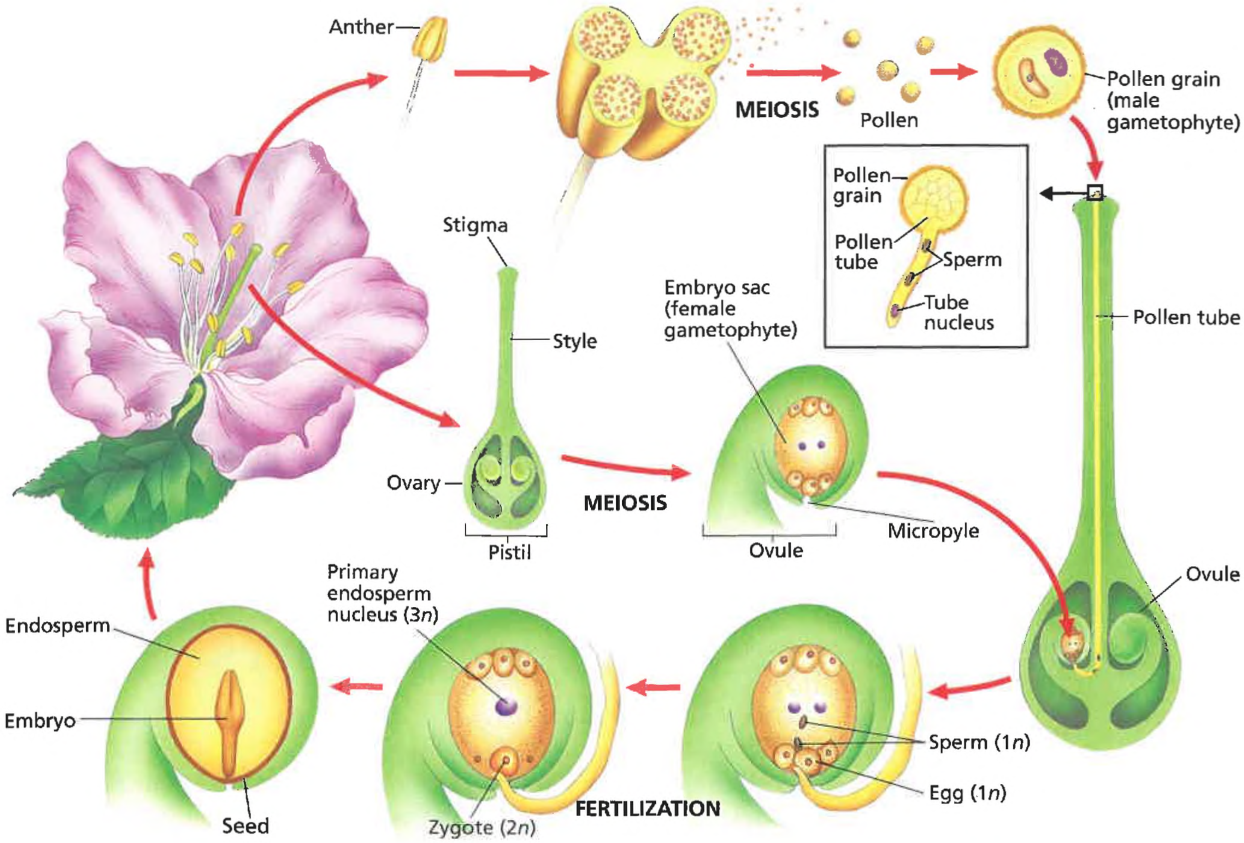
The pollination of flowering plants occurs in several ways. Flower structure promotes self-pollination in some plants, such as peas and beans, which have flowers with petals that completely enclose both the male and female flower parts. Aquatic plants, such as sea grasses, often have pollen that is dispersed by water. Many plants, such as oaks and grasses, release their pollen into the air. The flowers of wind-pollinated angiosperms are small and lack showy petals and sepals. Successful wind pollination depends on four conditions: the release of large amounts of pollen, the ample circulation of air to carry pollen, the relative proximity of individuals to one another, and dry weather to ensure that pollen is not washed from the air by rain.

Most plants with colorful or fragrant flowers are pollinated by animals. Bright petals and distinctive odors attract animals that feed on pollen and **nectar,** which is a nourishing solution of sugars. When animals gather nectar, the pollen sticks to their bodies. The animals deposit some of the pollen on other flowers as they collect more nectar. Pollinators include bats, bees, beetles, moths, butterflies, hummingbirds, monkeys, mosquitoes, and people. Of course, people pollinate to obtain desirable seeds or fruits, not to obtain nectar. The long beak of a hummingbird, such as the one shown in Figure 32-8, is adapted to collect nectar from flowers. As the hummingbird collects the nectar, pollen from the flowers is deposited on the hummingbird's body.

FERTILIZATION

Fertilization, which is the union of gametes, follows pollination. In order for fertilization to occur, a pollen tube must grow to an egg, and sperm must form. Unlike a conifer's pollen tubes, which take about a year to reach an egg, an angiosperm's pollen tubes usually reach an egg a day or two after pollination. The sequence of events leading to angiosperm fertilization is shown on the next page in Figure 32-9.

When a pollen grain germinates, the nucleus of its tube cell forms a pollen tube that grows through the stigma and style toward the ovary. As the pollen tube grows, its generative cell divides mitotically to form two haploid sperm. The pollen tube grows to an ovule within the ovary and enters it through the micropyle. After the pollen tube penetrates the ovule's embryo sac, the sperm can reach the egg through the passageway that has been formed.



One of the two sperm fuses with the egg, forming a diploid zygote. The zygote eventually develops into an embryo. The second sperm fuses with the two polar nuclei, producing a triploid ($3n$) nucleus. This nucleus then develops into a tissue called endosperm. The endosperm provides nourishment for the embryo. Kernels of corn are mostly endosperm. In many plants, however, the endosperm is absorbed by the embryos as the seeds mature. As you can see, two types of cell fusion occur in the embryo sac: one that produces the zygote and one that produces the endosperm. This process, which is called **double fertilization,** is unique to angiosperms.

FIGURE 32-9

Following pollination, a pollen grain germinates and forms a pollen tube, which grows through the style and enters an ovule through its micropyle. Two sperm travel down the pollen tube. One fertilizes the egg in the ovule's embryo sac, forming a zygote. The other sperm fertilizes the two polar nuclei, forming the endosperm. This process is called double fertilization.

SECTION 32-2 REVIEW

1. **Draw a generalized flower and show the four types of flower parts in relation to each other. Be sure to label each structure.**
2. **Which process in angiosperms, ovule formation or pollen formation, is more similar to the process as it occurs in gymnosperms? Justify your answer.**
3. **How do the flowers of wind-pollinated plants differ from the flowers of animal-pollinated plants?**
4. **Why is fertilization in flowering plants called double fertilization?**
5. **How are the conifer and angiosperm life cycles similar? How are they different?**
6. **CRITICAL THINKING Why is cross-pollination considered to be an adaptive advantage over self-pollination?**

SECTION

32-3

OBJECTIVES

▲ Name different types of fruits.

● Describe several adaptations for fruit and seed dispersal.

■ Compare and contrast the structure and germination of different types of seeds.

◆ Recognize the advantages and disadvantages of asexual reproduction.

▲ Describe methods of vegetative propagation.

DISPERSAL AND PROPAGATION

Fruits and seeds normally result from sexual reproduction in flowering plants. Fruits are adapted for dispersing seeds, while seeds function in the dispersal and propagation of plants. Many plants also propagate (produce new individuals) through asexual reproduction.

DISPERSAL OF FRUITS AND SEEDS

Recall from Chapter 20 that one property of populations is dispersion, the spacial distribution of the individuals. If individual plants are too close together, they must compete with each other for available water, nutrients, and sunlight. One reason for the success of the seed plants is the development of structures that are adapted for dispersing offspring—fruits and seeds.

Fruits and seeds are dispersed by animals, wind, water, forcible discharge, and gravity. You may have walked through a field and unwittingly collected burrs, or stickers, on your shoes or socks. These burrs are fruits, and you helped disperse them. The smell, bright color, or flavor of many fruits attract animals. When animals eat such fruits, the seeds often pass unharmed through their digestive system.

Fruits and seeds dispersed by wind or water are adapted to those methods of dispersal. Orchids have tiny, dustlike seeds that can easily be carried by a slight breeze. Figure 32-10 shows an example of seeds adapted for wind dispersal. Many plants that grow near water produce fruits and seeds that contain air chambers, which allow them to float. Coconuts, for example, may float thousands of kilometers on ocean currents.

The most dramatic method of seed dispersal occurs in plants that forcibly discharge their seeds from their fruits. The tropical sandbox tree, which has fruits that hurl seeds up to 100 m (328 ft), seems to hold the distance record.

Although gymnosperms do not produce fruits, their cones may help protect seeds and aid in seed dispersal. Pine seeds are often dispersed when gravity causes cones to drop and roll away from the parent tree. Pine seeds have wings that aid in wind dispersal.

FIGURE 32-10
Milkweed seeds have "parachutes" that help them drift with the wind.

TYPES OF FRUITS

Botanists define a fruit as a matured ovary. Many different types of fruits have evolved among the flowering plants. Figure 32-11 shows examples of some of these fruit types. Fertilization usually initiates the development of fruits. Fruits protect seeds, aid in their dispersal, and often delay their sprouting. Fruits are classified mainly on the basis of how many pistils or flowers form the fruit and whether it is dry or fleshy. Table 32-1 presents a classification system for fruits. Notice that fruits with common names that include "nut" or "berry" may not be nuts or berries. You may have heard the fleshy seeds of ginkgo, juniper, and yew referred to as berries. These names are misleading because ginkgo, juniper, and yew are gymnosperms, which do not form fruits.

FIGURE 32-11
A pea pod is a simple fruit. A raspberry is an aggregate fruit. A pineapple is a multiple fruit.

TABLE 32-1 ***Fruit Classification***

Major categories and types of fruits	Examples
I. **Simple fruit**—formed from one pistil of a single flower	
A. Dry at maturity	
1. Usually splits open	
a. **Legume**—splits along two sides to form two halves	pea, peanut, black locust
b. **Follicle**—splits along one side	milkweed, columbine
c. **Capsule**—splits in a variety of other ways	poppy, tulip
2. Usually does not split open	
a. **Grain**—thin ovary wall fused to seed coat	corn, wheat
b. **Nut**—thick, woody ovary wall not fused to single seed	oak, chestnut
c. **Achene**—thin ovary wall not fused to single seed	sunflower, dandelion
d. **Samara**—like an achene but with a thin, flat wing	ash, elm, maple
B. Fleshy at maturity and usually not opening	
1. Usually contains only one seed	
a. **Drupe**—stony inner layer around the seed	cherry, coconut, pecan
2. Usually contains many seeds	
a. **Pome**—core with seeds surrounded by papery ovary walls; outer part formed from sepals	apple, pear
b. **Typical berry**—thin skin	grape, tomato, banana
c. **Pepo**—berry with a thick, hard rind	watermelon, cucumber
d. **Hesperidium**—berry with leathery, easily removed skin	orange, grapefruit, lemon
II. **Aggregate fruit**—formed from several pistils of a single flower	
A. Dry at maturity	tulip tree, magnolia
B. Fleshy at maturity	raspberry, strawberry
III. **Multiple fruit**—formed from several flowers growing together	
A. Dry at maturity	sweetgum, sycamore
B. Fleshy at maturity	pineapple, fig

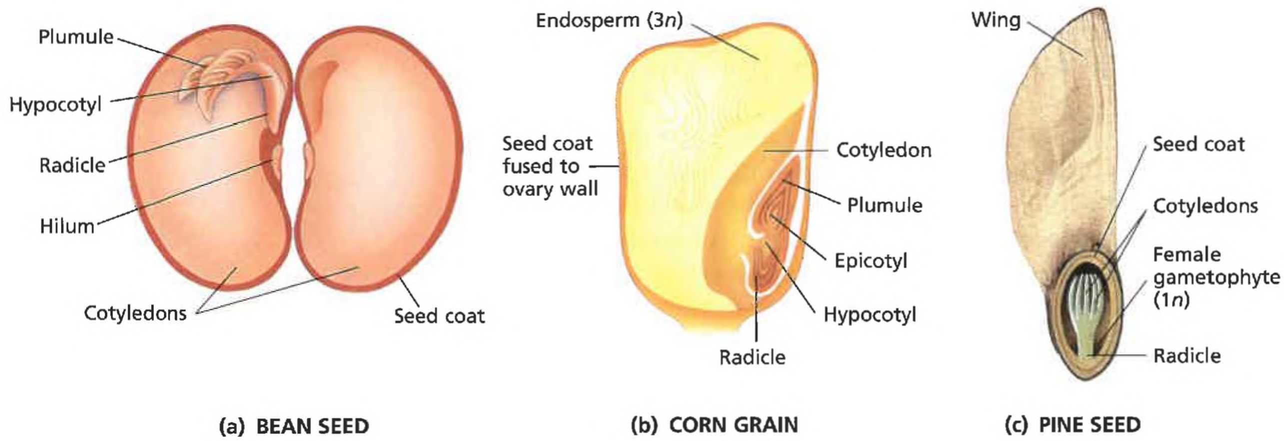


FIGURE 32-12

(a) A bean seed has two cotyledons and no endosperm. (b) A corn grain contains a single seed, which has one cotyledon and endosperm. (c) A pine seed has eight cotyledons and tissue from the female gametophyte.

STRUCTURE OF SEEDS

As you learned in Chapter 30, a seed is a plant embryo surrounded by a protective coat called the **seed coat.** The structure of seeds differs among the major groups of seed plants—angiosperms, which include monocots and dicots, and gymnosperms. To understand some of the differences, examine the seeds shown in Figure 32-12.

Look at the bean seed, which has been opened to reveal the structures inside. Most of the interior of a bean seed is filled by two large, fleshy cotyledons (seed leaves), which are part of the embryo. Recall that angiosperms are classified as either monocots or dicots, based on the number of cotyledons in their embryos. Therefore, beans are dicots. A mature bean seed has no endosperm. The endosperm was absorbed by the fleshy cotyledons.

Between the two cotyledons of a bean seed are the three parts that make up the rest of the embryo: the **radicle,** or embryonic root; the **hypocotyl** (HIE-poh-KAHT-uhl), which is the stem between the cotyledons and the radicle; and the **epicotyl** (EP-i-KAHT-uhl), which is the stem above the cotyledons. The epicotyl, along with any embryonic leaves, is called the **plumule** (PLOO-MYOOL). Along the concave edge of the seed is the **hilum** (HIE-luhm), which is a scar that marks where the seed was attached to the ovary wall.

Now examine the corn grain in Figure 32-12b. Technically, a corn grain is a fruit, but the seed occupies almost the entire grain. The wall of the fruit is very thin and is fused to the seed coat. A single umbrella-shaped cotyledon is pressed close to the endosperm. The cotyledon of a monocot seed does not store nutrients, as bean cotyledons do. Instead, it absorbs nutrients from the endosperm and transfers them to the embryo.

Finally, look at the pine seed in Figure 32-12c. A pine seed contains an embryo with an average of eight needle-like cotyledons. The embryo is surrounded by tissue of the female gametophyte. Like the triploid endosperm of angiosperm seeds, the haploid tissue of the female gametophyte functions as a source of nourishment for the embryo.

Quick Lab

Predicting Seed Dispersal

Materials five different fruits, balance or scale

Procedure

1. Create a data table that has at least five rows. Your table should have six columns with the following headings: "Fruit name," "Fruit type" (from Table 32-1, p. 635), "Dry/fleshy," "Seed mass in grams," "Whole fruit mass in grams," and "Dispersal method."
2. Examine your fruits, and fill in your data table. Discuss with your group how characteristics of fruits and seeds might relate to dispersal methods.

Analysis Form a hypothesis about a dispersal method for one of the fruits you have examined. Describe how you might test your hypothesis.

SEED GERMINATION

Many plants are easily grown from seeds. Although its embryo is alive, a seed will not germinate, or sprout, until it is exposed to certain environmental conditions. Delaying germination often assures the survival of a plant. For example, if seeds that mature in the fall were to sprout immediately, the young plants could be killed by cold weather. Similarly, if a plant's seeds were to sprout all at once and all of the new plants died before producing seeds, the species could become extinct. Many seeds will not germinate even when exposed to conditions ideal for germination. Such seeds exhibit **dormancy,** which is a state of reduced metabolism. The longevity of dormant seeds is often remarkable. Recently, a botanist germinated lotus seeds that were almost 1,000 years old.

Word Roots and Origins

dormancy

from the Latin *dormire,* meaning "to sleep"

Conditions Needed for Germination

Environmental factors, such as water, oxygen, and temperature, trigger seed germination. Most mature seeds are very dry and must absorb water to germinate. Water softens the seed coat and activates enzymes that convert starch in the cotyledons or endosperm into simple sugars, which provide energy for the embryo to grow. As the embryo begins to grow, the softened seed coat cracks open. This enables the oxygen needed for cellular respiration to reach the embryo. In addition, seeds germinate only if exposed to temperatures within a certain range. Many small seeds need light for germination. This adaptation prevents the seeds from sprouting if they are buried too deeply in the soil.

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Some seeds germinate only after being exposed to extreme conditions, as illustrated in Figure 32-13. Some seeds, such as black locust seeds, germinate after passing through the digestive systems of animals. Acids in the digestive system wear away the hard seed coat,

FIGURE 32-13

Many animals, including this raccoon, eat apples or other fruits. The seeds found in a fruit are swallowed by an animal and are exposed to acids as they pass through the animal's digestive system. The acids wear away the seed coat, allowing water and oxygen to enter and enabling the growing embryo to break out.

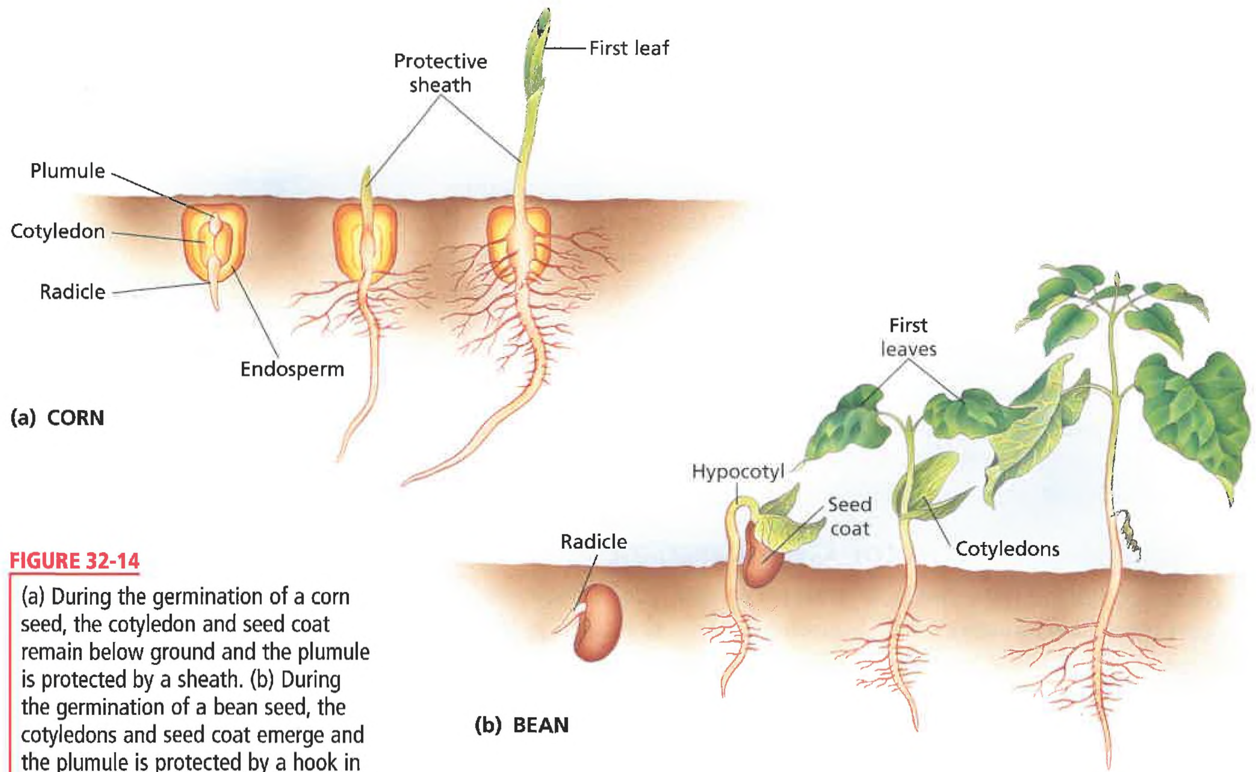

FIGURE 32-14

(a) During the germination of a corn seed, the cotyledon and seed coat remain below ground and the plumule is protected by a sheath. (b) During the germination of a bean seed, the cotyledons and seed coat emerge and the plumule is protected by a hook in the epicotyl.

and as an added bonus, the seed is deposited with a bit of natural fertilizer. Other seeds, such as apple seeds, must be exposed to near-freezing temperatures for several weeks before they sprout. This temperature requirement prevents the seeds from germinating in the fall and thus ensures that the seedlings will not be killed by the cold temperatures of winter. The cold temperatures cause chemical changes within the seed. These changes enable the embryo to grow.

Process of Germination

Figure 32-14 compares seed germination in corn and beans. The first visible sign of seed germination is the emergence of the radicle. In beans, the entire root system develops from the radicle. In corn, most of the root system develops from the lower part of the stem. Soon after the radicle breaks the seed coat, the shoot begins to grow.

In some seeds, such as bean seeds, the hypocotyl curves and becomes hook-shaped. Once the hook breaks through the soil, the hypocotyl straightens. This straightening pulls the cotyledons and the plumule into the air. The plumule's embryonic leaves unfold, synthesize chlorophyll, and begin photosynthesis. After their stored nutrients are used up, the shrunken bean cotyledons fall off.

In contrast, the cotyledon of the corn seed remains underground and transfers nutrients from the endosperm to the growing embryo. Unlike the bean shoot, the corn hypocotyl does not hook or elongate, and the cotyledon remains below ground. Instead, the corn plumule is protected by a sheath as it pushes through the soil. When the shoot breaks through the soil surface, the leaves of the plumule unfold.

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ASEXUAL REPRODUCTION

Recall that asexual reproduction is the production of an individual without the union of gametes. Elaborate technology has recently yielded some success in the asexual reproduction, or cloning, of mammals. Even so, movies and books that depict people who create **clones,** or exact duplicates of themselves, are still science fiction. However, asexual reproduction is common in the plant kingdom. Asexual reproduction can be an advantage to individuals that are well-adapted to their environment. Many new individuals can be produced in a short period of time, enabling the clones to spread rapidly and fill the available space. A disadvantage of asexual reproduction is the lack of genetic variation among the offspring. All of the offspring are genetically identical to the parent and to each other. Thus, the clones have the same tolerance to an environment and are attacked by the same diseases and pests. Many of our cultivars are clones.

In nature, plants reproduce asexually in a variety of ways. One type of asexual reproduction is shown in Figure 32-15. Reproduction with usually nonreproductive parts, such as leaves, stems, or roots, is termed **vegetative reproduction.** Many different types of structures specialized for vegetative reproduction have evolved among the plants. Table 32-2 lists some of these structures.

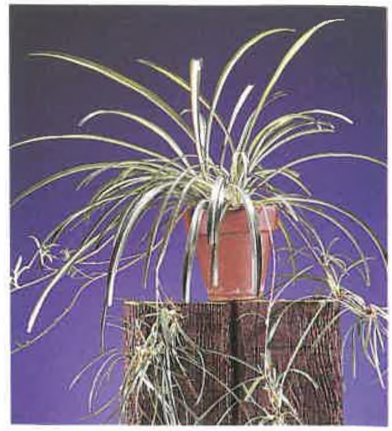


FIGURE 32-15
New plants are produced from the runners (or stolons) of an airplane plant. This plant is sometimes called a spider plant. Each new plant found on the runner can be put into a glass of water to grow roots. This is an example of vegetative propagation.

VEGETATIVE PROPAGATION

People often use vegetative structures to propagate plants. The use of vegetative structures to produce new plants is called **vegetative propagation.** Many species of plants are vegetatively propagated from specialized structures such as runners, rhizomes, bulbs, and tubers. People have also developed several methods of propagating plants from other vegetative parts. These methods include layering, grafting, and using cuttings and tissue cultures.

TABLE 32-2 ***Plant Structures Adapted for Vegetative Reproduction***

Name	Description	Examples
Runner (stolon)	horizontal, aboveground stem that produces leaves and roots at its nodes; a new plant can grow from each node	strawberry, spider plant, Boston fern
Rhizome	horizontal, belowground stem that produces leaves and roots at its nodes; a new plant can grow from each node	ferns, horsetails, iris, ginger, sugar cane
Bulb	very short, underground monocot stem with thick, fleshy leaves adapted for storage; bulbs divide naturally to produce new plants	tulip, daffodil, onion, garlic, hyacinth
Tuber	underground, swollen, fleshy stem specialized for storage; the buds on a tuber can grow into new plants	potato, caladium, Jerusalem artichoke

Cuttings

In some plants, roots will form on a cut piece of a stem, or shoots will form on a piece of a root. Pieces of stems and roots that are cut from a plant and used to grow new plants are called **cuttings.** Plants such as African violets can be grown from leaf cuttings, which will form both roots and shoots. Cuttings are widely used to propagate houseplants, ornamental trees and shrubs, and fruit crops such as grapes, figs, and olives.

Layering

In some species, such as raspberries, roots form on stems where they make contact with the soil. People often stake branch tips to the soil or cover the bases of stems with soil to propagate such plants. The process of causing roots to form on a stem is called **layering.** Air layering, which involves wounding a stem and placing moist sphagnum moss around the wound, is another common form of layering.

Grafting

Grafting is the joining of two or more plant parts to form a single plant. In grafting, a bud or small stem of one plant is attached to the roots or stems of a second plant. The vascular cambium of both parts must be aligned for a graft to be successful. Grafting enables the desirable characteristics of two cultivars to be combined. For example, an apple cultivar with excellent fruit can be grafted onto one with disease-resistant roots. Grafting is used to propagate virtually all commercial cultivars of fruit and nut trees and many ornamental trees and shrubs.

FIGURE 32-16

Tissue culture can be used to grow round-leaved sundews, *Drosera rotundifolia.* The jelly in the Petri dish is a sterile soil substitute that contains needed nutrients.

Tissue Culture

Figure 32-16 shows plants grown by **tissue culture,** the production of new plants from pieces of tissue placed on a sterile nutrient medium. Unlike most animal cells, plant cells contain functional copies of all the genes needed to produce a new plant. Thus, it is possible for a whole plant to regrow from a single cell. Millions of identical plants can be grown from a small amount of tissue. Tissue culture is used in the commercial production of orchids, houseplants, cut flowers, fruit plants, and ornamental trees, shrubs, and nonwoody plants.

SECTION 32-3 REVIEW

1. List 10 different types of fruits, and give an example of each type.
2. Name three common methods of fruit and seed dispersal, and give an example of each method.
3. How do the structure and germination of a bean seed differ from the structure and germination of a corn seed?
4. Compare asexual reproduction with sexual reproduction.
5. Make a table that compares structures and methods used for the vegetative propagation of plants.
6. CRITICAL THINKING Why is seed dormancy an evolutionary advantage?

CHAPTER 32 REVIEW

SUMMARY/VOCABULARY

32-1

- Plants have a life cycle called alternation of generations, in which a multicellular haploid gametophyte stage alternates with a multicellular diploid sporophyte stage.
- Mosses and most ferns are homosporous (produce only one type of spore).
- In the moss life cycle, a spore develops into a leafy green gametophyte that produces eggs in archegonia and swimming sperm in antheridia. A moss sporophyte grows from a gametophyte and is dependent on it for nourishment.
- In the fern life cycle, a spore develops into a small flat gametophyte that produces eggs in archegonia and swimming sperm in antheridia. A sporophyte grows from a gametophyte but later crushes it and is not dependent on it for nourishment.
- All seed plants, spike mosses, and quillworts as well as a few fern species are heterosporous (produce two types of spores, male microspores and female megaspores).
- The conifer life cycle features a reduced male gametophyte (pollen grain) and sperm without flagella. A sperm reaches an egg through a pollen tube that grows into a female gametophyte.

Vocabulary

antheridium (625)
archegonium (625)
heterospory (627)
homospory (626)
integument (628)
megagametophyte (628)
megasporangium (628)
megaspore (627)
microgametophyte (628)
micropyle (628)
microsporangium (628)
microspore (627)
ovule (628)
pollen grain (628)
pollen tube (628)
sorus (627)

32-2

- Flowers are reproductive structures of angiosperms. Most familiar flowers consist of four whorls of parts—protective sepals, colorful petals, pollen-producing stamens, and egg-containing carpels.
- Many flowering plants have flowers adapted for animal pollination or for wind pollination.
- In angiosperms, the female gametophyte is a microscopic embryo sac that usually has eight nuclei and is found within an ovule.
- Double fertilization is a unique feature of angiosperms. Two sperm reach the embryo sac through a pollen tube. One sperm combines with the egg to form a zygote. A second sperm combines with two polar nuclei to form a triploid nutritive tissue, the endosperm.

Vocabulary

anther (629)
carpel (629)
double fertilization (633)
embryo sac (630)
filament (629)
generative cell (631)
megaspore mother cell (630)
microspore mother cell (631)
nectar (632)
ovary (629)
petal (629)
pistil (629)
polar nuclei (630)
receptacle (629)
sepal (629)
stamen (629)
stigma (629)
style (629)
tube cell (631)

32-3

- Angiosperm seeds are enclosed by fruits, which protect seeds and aid in dispersion.
- Seeds need water, oxygen, suitable temperatures, and sometimes light to germinate.
- Asexual reproduction enables plants to spread rapidly in a favorable environment.
- Plants naturally reproduce vegetatively with specialized structures such as bulbs, rhizomes, runners, and tubers.
- People propagate plants asexually by using cuttings, layering, grafting, and tissue culture.

Vocabulary

clone (639)
cutting (640)
dormancy (637)
epicotyl (636)
grafting (640)
hilum (636)
hypocotyl (636)
layering (640)
plumule (636)
radicle (636)
seed coat (636)
tissue culture (640)
vegetative propagation (639)
vegetative reproduction (639)

REVIEW

Vocabulary

1. How is a megaspore related to a megasporangium?
2. Explain the differences between a gametophyte and a sporophyte.
3. List three similarities between an ovule and an ovary.
4. What do pomes, berries, and drupes have in common?
5. Using a dictionary, find the meaning of the word roots in *epicotyl* and *hypocotyl*. Explain why these terms are appropriate for the structures they describe.

Multiple Choice

6. Moss sperm are produced in (a) antheridia (b) anthers (c) archegonia (d) sori.
7. In pollen, the generative cell forms (a) polar nuclei (b) sperm (c) the epicotyl (d) endosperm.
8. The integuments of an ovule are interrupted by (a) a microspore (b) a micropyle (c) a hilum (d) a stamen.
9. The pistil of a flower is made up of (a) styles (b) ovaries (c) carpels (d) anthers.
10. The microspores in an anther become (a) megaspores (b) pollen grains (c) eggs (d) sperm.
11. Pollination occurs when (a) a sperm fuses with an egg (b) insects ingest nectar (c) a spore leaves a sporangium (d) pollen lands on a stigma.
12. Which of the following terms applies to angiosperms but not to gymnosperms? (a) integument (b) pollen (c) seed (d) double fertilization
13. The epicotyl in a dicot seed is part of the (a) hilum (b) hypocotyl (c) plumule (d) cotyledon.
14. Asexual reproduction in plants occurs in all but which of the following ways? (a) Sperm unite with eggs. (b) New plants form on runners. (c) Seed plants form bulbs. (d) New plants grow in tissue culture.
15. The process shown in the photograph below is termed (a) grafting (b) cutting (c) tissue culture (d) layering.

Short Answer

16. What are two important differences between the life cycle of a typical fern and that of a seed plant?
17. How is heterospory an advantage over homospory?
18. List four factors that promote successful wind pollination.
19. Draw a diagram showing the events and plant structures involved in pollination.
20. How does the process of fertilization occur in flowering plants?
21. How does the process of fertilization in conifers differ from the process of fertilization in flowering plants?
22. List three types of seed dispersal, and give an example of each.
23. In many seeds, the epicotyl forms a hook as the embryo emerges from the seed. What is the advantage of this hook?
24. Compare asexual reproduction with sexual reproduction in terms of their advantages and disadvantages.
25. Describe several methods of vegetative reproduction.

Critical Thinking

1. How is the growth habit of mosses an advantage for their method of sexual reproduction?
2. Suppose that a type of fern normally has a $2n$ chromosome number of 12. Also suppose that meiosis does not occur in the formation of spores, which grow into new gametophytes. What will be the chromosome number of the gametes produced by these gametophytes? What will be the chromosome number of a zygote that results from the fusion of two of these gametes?
3. Why do you think there are more heterosporous plants than there are homosporous plants?
4. In many flowers with both stamens and pistils, the stigma is located well above the anthers. What is the value of such an arrangement?
5. Following the self-pollination of some plants, the pollen tubes die before reaching ovules. What is the significance of this event?
6. Why are fruits and seeds a nutritious source of food for humans and other animals? How is this an advantage for plants?
7. Why do plants with fleshy fruits usually have seeds with hard seed coats?
8. The acorns (nuts) of many oak trees often germinate on the surface of ground that is hard or covered with grass. The new root may grow several centimeters before it reaches a crack or soft spot where it can enter the ground. How is the germinating seed able to survive and grow in such conditions?
9. If you were to discover a new type of rose, would you use seeds or vegetative parts to propagate the rose and produce large numbers of identical plants? Justify your answer.
10. In the photograph below, the houseplant on the left shows a *Sansevieria trifasciata,* which has yellow-edged leaves. A section of the leaf, or a leaf cutting, can be used to produce new plants. However, as shown on the right side of the photograph, only shoots with all-green leaves and no yellow edges will form. How do you explain this?

Extension

1. Buy a 5 cm (2 in.) or longer piece of ginger root at a supermarket. Examine it closely and determine if it is really a root. Plant it about 1 cm (0.4 in.) below the surface in a container of potting soil, keep it watered, and place it in a lighted area. Describe what happens over a period of two months.
2. Visit a commercial fruit-tree orchard and find out how the trees are propagated and pollinated.
3. Read "Life in Bloom" in *Natural History,* May 1999, on page 66. What are three factors that contribute to the life span of a flower?
4. Read "She Loves Me, She Loves Me Not" in *National Wildlife*, January 1999, on page 10. Describe the mystery that plant geneticists have discovered about the instant and strong attraction flowers have for their own species' pollen.
5. Try air-layering an overly tall houseplant, such as a dieffenbachia or a dracena.

Comparing Seed Structure and Seedling Development

OBJECTIVES

- Observe the structures of dicot and monocot seeds.
- Compare the structure of dicot and monocot embryos.
- Compare the development of dicot and monocot seedlings.

PROCESS SKILLS

- relating structure to function
- comparing and contrasting
- identifying
- collecting data

MATERIALS

- 1 pea seed soaked overnight
- 6 bean seeds soaked overnight
- 6 corn kernels soaked overnight
- stereomicroscope
- scalpel
- Lugol's iodine solution in dropper bottle
- paper towels
- 2 rubber bands
- 2 150 mL beakers
- glass-marking pen
- metric ruler
- microscope slide
- medicine dropper
- compound light microscope

Background

1. What are the parts of a seed?
2. In what ways are seeds like their parent plant?
3. How do monocotyledons and dicotyledons differ?
4. What changes occur as a seed germinates?

PART A Seed Structure

1. Obtain one each of the following seeds—pea, bean, and corn.
2. Remove the seed coats of the pea and bean seeds. Open the seeds, and locate the two cotyledons in each seed.
3. Using the stereomicroscope, examine the embryos of the pea seed and the bean seed.
4. In your lab report, draw the pea and bean embryos and label all of the parts that you can identify.
5. CAUTION **Use the scalpel carefully to avoid injury.** Examine a corn kernel, and find a small, oval, light-colored area that shows through the seed coat. Use the scalpel to cut the seed in half along the length of this area. Place a drop of iodine solution on the cut surface.
6. Use the stereomicroscope to examine the corn embryo. In your lab report, sketch the embryo and label all the parts that you can identify.

PART B Seedling Development

7. Set five corn kernels on a folded paper towel. Roll up the paper towel, and put a rubber band around the roll. Stand the roll in a beaker with 1 cm of water in the bottom. The paper towel will soak up water and moisten the corn. Keep water at the bottom of the beaker, but do not allow the corn kernels to be covered by the water.

8. Repeat step 7 with five bean seeds.
9. After three days, unroll the paper towels and examine the corn and bean seedlings. Use a glass-marking pen to mark the roots and shoots of the developing

seedlings. Starting at the seed, make a mark every 0.5 cm along the root of each seedling. And again starting at the seed, make a mark every 0.5 cm along the stem of each seedling. Measure the distance from the last mark on the root to the root tip of each seedling. Also measure the distance from the last mark on the stem to the shoot tip of each seedling. Record these data in your lab report.

10. Draw a corn seedling and a bean seedling in your lab report. Using a fresh paper towel, roll up the seeds, place the rolls in the beakers, and add fresh water to the beakers.
11. Make a data table similar to the one shown below in your lab notebook. Expand your table by adding columns under each "Roots" and "Stems" head to account for every section of the roots and stems of your seedlings.
12. After two days, reexamine the seedlings. Measure the distance between the marks, and record the data in your data table.
13. CAUTION **Use the scalpel carefully to avoid injury.** Using the scalpel, make a cut about 2 cm from the tip of the root of a bean seedling. Place the root tip on a microscope slide and add a drop of water. Using a compound light microscope on low power, observe the root tip. In your lab report, draw the root tip.
14. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. What protects the tips of corn shoots as they push through the soil? What protects the bean shoots?
2. What types of leaves first appear on the bean seedling?
3. What substance does the black color in the corn kernel indicate? Why might you expect to find this substance in the seed?
4. Examine the data you recorded for steps 9 and 12. Has the distance between the marks changed? If so, where has it changed?
5. What parts of the embryo were observed in all seeds on the third day?
6. How does the structure and development of the corn kernel differ from the structure and development of the pea and bean seeds?
7. What was the source of nutrients for each seed embryo? What is your evidence?
8. Describe the growth in the seedlings you observed.
9. Corn and beans are often cited as representative examples of monocots and dicots, respectively. Relate the seed structure of each to the terms *monocotyledon* and *dicotyledon.*

Further Inquiry

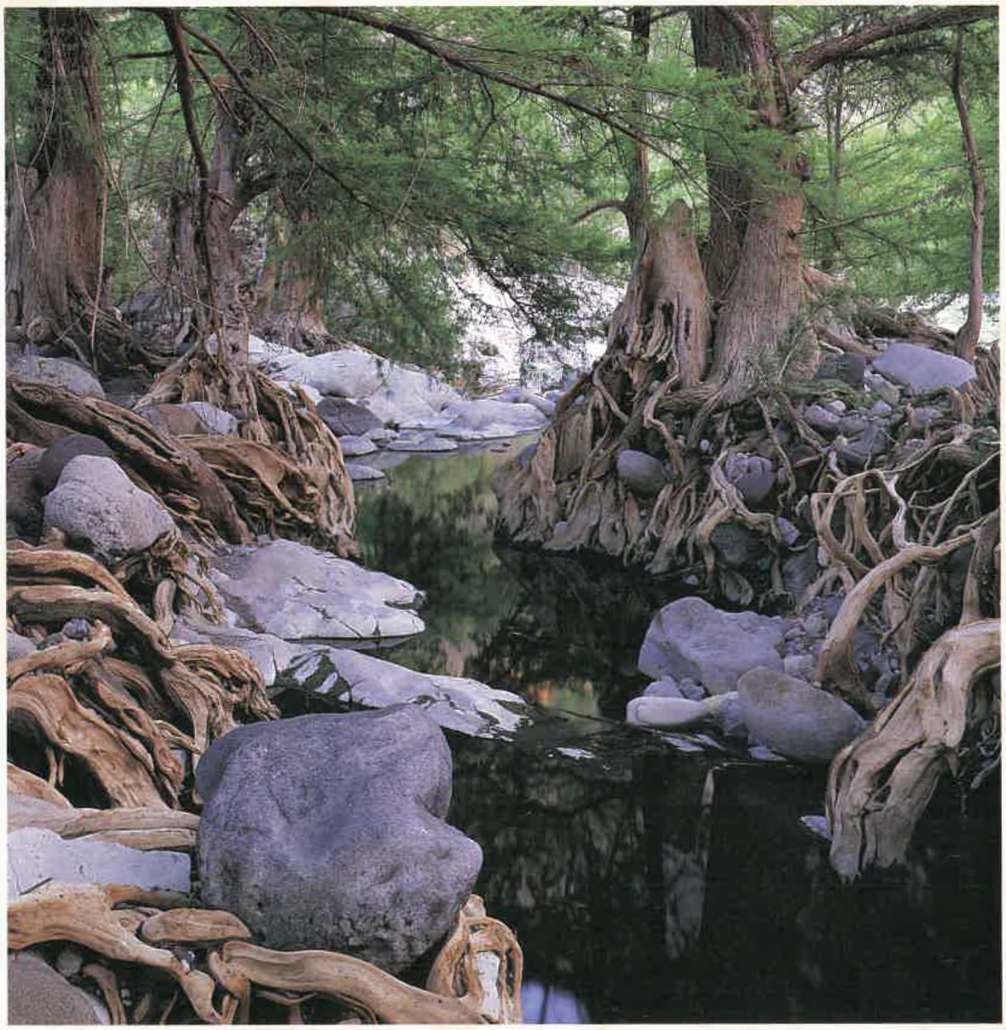
Design an experiment to find out how monocots and dicots compare in general plant growth and in the structure of their leaves and flowers.

CORN AND BEAN SEEDLING GROWTH AFTER TWO DAYS

	Corn seedlings				Bean seedlings			
	Roots		Stems		Roots		Stems	
Seedling	Seed to first mark	Root tip to last mark	Seed to first mark	Shoot tip to last mark	Seed to first mark	Root tip to last mark	Seed to first mark	Shoot tip to last mark
1								
2								
3								
4								
5								

CHAPTER 33

PLANT RESPONSES



Montezuma baldcypress trees, Taxodium mucronatum, *with their tangled roots, line the banks of the Rio Cuchujaqui in the southern region of the Mexican state of Sonora.*

FOCUS CONCEPT: *Evolution*

As you read, notice how plants respond to their environment and to hormones. Plant responses to environmental conditions are adaptive advantages.

SECTION

33-1

PLANT HORMONES

The growth and development of a plant are influenced by genetic factors, external environmental factors, and chemicals inside the plant. Plants respond to many environmental factors, such as light, gravity, water, inorganic nutrients, and temperature.

OBJECTIVES

▲ List the five major types of plant hormones, and give some effects of each.

● Give examples of the adaptive advantages of hormonal responses.

■ Describe three agricultural or gardening applications for each of three classes of plant hormones.

GROUPS OF HORMONES

Plant **hormones** are chemical messengers that affect a plant's ability to respond to its environment. Hormones are organic compounds that are effective at very low concentrations; they are usually synthesized in one part of the plant and transported to another location. They interact with specific target tissues to cause physiological responses, such as growth or fruit ripening. Each response is often the result of two or more hormones acting together.

Because hormones stimulate or inhibit plant growth, many botanists also refer to them as plant **growth regulators.** Many hormones can be synthesized in the laboratory, increasing the quantity of hormones available for commercial applications. Botanists recognize five major groups of hormones: auxins, gibberellins, ethylene, cytokinins, and abscisic acid. These groups of hormones are examined in Table 33-1 on the next page.

Auxins

Auxins (AWK-suhnz) are hormones involved in plant-cell elongation, apical dominance, and rooting. A well known natural auxin is **indoleacetic** (IN-DOHL-uh-SEET-ik) **acid,** or **IAA.** Developing seeds produce IAA, which stimulates the development of a fleshy fruit. Figure 33-1 shows how the removal of seeds from a strawberry prevents the fruit from enlarging. The application of IAA after removing the seeds causes the fruit to enlarge normally.

(a) (b) (c)

FIGURE 33-1

(a) Strawberry plants produce a fleshy, heart-shaped fruit that is covered with yellow seeds. (b) When the seeds are removed from the fruit, the growth of the fruit is retarded. (c) When the seeds are removed and the fruit is treated with an auxin, growth is normal.

TABLE 33-1 Five Groups of Plant Hormones

Plant hormone	Function	Features	Examples
Auxins	• promote cell growth • promote root formation on stem and leaf cuttings • promote apical dominance • increase number of fruits • prevent dropping of fruit • prevent sprouting of stored potatoes and onions	• produced in growing regions of plant (shoot tips, young leaves, developing fruit) • important role in tropisms	• indoleacetic acid, IAA (natural) • naphthalene acetic acid, NAA (synthetic) • herbicides 2,4-D and Agent Orange (synthetic)
Gibberellins (GA)	• promote elongation growth • promote germination, and seedling growth • increase size of fruit • overcome bud dormancy • substitute for long-day or vernalization requirements for flowering	• produced in all parts of plant, especially in immature seeds • more than 80 types	• GA_3 (natural)
Ethylene	• promotes ripening of fruit • promotes flowering in mangoes and pineapples • promotes abscission	• produced in fruits, flowers, leaves, and roots • colorless gas	• ethephon (synthetic) breaks down and releases ethylene (natural)
Cytokinins	• promote cell division • promote lateral bud growth in dicots	• produced in developing roots, fruits, and seeds • auxin-to-cytokinin ratio is important	• zeatin (natural) • kinetin (synthetic) • benzyladenine (synthetic)
Abscisic acid (ABA)	• promotes stomatal closure • promotes dormancy • inhibits other hormones • blocks growth	• produced in leaves • expensive to synthesize	• ABA (natural or synthetic)

IAA is produced in actively growing shoot tips and developing fruit, and it is involved in elongation. Before a cell can elongate, the cell wall must become less rigid so that it can expand. IAA triggers an increase in the plasticity, or stretchability, of cell walls, allowing elongation to occur.

Synthetic Auxins

Chemists have synthesized several inexpensive compounds similar in structure to IAA. Synthetic auxins, like **naphthalene** (NAF-thuh-LEEN) **acetic** (uh-SEET-ik) **acid,** or **NAA,** are used extensively to promote root formation on stem and leaf cuttings, as shown in Figure 33-2. Gardeners often spray auxins on tomato plants to increase the number of fruits on each plant.

FIGURE 33-2

(a) This coleus plant, *Coleus hybridus,* is growing roots in pure water. (b) This coleus stem cutting has been treated with the auxin NAA. Roots form more rapidly when the stem is treated with NAA. Both cuttings were taken at the same time.

When NAA is sprayed on young fruits of apple and olive trees, some of the fruits drop off so that the remaining fruits grow larger. When NAA is sprayed directly on fruits—such as apples, pears, and citrus fruits—several weeks before they are ready to be picked, NAA prevents the fruits from dropping off the trees before they are mature. The fact that auxins can have opposite effects—causing fruit to drop or preventing fruit from dropping—illustrates an important point. The effects of a hormone on a plant often depend on the stage of the plant's development.

NAA is used to prevent the undesirable sprouting of stems from the base of ornamental trees. As discussed in Chapter 32, stems contain a lateral bud at the base of each leaf. In many stems, these buds fail to sprout as long as the plant's shoot tip is intact. The inhibition of lateral buds by the presence of a shoot tip is called **apical dominance.** If the shoot tip of a plant is removed, the lateral buds begin to grow. If IAA or NAA is applied to the cut tip of the stem, the lateral buds remain dormant. This adaptation is manipulated to cultivate beautiful ornamental trees. NAA is used commercially to prevent buds from sprouting on potato tubers during storage.

Another important synthetic auxin is **2,4-D,** which is a herbicide, or weedkiller. It selectively kills dicots, such as dandelions and pigweed, without injuring monocots, such as lawn grasses and cereal crops. Given our major dependence on cereals for food, 2,4-D has been of great value to agriculture. A mixture of 2,4-D and another auxin, called **Agent Orange,** was used to defoliate jungles in the Vietnam War. A nonauxin contaminant in Agent Orange has caused severe health problems in many people who were exposed to it.

Gibberellins

In the 1920s, scientists in Japan discovered that a substance produced by the fungus *Gibberella* caused fungus-infected plants to grow

FIGURE 33-3

The bird's nest ferns, *Asplendium nidus,* shown in (a) and (b) are the same age. The fern in (b), however, has been treated with gibberellin, which stimulates the leaves to grow larger.

(a) (b)

abnormally tall. The substance, named **gibberellin** (JIB-uh-REL-uhn), was later found to be produced in small quantities by plants themselves. It has many effects on a plant, but it primarily stimulates elongation growth. Spraying a plant with gibberellins will usually cause the plant to grow to a larger than normal height, as shown in Figure 33-3.

Like auxins, gibberellins are a class of hormones that have important commercial applications. Almost all seedless grapes are sprayed with gibberellins to increase the size of the fruit, as Figure 33-4 shows. Beer makers use gibberellins to increase the alcohol content of beer by increasing the amount of sugar produced in the malting process. Gibberellins are also used to treat seeds of some food crops because they break seed dormancy and promote uniform germination.

FIGURE 33-4

Almost all of the raisins produced in California are made from Thompson Seedless grapes. Normal Thompson Seedless grapes are smaller than those treated with a gibberellin hormone. The grapes on the left were treated with a gibberellin. As you can see, the addition of a gibberellin to grapes stimulates the grapes to grow larger.

Ethylene

The hormone **ethylene** (ETH-uh-LEEN) is responsible for the ripening of fruits. Unlike the other four classes of plant hormones, ethylene is a gas at room temperature. Ethylene gas diffuses easily through the air from one plant to another. The saying "One bad apple spoils the barrel" has its basis in ethylene gas. One rotting apple will produce ethylene gas, which stimulates nearby apples to ripen and eventually spoil.

Ethylene is usually applied in a solution of **ethephon** (ETH-uh-fohn), a synthetic chemical that breaks down to release ethylene gas. It is used to ripen bananas, honeydew melons, and tomatoes. Oranges, lemons, and grapefruits often remain green when they are ripe. Although the green fruit tastes good, consumers will not usually buy them. The application of ethylene to green citrus fruits causes the development of desirable citrus colors, such as yellow and orange.

In some plant species, ethylene promotes **abscission,** which is the detachment of leaves, flowers, or fruits from a plant. Cherries and walnuts are harvested with mechanical tree shakers. Ethylene treatment increases the number of fruits that fall to the ground when the trees are shaken. Leaf abscission is also an adaptive advantage for the plant. Dead, damaged, or infected leaves drop to the ground rather than shading healthy leaves or spreading disease. The plant can minimize water loss in the winter, when the water in a plant is often frozen.

Cytokinins

Cytokinins (sie-toh-KIE-nuhnz) promote cell division in plants. Produced in the developing shoots, roots, fruits, and seeds of a plant, cytokinins are very important in the culturing of plant tissues in the laboratory. A high ratio of auxins to cytokinins in a tissue-culture medium stimulates root formation. A low ratio promotes shoot formation. Cytokinins are also used to promote lateral bud growth of flower crops.

Word Roots and Origins

abscisic

from the Latin *abscisus*, meaning "to cut off"

Abscisic Acid

Abscisic (ab-SIS-ik) **acid,** or **ABA,** generally inhibits other hormones, such as IAA. It was originally thought to promote abscission, hence its name. Botanists now know that ethylene is the main abscission hormone. ABA helps to bring about dormancy in a plant's buds and maintains dormancy in its seeds. ABA causes the closure of a plant's stomata in response to drought. Water-stressed leaves produce large amounts of ABA, which triggers potassium ions to be transported out of the guard cells. This causes the stomata to close. It is too costly to synthesize ABA for agricultural use.

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TOPIC: Plant growth regulators
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Other Growth Regulators

Many growth regulators are widely used on ornamental plants. These substances do not fit into any of the five classes of hormones. For example, utility companies in California often apply **growth retardants,** chemicals that prevent plant growth, to trees to prevent them from interfering with overhead utility lines. It is less expensive to apply these chemicals than to prune the trees. Also, azalea growers sometimes apply a chemical to kill an azalea's terminal buds rather than hand-pruning them. Scientists are still searching for a hormone to slow the growth of lawn grass so that it does not have to be mowed so often.

SECTION 33-1 REVIEW

1. What are important commercial uses of auxins, gibberellins, and ethylene?
2. Explain one way ethylene differs from the other plant hormones.
3. How are a plant's shoot tip and lateral buds affected by apical dominance?
4. Why are growth retardants often sprayed on potted flowers?
5. Explain how auxins and cytokinins interact.
6. CRITICAL THINKING What factors influence the effect of a hormone on target cells?

SECTION

33-2

OBJECTIVES

▲

Explain the difference between tropisms and nastic movements.

●

List the environmental stimuli to which plants respond and the tropism for each stimulus.

■

Explain the current hypotheses regarding auxins and their function in phototropism and gravitropism.

◆

Describe common nastic movements and explain how they help a plant survive.

PLANT MOVEMENTS

Plants appear immobile because they are rooted in place. However, time-lapse photography reveals that parts of plants frequently move. Most plants move too slowly for us to notice. Plants move in response to several environmental stimuli, such as light, gravity, and mechanical disturbances. These movements fall into two groups, tropisms and nastic movements.

TROPISMS

A **tropism** (TROH-piz-uhm) is a plant movement that is determined by the direction of an environmental stimulus. Movement toward an environmental stimulus is called a *positive* tropism, and movement away from a stimulus is called a *negative* tropism. Each kind of tropism is named for its stimulus. For example, a plant movement in response to light coming from one direction is called **phototropism.** Thus, in Figure 33-5, the shoot tips of a plant that grow toward the light source are positively phototropic. The various types of tropisms are summarized in Table 33-2.

Phototropism

Phototropism is illustrated by the movement of the sprouts in Figure 33-5. Light causes the hormone auxin to move to the shaded side of the shoot. The auxin causes the cells on the shaded side to elongate more than the cells on the lighted side. As a result, the shoot bends toward the light and exhibits positive phototropism. In some plant stems, phototropism is not caused by auxin movement.

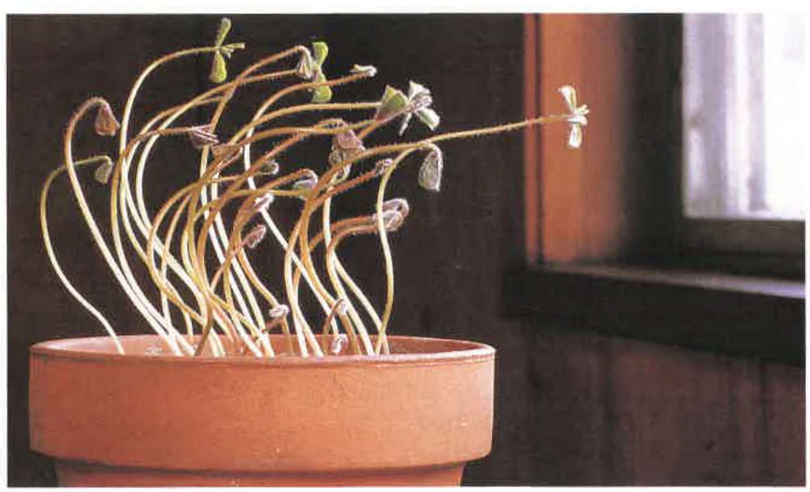

FIGURE 33-5

The way these new sprouts of the flowering shamrock, *Oxalis rubra,* grow toward a light is an example of positive phototropism. The auxin hormone stimulates the cells on the shaded side of the plant stem to elongate.

TABLE 33-2 Various Plant Tropisms

Tropism	Stimulus	Positive example
Phototropism	light	plant leans toward light
Thigmotropism	contact with object	vine twines around a tree
Gravitropism	gravity	roots grow downward
Chemotropism	chemical	pollen tube grows toward ovule

In these instances, light causes the production of a growth inhibitor on the lighted side. Negative phototropism is sometimes seen in vines that climb on flat walls where coiling tendrils have nothing to coil around. These vines have stem tips that grow away from light, toward the wall. This brings adventitious roots or adhesive discs in contact with the wall on which they can cling.

Solar tracking is the motion of leaves or flowers as they follow the sun's movement across the sky, as shown in Figure 33-6. By continuously facing toward a moving light source, the plant maximizes the light available for photosynthesis.

Thigmotropism

Thigmotropism is a plant's growth response to touching a solid object. Tendrils and stems of vines, such as morning glories, coil when they touch an object. Thigmotropism allows some vines to climb other plants or objects, increasing its chance of intercepting light for photosynthesis. It is thought that an auxin and ethylene are involved in this response.

FIGURE 33-6

These sunflower plants face the sun as it sets in the evening. In the morning, they face the sun as it rises, then they follow it as it moves across the sky. This form of phototropism is called solar tracking.

Quick Lab

Visualizing Phototropism

Materials 2 in. pots (2) containing potting soil, 4 bean seeds, cardboard box

Procedure

1. Plant two bean seeds in each pot. Label each pot for your group. Place one pot in a window or under a plant light.
2. Cut a rectangular window in the box, and place the box over the second pot so that the window faces the light. Place the box in a different location from the open pot. Keep both pots moist for several days.
3. Remove the box 2–3 days after the seedlings have emerged from the soil. Compare the seedlings grown in the light with the ones grown in the box. Sketch your observations.

Analysis How are the seedlings different? How do you account for the difference? Describe or draw what you think the cells inside the curved part of the stem look like.

Word Roots and Origins

thigmotropism

from the Greek *thiga,* meaning "touch," and *tropos,* meaning "turning"

FIGURE 33-7

This photograph was taken seven days after three cuttings of the inch plant, *Zebrina pendula,* were placed in growing tubes in different orientations. Notice that the two lower cuttings have started to grow upward, while the cutting on top, which was placed upright to begin with, has not changed its direction of growth. The growth movement of the lower cuttings is caused by the plants' response to gravity and is called negative gravitropism. When the roots turn and begin to grow in a downward direction, the movement is called positive gravitropism.

Gravitropism

Gravitropism is a plant's growth response to gravity. A root usually grows downward and a stem usually grows upward—that is, roots are positively gravitropic and stems are negatively gravitropic.

Like phototropism, gravitropism appears to be regulated by auxins. One hypothesis proposes that when a seedling is placed horizontally, auxins accumulate along the lower sides of both the root and the stem. This concentration of auxins stimulates cell elongation along the lower side of the stem, and the stem grows upward. A similar concentration of auxins inhibits cell elongation in the lower side of the root, and the root grows downward, as shown in Figure 33-7.

Chemotropism

A plant's growth in response to a chemical is called **chemotropism.** After a flower is pollinated, a pollen tube grows down through the stigma and style and enters the ovule through the micropyle. The growth of the pollen tube in response to chemicals produced by the ovule is an example of a chemotropism.

NASTIC MOVEMENTS

Plant movements that occur in response to environmental stimuli but that are independent of the direction of stimuli are called **nastic movements.** These movements are regulated by changes in the water pressure of certain plant cells.

Thigmonastic Movements

Thigmonastic (THIG-mah-NAS-tik) **movements** are a type of nastic movement that occurs in response to touching or shaking a plant. Many thigmonasties involve rapid plant movements, such as the closing of the leaf trap of a Venus' flytrap or the folding of a plant's leaves in response to being touched. Figure 33-8 shows how the leaves of a sensitive plant fold within a few seconds after being touched. This movement is caused by the rapid loss of turgor pressure in certain cells, a process similar to that which occurs in guard cells. Physical stimulation of the plant leaf causes potassium

(a) (b)

FIGURE 33-8

(a) *Mimosa pudica,* also called the sensitive plant, is a small shrub that has leaflets. (b) When a leaflet is touched, it folds together. This rapid movement is a thigmonastic movement.

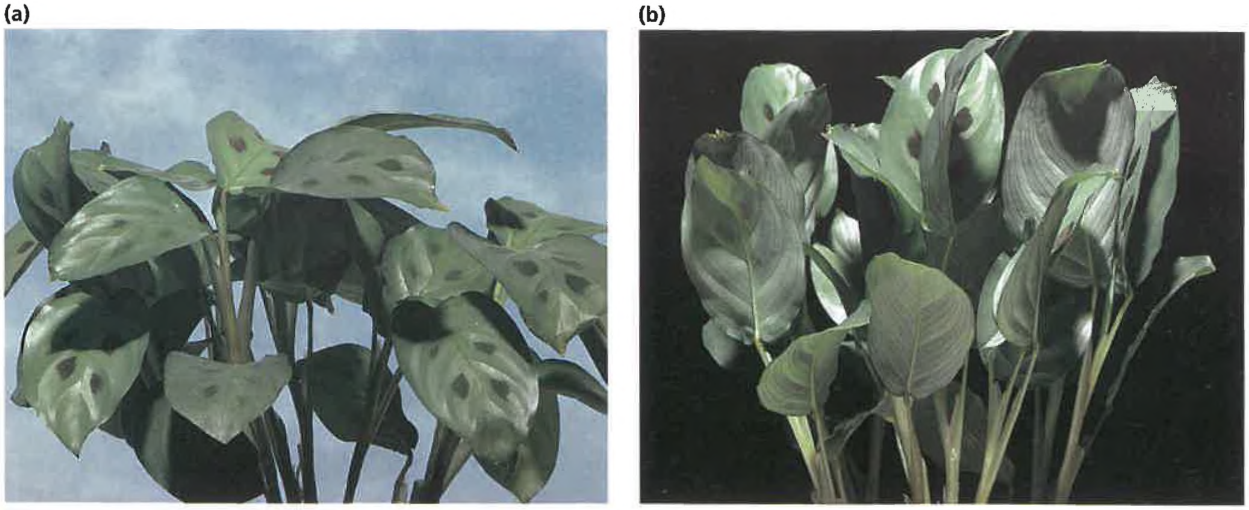

FIGURE 33-9

A common houseplant is the prayer plant, *Maranta leuconeura*. (a) During the day, the leaf blades of the prayer plant are oriented horizontally in response to light. (b) During the night, the leaf blades are oriented vertically. This movement is called nyctinastic movement.

ions to be pumped out of the cells at the base of leaflets and petioles. Water then moves out of the cells by osmosis. As the cells shrink, the plant's leaves move. It is believed that the folding of a plant's leaves in response to touch discourages insect feeding.

In addition, thigmonastic movements may help prevent water loss in plants. When the wind blows on a plant, the rate of transpiration is increased. So if the leaves of a plant fold in response to the "touch" of the wind, water loss is reduced. This could be an important adaptive advantage to a plant.

Nyctinastic Movements

Nyctinastic (NIK-tuh-NAS-tik) **movements** are plant movements in response to the daily cycle of light and dark. Nyctinastic movements involve the same type of osmotic mechanism as thigmonastic movements, but the changes in turgor pressure are more gradual. Nyctinastic movements occur in many plants, including bean plants, honeylocust trees, and silk trees. The prayer plant, shown in Figure 33-9, gets its name from the fact that its leaf blades are vertical at night, resembling praying hands. During the day, the leaf blades of the prayer plant are horizontal. The botanist Linnaeus planted many different species of plants with nyctinastic movements in a big circle to make a "flower clock." The nyctinastic movements of each species occurred at a specific time of day.

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TOPIC: Nastic movements
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SECTION 33-2 REVIEW

1. **How do a tropism and a nastic movement differ?**
2. **Define the three major plant tropisms, and give an example of each.**
3. **How does auxin cause plant movements in response to light and gravity?**
4. **What adaptive advantage might nastic movements provide a plant?**
5. **How do nastic movements occur?**
6. **CRITICAL THINKING Why is it an advantage for plant growth and development to be regulated by stimuli received from the environment?**

SECTION

33-3

OBJECTIVES

▲

Define *critical night length,* and explain its role in flowering.

●

Describe vernalization, and give an example of a human application of this phenomenon.

■

Describe what causes the spectacular fall leaf colors.

◆

What is the role of phytochrome in plant responses?

SEASONAL RESPONSES

In nontropical areas, plant responses are strongly influenced by seasonal changes. For example, many trees shed their leaves in the fall, and most plants flower only at certain times of the year. How do plants sense seasonal changes? Although temperature is involved in some cases, plants mark the seasons primarily by sensing changes in night length.

PHOTOPERIODISM

A plant's response to changes in the length of days and nights is called **photoperiodism.** Photoperiodism affects many plant processes, including the formation of storage organs and bud dormancy. However, the most-studied photoperiodic process is flowering. Some plants require a particular night length to flower. In other species, a particular night length merely makes the plant flower sooner than it otherwise would.

Critical Night Length

Researchers have found that the important factor in flowering is the amount of darkness, or night length, that a plant receives. Each plant species has its own specific requirement for darkness, called the **critical night length.** Although scientists now know that night length, and not day length, regulates flowering, the terms short-day plant, and long-day plant are still used. A **short-day plant** flowers when the days are short and the nights are longer than a certain length. Conversely, a **long-day plant** flowers when the days are long and the nights are shorter than a certain length.

Responding to Day Length and Night Length

Plants can be divided into three groups, depending on their response to the photoperiod, which acts as a season indicator. One group, called **day-neutral plants** (DNPs), are not affected by day length. DNPs for flowering include tomatoes, dandelions, roses,

TABLE 33-3 *Flowering Photoperiodism*

Type of plant	Conditions needed for flowering	Seasons of flowering
Day-neutral plant (DNP)	not affected by day-night cycle	spring to fall
Short-day plant (SDP)	short days (long nights)	spring, fall
Long-day plant (LDP)	long days (short nights)	summer

corn, cotton, and beans. DNPs and the other two groups of plants are summarized in Table 33-3.

Short-day plants (SDPs) flower in the spring or fall, when the day length is short. For example, ragweed flowers when the days are shorter than 14 hours, and poinsettias flower when the days are shorter than 12 hours. Chrysanthemums, goldenrods, and soybeans are SDPs for flowering.

Long-day plants (LDPs) flower when days are long, usually in summer. For example, wheat flowers only when the days are longer than about 10 hours. Radishes, asters, petunias, and beets are LDPs for flowering.

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Adjusting the Flowering Cycles of Plants

Examine Figure 33-10, which compares the flowering of an SDP with that of an LDP. With an 8-hour night, the LDP flowers but the SDP does not. With a 16-hour night, the SDP flowers and the LDP does not. However, if a 16-hour night is interrupted in the middle by one hour of light, the LDP flowers and the SDP does not. This response shows that the length of uninterrupted darkness is the important factor. Even though there is a daily total of 15 hours of darkness, the SDP does not flower because of that one hour of light. Flower growers who want to obtain winter flowering of LDPs simply expose them to a low level of incandescent light in the middle of the night. Summer flowering of SDPs is obtained by covering the plants in the late afternoon with an opaque cloth so that the SDPs receive enough darkness.

Regulation by Phytochrome

Plants monitor changes in day length with a bluish, light-sensitive pigment called **phytochrome** (FIET-uh-KROHM). Phytochrome exists in two forms, based on the wavelength of the light that it absorbs. The form that absorbs red rays is called P_r, and the form that absorbs far red (infrared) rays is called P_{fr}. Daylight converts P_r to P_{fr}. In the dark, P_{fr} is converted to P_r. Besides photoperiodism, phytochrome is involved in bud dormancy and seed germination.

FIGURE 33-10

The figure compares a short-day plant (SDP) with a long-day plant (LDP) in three variations of night length. The SDP has a critical night length of 14 hours. The LDP has a critical night length of 10 hours.

VERNALIZATION

Vernalization is a low-temperature stimulation of flowering. Vernalization is important for fall-sown grain crops, such as winter wheat, barley, and rye. For example, wheat seeds are sown in the fall and survive the winter as small seedlings. Exposure to cold winter temperatures causes the plants to flower in early spring, and an early crop is produced. If the same wheat is sown in the spring, it will take about two months longer to produce a crop. Thus, cold temperatures are not absolutely required for most cultivars, but they do quicken flowering. Farmers often use vernalization to grow and harvest their crops before a summer drought sets in.

A **biennial** plant is a plant that lives for two years, usually producing flowers and seeds during the second year. Biennial plants, such as carrots, beets, celery, and foxglove, survive their first winter as short plants. In the spring, their flowering stem elongates rapidly, a process called **bolting.** Most biennials must receive vernalization before they flower during the second year. They then die after flowering. One botanist kept a biennial beet alive for over three years by protecting it from exposure to cold temperatures. Treating a biennial with gibberellin is sometimes a substitute for cold temperatures and can stimulate the plant to flower.

FIGURE 33-11

The colors of the carotenoids are visible in these autumn leaves, which have lost most of their chlorophyll.

Fall Colors

Some tree leaves are noted for their spectacular fall color. The changing **fall colors** are caused mainly by a photoperiodic response but also by a temperature response. As nights become longer in the fall, leaves stop producing chlorophyll. As the chlorophyll degrades, it is not replaced. Other leaf pigments, the carotenoids (kuh-RAHT-uhn-OYDZ), become visible as the green chlorophyll degrades. Carotenoids include the orange carotenes and the yellow xanthophylls (ZAN-thuh-filz). The carotenoids were always in the leaf; they were just hidden by the more abundant chlorophyll. Another group of pigments found in leaves, the anthocyanins (AN-thoh-SIE-uh-ninz), are produced in cool, sunny weather. Anthocyanins produce beautiful red and purplish-red colors.

SECTION 33-3 REVIEW

1. Distinguish between short-day and long-day plants.
2. How do flower growers get short-day plants, such as chrysanthemums, to flower at any time of year?
3. How does phytochrome enable plants to detect changes in seasons?
4. How do farmers use vernalization to their benefit?
5. Explain why tree leaves change color in the fall.
6. CRITICAL THINKING Why would the term *nyctoperiodism* be a better term for describing the process known as photoperiodism?

CHAPTER 33 REVIEW

SUMMARY/VOCABULARY

33-1

- Small concentrations of plant hormones are formed in many plant parts and transported to other locations in the plant, where they regulate almost all aspects of growth and development.
- Hormones are natural chemicals. Many hormones can be synthesized in the laboratory.
- There are five major groups of plant hormones: auxins, gibberellins, ethylene, cytokinins, and abscisic acid.
- Synthetic auxins are used for many purposes, including to promote rooting of cuttings, to kill weeds, to prevent bud sprouting, and to stimulate or prevent fruit drop.
- Apical dominance is the inhibition of lateral bud growth by auxin produced by the terminal bud.
- Gibberellins are used to increase the size of seedless grapes, to stimulate seed germination, and to brew beer.
- Growth retardants interfere with gibberellins and are widely used to reduce plant height.
- Ethylene, the only gaseous hormone, promotes abscission, fruit ripening, and pineapple flowering.
- Cytokinins stimulate cell division and growth of lateral buds.
- Abscisic acid promotes dormancy and stomatal closing in response to water shortage.

Vocabulary

2,4-D (649)
abscisic acid (ABA) (651)
abscission (650)
Agent Orange (649)
apical dominance (649)
auxin (647)
cytokinin (651)
ethephon (650)
ethylene(650)
gibberellin (GA) (650)
growth regulator (647)
growth retardant (651)
hormone (647)
indoleacetic acid (IAA) (647)
naphthaleneacetic acid (NAA) (648)

33-2

- Tropisms are plant-growth movements in which the direction of growth is determined by the direction of the environmental stimulus.
- Most stems and leaves are positively phototropic, but some vine stems are positively thigmotropic or negatively phototropic, which allows them to climb walls.
- Roots are usually positively gravitropic, and shoots are usually negatively gravitropic.
- Nastic plant movements result from an environmental stimulus and are independent of the direction of the stimuli.

Vocabulary

chemotropism (654)
gravitropism (654)
nastic movement (654)
nyctinastic movement (655)
phototropism (652)
solar tracking (653)
thigmonastic movement (654)
thigmotropism (653)
tropism (652)

33-3

- Photoperiodism is the triggering of a plant response, such as flowering or dormancy, by relative length of light and darkness.
- Plants fit in one of three photoperiodic classes for flowering: day-neutral, short-day, and long-day.
- Plants sense night and day lengths using the pigment phytochrome.
- Vernalization is the promotion of flowering by cold temperatures.
- Fall colors in tree leaves are caused by chlorophyll degradation, which reveals yellow pigments that have always been present, and by the synthesis of red pigments.

Vocabulary

biennial (658)
bolting (658)
critical night length (656)
day-neutral plant (DNP) (656)
fall color (658)
long-day plant (LDP) (657)
photoperiodism (656)
phytochrome (657)
short-day plant (SDP) (657)
vernalization (658)

REVIEW

Vocabulary

In the following sets of related words, explain the differences between the terms.

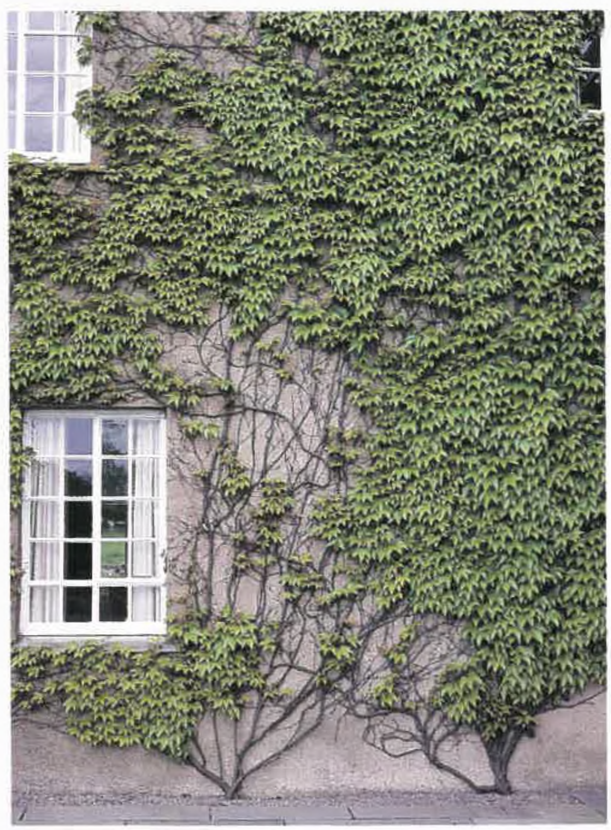
1. thigmotropism, gravitropism, chemotropism
2. hormone, plant growth regulator
3. vernalization, abscission, photoperiodism
4. positive phototropism, negative phototropism, nastic movement
5. critical night length, short-day plant, long-day plant

Multiple Choice

6. Exposure of some plants to cold promotes flowering, a process called (a) photoperiodism (b) vernalization (c) dormancy (d) thermotropism.
7. The growth of roots above the soil surface, where oxygen would be more available, is called (a) negative gravitropism (b) negative chemotropism (c) positive phototropism (d) positive chemotropism.
8. Nastic movements occur (a) without a stimulus (b) toward a stimulus (c) away from a stimulus (d) independent of the direction of the stimulus.
9. Cytokinins promote cell (a) aging (b) division (c) storage (d) transport.
10. Fall color changes in tree leaves are caused by the synthesis of (a) chlorophyll (b) carotenoids (c) xanthophylls (d) anthocyanins.
11. Seedless grapes are usually treated with (a) cytokinins (b) gibberellins (c) ethylene (d) abscisic acid.
12. A ripe avocado will cause nearby avocados to ripen through the release of (a) auxin (b) ethylene (c) abscisic acid (d) gibberellin.
13. Abscission layers are areas where (a) leaves fall off stems (b) plants sense night length (c) abscisic acid is produced (d) cuttings are produced.
14. The tropism that is a response to touch is (a) phototropism (b) thigmotropism (c) chemotropism (d) gravitropism.
15. A hormone that is a gas is (a) auxin (b) gibberellin (c) ethylene (d) abscisic acid.

Short Answer

16. Explain how shoot tips and lateral buds are influenced by apical dominance.
17. Define a biennial plant, and explain why vernalization is important in its life cycle.
18. Define critical night length, and explain how it applies to photoperiodism.
19. How might a fruit grower use ethylene on crops?
20. Describe three ways a home gardener could use auxin.
21. What is an adaptive advantage of leaf abscission?
22. Name two factors that affect the influence a hormone will have.
23. Why is 2,4-D effective as a weedkiller in cornfields?
24. Explain why tree leaves change color in autumn.
25. Look at the photograph below. Explain how negative phototropism could result in greater absorption of sunlight for photosynthesis.



CRITICAL THINKING

1. Suppose you placed a green banana in each of several plastic bags, placed a ripe pear in half of the bags, and then sealed all of the bags. Which group of bananas (with or without pears) do you think would ripen sooner? Justify your answer.
2. Suppose that a friend who lives in North Dakota gives you some seeds from a plant that you admired when you saw it growing in your friend's yard. You plant the seeds at your home in Georgia, but they fail to germinate. Based on your knowledge of seed germination, what might be preventing the germination of the seeds?
3. If abscisic acid were inexpensive, what would be some of its possible agricultural or gardening uses?
4. If a whole potato tuber is planted, only one or two buds at one end will sprout. However, if the potato is cut into pieces that each have a bud, all the buds will sprout. Explain why.
5. Potted poinsettias purchased for Christmas will often survive in people's homes for many years but will rarely bloom again. Explain why this happens.
6. The growth of most deciduous trees in the northern United States and Canada, where winters are severe, is regulated strictly by photoperiodism. That is, temperature plays no part in the regulation of their yearly growing cycle. Explain why this is significant.
7. The seasonal loss of leaves by trees and shrubs serves the adaptive advantage of conserving nutrients. What other adaptive advantages might loss of leaves provide?
8. Suppose you notice that your neighbor has a perfect lawn and that some of the trees in your yard have distorted leaves, like those in the photo shown below. What is the probable cause of the leaves' unusual appearance?

EXTENSION

1. Read the book *The Private Life of Plants: A Natural History of Plant Behaviour,* by David Attenborough (Princeton University Press). This book accompanies a six-hour television series that is available on videotape. Attenborough spent three years taking incredible time-lapse photography to show how plants respond to various stimuli.
2. Try taking time-lapse photos to capture plant movements using either a regular camera or a video camera with an automatic time-lapse feature.
3. Select several plant species, and plant six seeds of each species in separate pots of soil. Allow the seeds to sprout and grow until the plants are about 10 cm tall. Lay the pots on their sides and observe how long it takes the plants to point upward again. Do the species differ in their rate of bending?
4. Read about Charles Darwin's famous experiments on Venus' flytraps in his book *Insectivorous Plants.* If you can obtain a potted Venus' flytrap, repeat Darwin's experiments to determine how many touches are needed to make the leaf trap close.

Testing the Effect of Gibberellin on Plant Growth

OBJECTIVE

- Study the effect of gibberellin on the growth of bean seedlings.

PROCESS SKILLS

- observing
- hypothesizing
- measuring
- comparing and contrasting
- collecting data
- organizing data

MATERIALS

- safety goggles
- lab apron
- disposable gloves
- 2 flowerpots, 20 cm or larger
- marking pen
- labeling tape
- potting-soil mixture
- 10 bean seedlings, at least 3 cm tall
- centimeter ruler
- cotton swabs
- gibberellic acid solution (contains gibberellin)
- water

Background

1. Gibberellins are found in all parts of plants, but are most concentrated in immature seeds. Gibberellins are only one group of many hormones that affect plant functions.
2. What is the major effect of gibberellins on plant tissues?

PART A Setting Up

1. Discuss the objective of this investigation with your lab partners. You will apply gibberellic acid solution to the leaves and shoot tips of one group of bean seedlings, and you will apply only water to an identical group of bean seedlings. Develop a hypothesis about the effect of gibberellic acid solution on bean seedlings. Record your hypothesis in your lab report.
2. CAUTION **Wear safety goggles, a lab apron, and disposable gloves at all times during this investigation.**
3. Obtain two flowerpots, and label them A and B. Also write your initials on the flowerpots.
4. Fill each flowerpot with potting-soil mixture. The pots should be filled to the same level.
5. CAUTION **Keep the seeds, which may have been treated with a fungicide, away from your skin.** Plant five bean seedlings in each flowerpot, spacing them evenly around the edge. Each seedling's roots should be at least 1 cm below the soil surface.
6. Measure the height of each plant in pot A to the nearest millimeter. Measure from the soil surface to the shoot tip. In your lab report, record your measurements in a data table similar to the table on the facing page.
7. Average the height of the five seedlings. In your lab report, record your average measurement under "Initial height" in a data table like the one shown.
8. Repeat steps 6 and 7 using the plants in pot B.
9. Wet a cotton swab with water. Rub the water over the leaves and shoot tips of each seedling in pot A.
10. CAUTION **Gibberellic acid is an irritant. If you get gibberellic acid solution on your skin or clothing, rinse it off at the sink while calling to your teacher. If you get gibberellic acid solution in your eyes, flush it out immediately at an eyewash station while calling to your teacher.** Wet a clean cotton swab with gibberellic acid solution. Apply the solution to the seedlings in pot B by rubbing the cotton swab on the leaves and shoot tips.
11. Place both flowerpots in a window or other area where they are likely to get light. The seedlings should receive the same amount of water, sunlight, darkness, and air circulation.
12. Clean up your materials and wash your hands before leaving the lab.

PART B Observing the Results

13. Each day over the next 10 days, measure the height of each seedling. Average the height of the seedlings in each flowerpot, and record the average height in your data table.
14. Calculate the average change in height for each day. For example, the average change in height during the second day is equal to the average height on day 2 minus the average height on day 1.
15. If you are unable to make measurements over the weekend, simply record in your data table the number of days that elapsed since the last measurement was taken. To calculate the average change in height for the days when measurements were not taken, you will need to divide the amount of change by the number of days that have elapsed since your last measurement.
16. At the end of 10 days, clean up your materials according to your teacher's instructions.

Analysis and Conclusions

1. Use the data you have recorded to calculate the percentage increase—between your first measurement and your last measurement—in the average height of the two groups of plants.
2. Use your data to make a line graph of height as a function of time. Label the *x*-axis of your graph *Time*, and measure time in days. Label the *y*-axis *Height*, and measure height in millimeters.
3. Do your data support your hypothesis? Explain why or why not.
4. What differences, other than height, did you detect in the bean seedlings?
5. What were some of the possible sources of error in this experiment?
6. How might a knowledge of plant regulatory chemicals be of use to farmers and other plant growers?

Further Inquiry

Design an experiment to determine whether gibberellic acid accelerates the germination of bean seeds.

FLOWERPOT A: *EFFECTS OF WATER ON BEAN SEEDLINGS*

Day	Height (mm)	Total change in height (mm)
Initial		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

FLOWERPOT B: *EFFECTS OF GIBBERELLIC ACID ON BEAN SEEDLINGS*

Day	Height (mm)	Total change in height (mm)
Initial		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		