22–1 Introduction to Plants

What color is life? That's a silly question, of course, because living things can be just about any color. But consider it in a different way. Imagine yourself in a place on Earth where the sounds and scents of life are all around you. The place is so abundant with life that when you stand on the ground, living things blot out the sun. Now, what color do you see? If you have imagined a thick forest or a teeming jungle, then one color will fill the landscape of your mind—green—the color of plants.

Plants dominate the landscape. Where plants are plentiful, other organisms, such as animals, fungi, and microorganisms, take hold and thrive. Plants provide the base for food chains on land. They also provide shade, shelter, and oxygen for animals of every size and kind. The oldest fossil evidence of plants dates from about 470 million years ago. Since then, plants have colonized and transformed nearly every corner of Earth.

What Is a Plant?

Plants are members of the kingdom Plantae. **Plants are multicellular eukaryotes that have cell walls made of cellulose. They develop from multicellular embryos and carry out photosynthesis using the green pigments chlorophyll *a* and *b*.** Plants include trees, shrubs, and grasses as well as other organisms such as mosses and ferns. Most plants, including the one in **Figure 22–1**, are autotrophs, although a few are parasites or saprobes that live on decaying materials.

Plants are so different from animals that sometimes there is a tendency to think of them as not being alive. With few exceptions, plants do not gather food, nor do they move about or struggle directly with their predators. Plants can neither run away from danger nor strike blows against an adversary. But as different as they are from animals, plants are everywhere. How have they managed to be so successful?

That question has many answers. In the next few chapters, we will explore some of them. For now, it might help to think of plants as a well-known botanist once described them—as "stationary animals that eat sunlight"!

Guide for Reading

Key Concepts
- What is a plant?
- What do plants need to survive?
- How did the first plants evolve?

Vocabulary
gametophyte
sporophyte

Reading Strategy: Using Prior Knowledge
Before you read the chapter, make a list of the different groups of plants that you know. As you read, revise your list to include new information about plant groups.

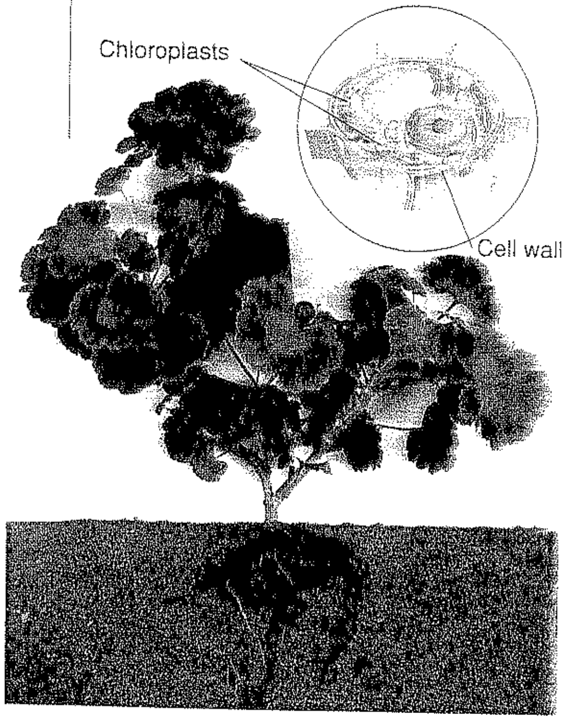
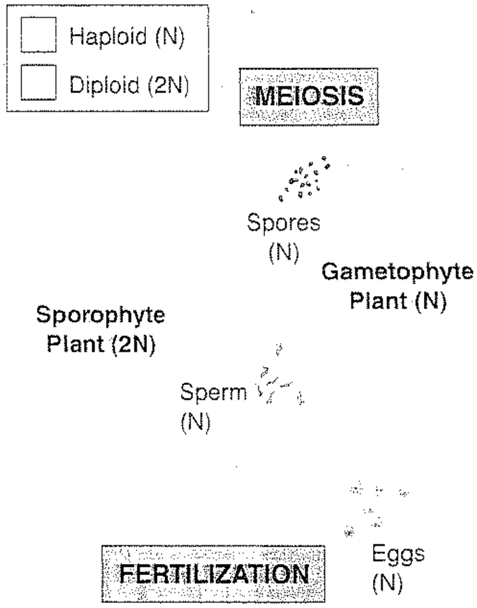
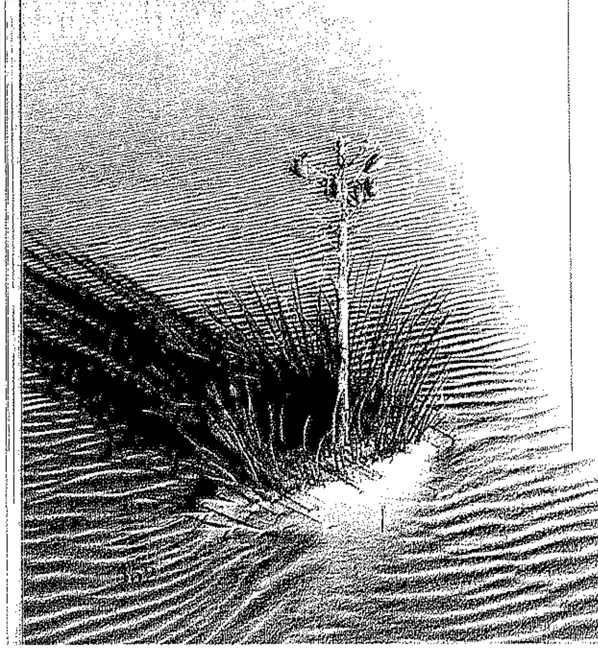


Figure 22–1 All plants are multicellular eukaryotes that have cell walls made of cellulose. Their leaves appear green because of the photosynthetic pigments chlorophyll *a* and *b*, which are located in chloroplasts.



▲ **Figure 22–2** All plants have a life cycle with alternation of generations, in which the haploid gametophyte phase alternates with the diploid sporophyte phase. **Interpreting Graphics** *What stage in the life cycle is produced by fertilization?*

▼ **Figure 22–3** **All plants need sunlight, water, minerals, oxygen, carbon dioxide, and a way to move water and nutrients to all their cells.** Adaptations allow them to live in even the driest locations, such as this desert.



The Plant Life Cycle

Plants have life cycles that are characterized by alternation of generations, as shown in **Figure 22–2.** As you learned in Chapter 20, the two generations are the haploid (N) **gametophyte,** or gamete-producing plant, and the diploid (2N) **sporophyte,** or spore-producing plant. Recall that gametes—eggs and sperm—are haploid cells that fuse together to produce a new diploid individual. Spores are reproductive cells that produce a new individual by mitosis. Although all plants have a gametophyte stage and a sporophyte stage, their forms differ dramatically from phylum to phylum.

To be fully terrestrial, plants must be able to reproduce in dry environments where there is no water through which gametes can move from plant to plant. Seed plants have evolved reproductive cycles that are carried out independently of water. Many plants also have forms of vegetative, or asexual, reproduction.

What Plants Need to Survive

Surviving as stationary organisms on land is a difficult task, and plants have developed a number of adaptations that make them successful. **The lives of plants revolve around the need for sunlight, water and minerals, gas exchange, and the movement of water and nutrients throughout the plant body.**

Sunlight Plants use the energy from sunlight to carry out photosynthesis. As a result, every plant displays adaptations shaped by the need to gather sunlight. Photosynthetic organs such as leaves are typically broad and flat and are arranged on the stem so as to maximize light absorption.

Water and Minerals All cells require a constant supply of water. For this reason, plants must obtain and deliver water to all their cells—even those that grow above ground in the dry air. Water is one of the raw materials of photosynthesis, so it is used up quickly when the sun is shining. Sunny conditions, such as those in the desert shown in **Figure 22–3,** can cause living tissues to dry out. Thus, plants have developed structures that limit water loss.

As they absorb water, plants also absorb minerals. Minerals are nutrients in the soil that are needed for plant growth.

Gas Exchange Plants require oxygen to support respiration as well as carbon dioxide to carry out photosynthesis. They must exchange these gases with the atmosphere without losing excessive amounts of water through evaporation.

Movement of Water and Nutrients Plants take up water and minerals through their roots but make food in their leaves. Most plants have specialized tissues that carry water and nutrients upward from the soil and distribute the products of photosynthesis throughout the plant body. Simpler types of plants carry out these functions by diffusion.

Problem Solving

"Plantastic" Voyage

You are part of a team that is planning a space mission that will send astronauts into space for two years. As part of their food, the astronauts will be growing yam plants, *Dioscorea composita*. Your job is to develop a plan to help plants grow on the spacecraft.

Defining the Problem In your own words, state the problem at hand.

Organizing Information Research the types of conditions these plants would need. What requirements would the plants have for moisture? Soil conditions? Light intensity? Day length?

Creating a Solution Make a detailed scale drawing of a container for growing 10 of these plants. (*Dioscorea* plants are vines; assume that each is 10 cm long and 0.5 cm wide.) Determine what material(s) you will use for your container. As you devise your plan, be sure to keep a journal in which you record your team's ideas, drawings, data, and other information.

Presenting Your Plan Prepare a multimedia presentation for your classmates as if they were the managers of the space mission. Describe how your team solved the problem, the sources of information you used, the design itself, and what you learned during the project.

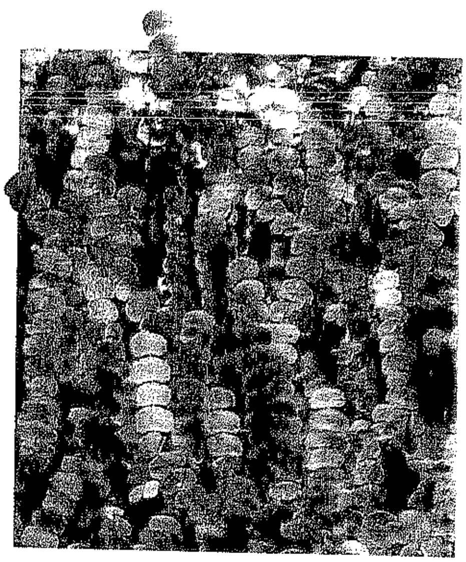
Early Plants

For most of Earth's history, plants did not exist. Life was concentrated in oceans, lakes, and streams. Algae and photosynthetic prokaryotes added the oxygen to our planet's atmosphere and provided food for animals and microorganisms.

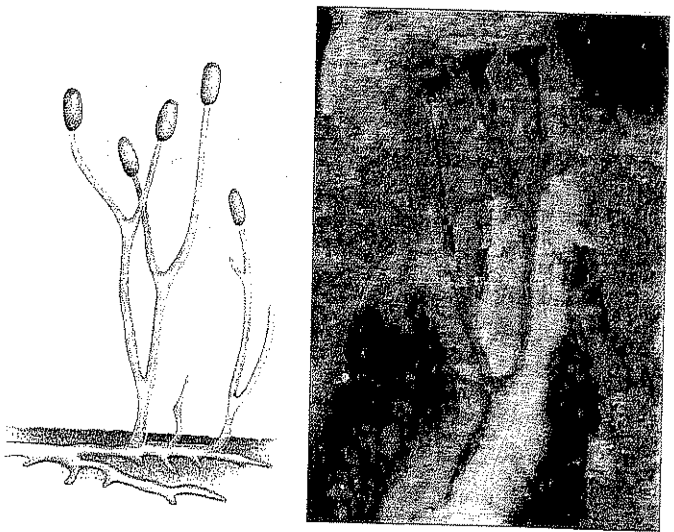
When plants appeared, much of the existing life on Earth changed. As these new photosynthetic organisms colonized the land, they changed the environment in ways that made it possible for other organisms to develop. New ecosystems emerged, and organic matter began to form soil. How did plants adapt to the conditions of life on land? How plants evolved structures that acquire, transport, and conserve water is the key to answering this question.

Origins in the Water You may recall from Chapter 20 that green algae, shown in **Figure 22–4**, are photosynthetic, plantlike protists. Many of these algae are multicellular. **The first plants evolved from an organism much like the multicellular green algae living today.** Multicellular green algae have the size, color, and appearance of plants. But the resemblance of many green algae to plants is more than superficial. They have reproductive cycles that are similar to those of plants. In addition, green algae have cell walls and photosynthetic pigments that are identical to those of plants.

CHECKPOINT *What was the greatest "challenge" to plants as they began to live on land?*



▲ **Figure 22–4** **The first plants evolved from an organism much like the modern multicellular green algae.** The alga *Halimeda* is found in Honduras in Central America. It has many cellular features in common with plants.

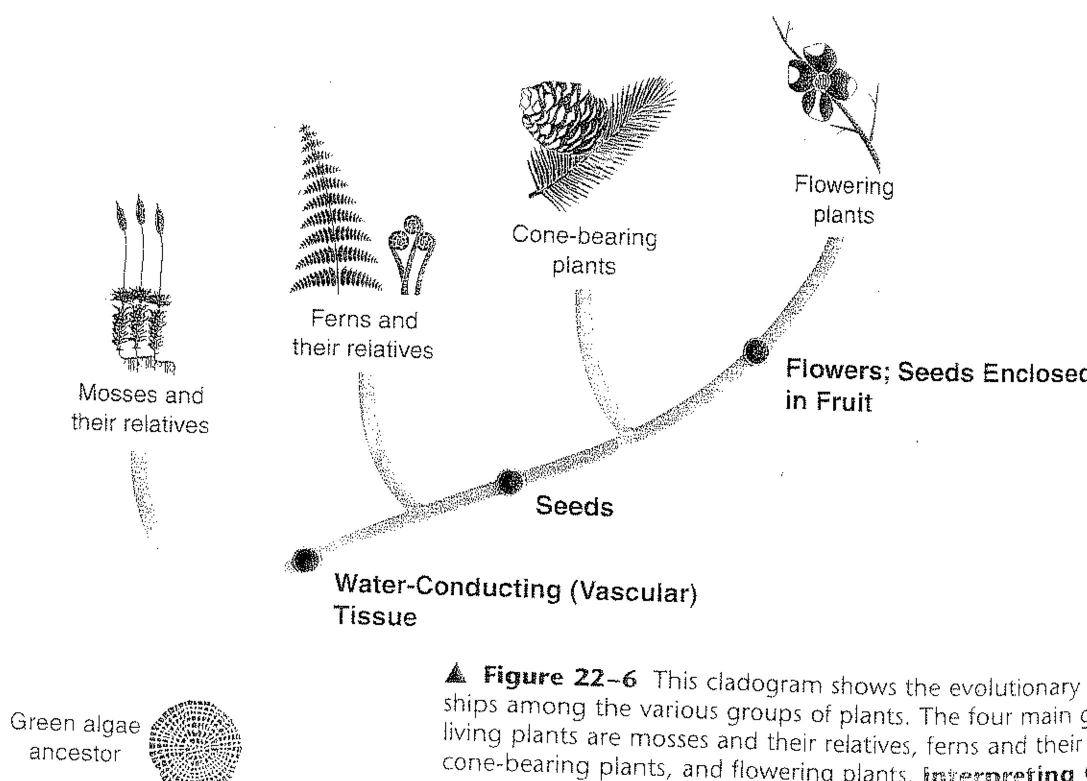


▲ **Figure 22–5** One of the earliest fossil plants was *Cooksonia*, which looked similar to mosses living today. *Cooksonia* had simple branched stalks that bore reproductive structures at their tips. **Inferring** *Which structures of this early plant seem to be adapted to carry out photosynthesis? To obtain water and minerals?*

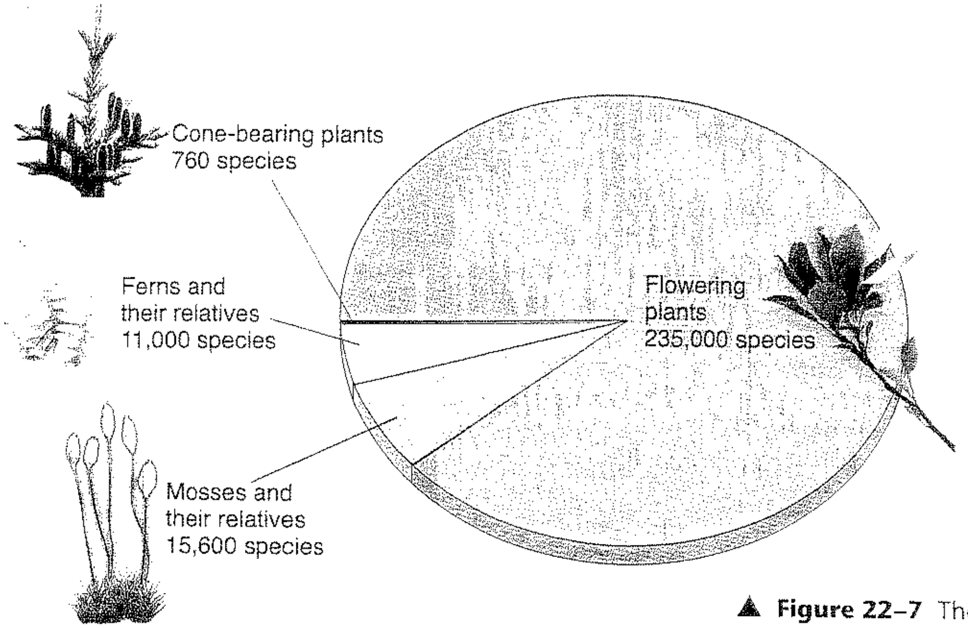
The First Plants The first true plants were still dependent on water to complete their life cycles. But before long, the demands of life on land favored the evolution of plants that were more resistant to the drying rays of the sun, more capable of conserving water, and more capable of reproducing on dry land. Early plants were similar to today's mosses in that they were simple in structure and grew close to the ground. **Figure 22–5** shows how these plants may have looked. Soon these early plants were common in damp and swampy regions, just as most mosses are today.

From these plant pioneers, several major groups of plants evolved. One group developed into mosses and their relatives. Another lineage gave rise to all the other plants on Earth today—ferns, cone-bearing plants, and flowering plants. All of these groups of plants are now successful in living on dry land, but they have evolved very different adaptations for a wide range of terrestrial environments.

✔ CHECKPOINT *To what group of living plants were early plants most similar?*



▲ **Figure 22–6** This cladogram shows the evolutionary relationships among the various groups of plants. The four main groups of living plants are mosses and their relatives, ferns and their relatives, cone-bearing plants, and flowering plants. **Interpreting Graphics** *Which two groups of plants contain seeds?*



▲ **Figure 22–7** The great majority of plants alive today are angiosperms, which are also known as flowering plants. **Interpreting Graphics** *What is the second largest group of plants?*

Overview of the Plant Kingdom

Botanists divide the plant kingdom into four groups based on three important features: water-conducting tissues, seeds, and flowers. The relationship of these groups is shown in **Figure 22–6.** There are, of course, many other features by which plants are classified, including reproductive structures and body plan.

Today, plant scientists can classify plants more precisely by comparing the DNA sequences of various species. Since 1994, a t… of biologists from twelve nations has begun to change our … plant relationships. Their project, known as Deep Green, has …ovided strong evidence that the first plants evolved from green algae that lived in fresh water, not in the sea as had been thought.

In the rest of this chapter, we will explore how important plant traits evolved over the course of millions of years. In particular, we will examine the success of the flowering plants. As shown in **Figure 22–7**, flowering plants consist of 235,000 species—almost 90 percent of all living species of plants.

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22–1 Section Assessment

1. **Key Concept** What features distinguish plants from other organisms?
2. **Key Concept** To live successfully on land, what substances must plants obtain from their environment?
3. **Key Concept** From which …roup of protists did the first …ts evolve? How are plants s…ilar to these protists?
4. **Critical Thinking Comparing and Contrasting** Compare the gametophyte and sporophyte stages of the plant life cycle. Which is haploid? Which is diploid?

iTEXT **Assessment** Use iText to review the important concepts in Section 22–1.

MAKING CONNECTIONS

Cell Structure How do the cells of plants differ from those of animals? How are they different from those of fungi? Refer to Chapters 7 and 21 for help in answering this question.

22–2 Bryophytes

Guide for Reading

Key Concepts
- What adaptations of bryophytes enable them to live on land?
- What are the three groups of bryophytes?
- How do bryophytes reproduce?

Vocabulary
bryophyte
rhizoid
gemma
protonema
antheridium
archegonium

Reading Strategy: Using Visuals
Before you read, preview **Figure 22–11,** which shows the life cycle of a moss. In your own words, describe the basic process of reproduction shown. As you read the section, add information that you learn about reproduction in bryophytes.

In the cool forests of the northern woods, the moist ground is carpeted with green. When you walk, this soft carpet feels spongy. Look closely and you will see the structure of this carpet—mosses. Mosses and their relatives are generally called **bryophytes** (BRY-oh-fyts), or nonvascular plants. Unlike all other plants, these organisms do not have vascular tissues, or specialized tissues that conduct water and nutrients. **Bryophytes have life cycles that depend on water for reproduction. Lacking vascular tissue, these plants can draw up water by osmosis only a few centimeters above the ground.** This arrangement keeps them relatively small.

During at least one stage of their life cycle, bryophytes produce sperm that must swim through water to reach the eggs of other individuals. Therefore, they must live in places where there is rainfall or dew for at least part of the year.

Groups of Bryophytes

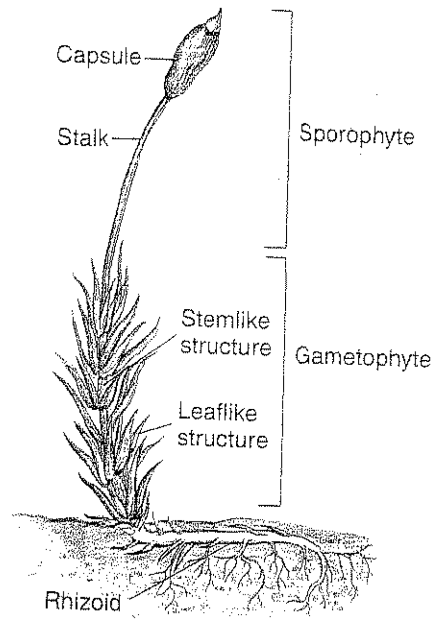
The most recognizable feature of bryophytes is that they are low-growing plants that can be found in moist, shaded areas. Where water is in regular supply—in habitats from the polar regions to the tropics—these plants thrive. **Bryophytes include mosses, liverworts, and hornworts.** Today, most botanists classify these groups of plants in three separate phyla.

Mosses The most common bryophytes are mosses, which are members of the phylum Bryophyta (bry-OH-fy-tuh). Mosses grow most abundantly in areas with water—in swamps and bogs, near streams, and in rain forests. Bryophytes are well adapted to life in wet habitats and nutrient-poor soils. Many mosses can tolerate low temperatures, allowing them to grow in harsh environments where other plants cannot. In fact, mosses are the most abundant plants in the polar regions.

Mosses vary in appearance from miniature evergreen trees to small, filamentous plants that together form a threadlike carpet of green, as shown in **Figure 22–8.** The moss plants that you might have observed on a walk through the woods are actually clumps of gametophytes growing close together. When mosses reproduce, they produce thin stalks, each containing a capsule. This is the sporophyte stage, as shown in **Figure 22–9.** Each moss plant has a thin, upright shoot that looks like a stem with tiny leaves. These are not true stems or leaves, however, because they do not contain vascular tissue.

Figure 22–8 Mosses grow best in moist environments, such as on the rocks by this waterfall. **Like all bryophytes, mosses have life cycles that depend on water for reproduction.**

Because the "leaves" of mosses are only one cell thick, these plants lose water quickly if the surrounding air is dry. The lack of vascular tissues also means that mosses do not have true roots. Instead, they have **rhizoids,** which are long, thin cells that anchor them in the ground and absorb water and minerals from the surrounding soil. Water moves from cell to cell through the rhizoids and into the rest of the plant.



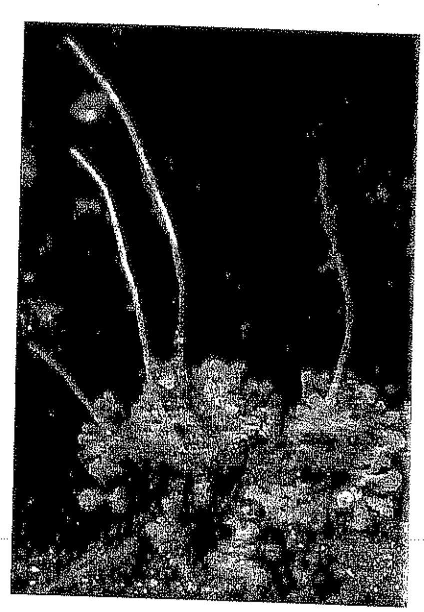
▲ **Figure 22–9** This illustration shows the structure of a typical moss plant. The green photosynthetic portion is the gametophyte. The brown structure on the tip of the gametophyte is the sporophyte. **Applying Concepts** *Which stage of the moss plant provides nutrients for the other stage?*

Liverworts If you have come across odd little plants that look almost like flat leaves attached to the ground, you have probably seen a liverwort, shown in **Figure 22–10.** These plants belong to the phylum Hepaticophyta (hih-pat-ik-OH-fy-tuh) and get their name from the fact that some species resemble the shape of a liver. Liverworts in their gametophyte stage are broad and thin structures that draw up moisture directly from the surface of the soil. When the plants mature, the gametophytes produce structures that look like tiny green umbrellas. These "umbrellas" carry the structures that produce eggs and sperm.

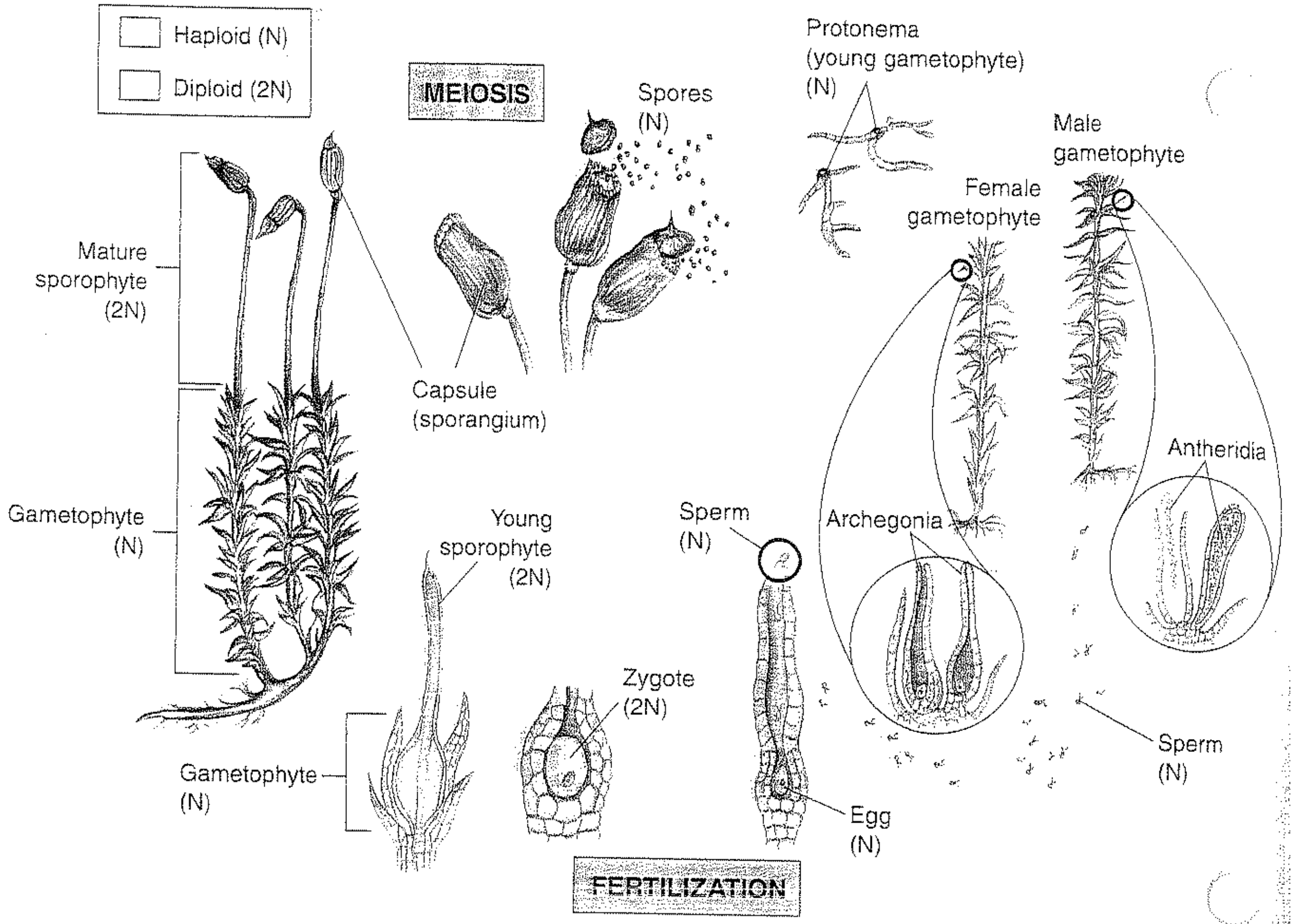
Liverworts can also reproduce asexually by means of gemmae. **Gemmae** (JEM-ee; singular: gemma) are small multicellular spheres that contain many haploid cells. In some species of liverworts, gemmae are produced in cuplike structures called gemma cups. When washed out of the gemma, these cells can divide by mitosis to produce a new individual.

Hornworts Hornworts are members of the phylum Anthocerophyta (an-thoh-sehr-UH-fy-tuh). Like the liverworts, hornworts are generally found only in soil that is damp nearly year-round. Their gametophytes look very much like those of liverworts. The hornwort sporophyte, however, looks like a tiny green horn.

✓CHECKPOINT *How do bryophytes reproduce asexually?*



◀ **Figure 22–10** **Bryophytes include liverworts and hornworts.** The liverworts (left) produce gametes in structures that look like little green umbrellas. The tiny cuplike structures on the liverworts are gemma cups. The hornworts (right) have sporophytes that look like tiny green horns.



▲ **Figure 22–11** **In bryophytes, the gametophyte is the dominant, recognizable stage of the life cycle and is the form that carries out photosynthesis.** Sporophytes, which produce haploid spores, grow at the top of the gametophyte plant. When the spores are ripe, they are shed from the capsule like pepper from a shaker. In some species, gametes (sperm and eggs) are produced on separate male and female gametophyte plants.

Life Cycle of Bryophytes

Like all plants, bryophytes reproduce with alternation of generations. **In bryophytes, the gametophyte is the dominant, recognizable stage of the life cycle and is the stage that carries out most of the plant's photosynthesis.** The sporophyte is dependent on the gametophyte for supplying water and nutrients.

Dependence on Water For fertilization to occur, the sperm of a bryophyte must swim to an egg. The sperm may swim through standing water or through a coating of water left by dew. Sometimes raindrops can splash sperm from one plant to another. Because of this limit to reproduction, bryophytes must live in habitats where water is available.

Life Cycle of a Moss The life cycle of a moss, shown in **Figure 22–11**, helps illustrate how bryophytes reproduce. When a moss spore lands in a moist place, it germinates and grows into a mass of tangled green filaments called a **protonema** (proh-toh-NEE-muh). As the protonema grows, it forms rhizoids that grow into the ground and shoots that grow into the air. These shoots grow into the familiar green moss plants, whi[ch] are the gametophyte stage of its life cycle.

✓CHECKPOINT *What is a protonema?*

Gametes are formed in reproductive structures at the tips of the gametophytes. Sperm with whiplike tails are produced in **antheridia** (an-thur-ID-ee-uh; singular: antheridium), and egg cells are produced in **archegonia** (ahr-kuh-GOH-nee-uh; singular: archegonium). Some species produce both sperm and eggs on the same plant, whereas other species produce sperm and eggs on separate plants. Once sperm are released and reach egg cells, fertilization produces a diploid zygote. This zygote is the beginning of the sporophyte stage of the life cycle. It grows directly out of the body of the gametophyte and actually depends on it for water and nutrients. The mature sporophyte is a long stalk ending in a capsule that looks like a saltshaker. Inside the capsule, haploid spores are produced by meiosis. When the capsule ripens, it opens and haploid spores are scattered to the wind to start the cycle again.

Human Use of Mosses

Sphagnum (SFAG-num) mosses are a group of mosses that thrive in the acidic water of bogs. Dried sphagnum moss absorbs many times its own weight in water and thus acts as a sort of natural sponge. In certain environments the dead remains of sphagnum accumulate to form thick deposits of peat. Peat can be cut from the ground, as shown in **Figure 22–12**, and then burned as a fuel.

Peat moss is also used in gardening. Gardeners add peat moss to the soil because it improves the soil's ability to retain water. Peat moss also has a low pH, so when added to the soil it increases the soil's acidity. Some plants, such as azaleas, grow well only if they are planted in acidic soil.

▼ **Figure 22–12** The compacted remains of sphagnum moss may eventually form thick deposits of peat. When it is cut and dried, it can be burned to produce heat. Peat has been used as a form of fuel in Ireland for many centuries. **Inferring** *What can you infer about the climate of an area where sphagnum moss grows abundantly in peat bogs?*

22–2 Section Assessment

1. **Key Concept** How is water essential in the life cycle of a bryophyte?
2. **Key Concept** List the three groups of bryophytes. In what type of habitat do they live?
3. **Key Concept** What is the relationship between the gametophyte and the sporophyte in mosses and other bryophytes?
4. What is an archegonium? An antheridium? How are these structures important in the life cycle of a moss?
5. **Critical Thinking Inferring** What characteristic of bryophytes is responsible for their small size? Explain.

iTEXT Assessment Use iText to review the important concepts in Section 22–2.

Take It to the NET

Find out more about sphagnum moss. Then, write a paragraph about the growth, harvesting, and use of sphagnum moss. Use the links provided in the Biology area at the Prentice Hall Web site for help in completing this activity: **www.phschool.com**

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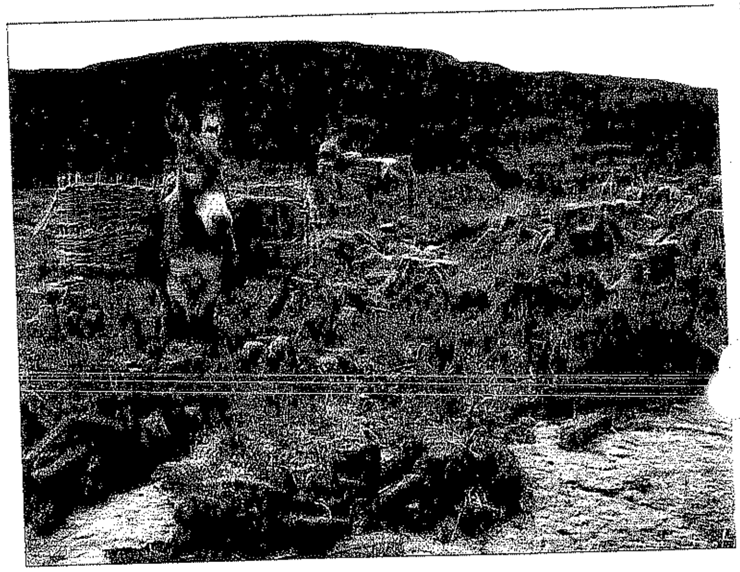

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22–3 Seedless Vascular Plants

Guide for Reading

Key Concepts
- How is vascular tissue important to ferns and their relatives?
- What are the characteristics of the three phyla of seedless vascular plants?
- What are the stages in the life cycle of ferns?

Vocabulary
- vascular tissue • tracheid
- xylem • phloem • lignin
- root • vein • leaf • stem
- rhizome • frond
- sporangium • sorus

Reading Strategy: Building Vocabulary
Before you read, preview new vocabulary by skimming the section and making a list of the boldfaced terms. Leave space to make notes about each term as you read.

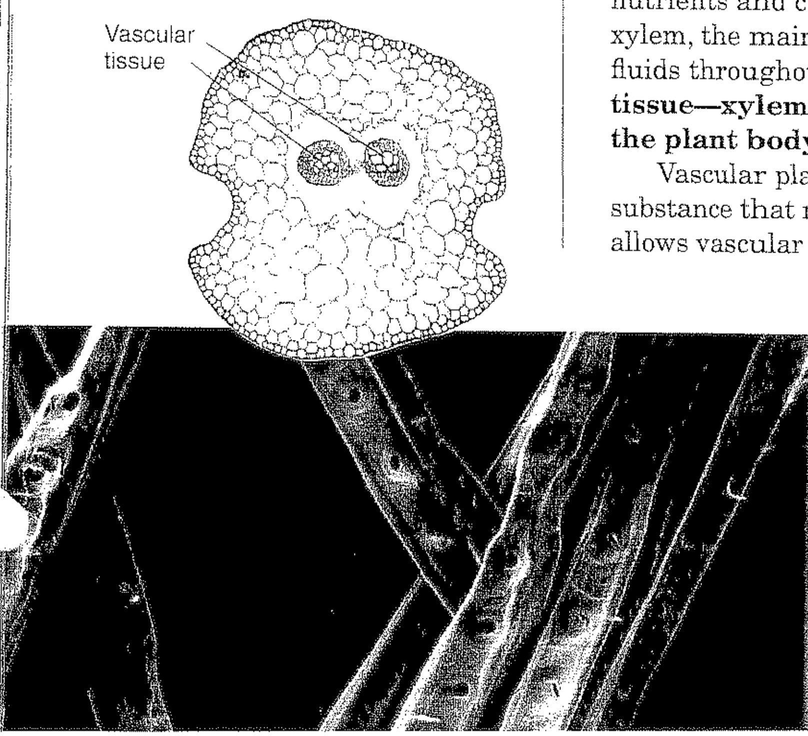
As you have read, bryophytes have only one way of transporting water—from cell to cell by osmosis. This fact limits them to just a few centimeters in height. About 420 million years ago, something remarkable happened. In just a few million years, plants grew to a whole new scale on the landscape. The small, mosslike plants were still around, of course, just as they are today. But now, they were joined by plants that were more than a meter in height, and others that were as large as small trees. What had happened? Fossil evidence shows that these plants contained **vascular tissue,** a type of tissue that is specialized to conduct water and nutrients through the body of the plant.

Evolution of Vascular Tissue

The first vascular plants had a new type of cell that was specialized to conduct water. **Tracheids** (TRAY-kee-idz), shown in **Figure 22–13,** were one of the great evolutionary innovations of the plant kingdom. They are the key cells in **xylem** (ZY-lum), a form of vascular tissue that carries water upward from the roots to every part of a plant. Tracheids are hollow cells with thick cell walls that resist pressure. Within a plant, they are connected end to end like a series of drinking straws. Tracheids allow water to move through a plant much more efficiently than by diffusion alone.

Vascular plants also possess a second type of vascular tissue called phloem. **Phloem** (FLOH-um) transports solutions of nutrients and carbohydrates produced by photosynthesis. Like xylem, the main cells of phloem are long and specialized to move fluids throughout the plant body. **Both forms of vascular tissue—xylem and phloem—can move fluids throughout the plant body, even against the force of gravity.**

Vascular plants also evolved the ability to produce **lignin,** a substance that makes cell walls rigid. The presence of lignin allows vascular plants to grow upright and to reach great heights.



◀ **Figure 22–13** Vascular tissue conducts water and nutrients throughout the plant body. It also provides support for the leaves and other organs of the plant. The two types of vascular tissue are xylem, which conducts water, and phloem, which conducts solutions of nutrients. The cross section (top) shows the vascular tissue in a club moss. The bottom photo shows a much-magnified view of tracheids from the xylem of a white pine.

Ferns and Their Relatives

Seedless vascular plants include club mosses, horsetails, and ferns. The most numerous phylum of these is the ferns.

Like other vascular plants, ferns and their relatives have true roots, leaves, and stems. **Roots** are underground organs that absorb water and minerals. Water-conducting tissues are located in the center of the root. **Leaves** are photosynthetic organs that contain one or more bundles of vascular tissue. This vascular tissue is gathered into **veins** made of xylem and phloem. **Stems** are supporting structures that connect roots and leaves, carrying water and nutrients between them.

Club Mosses What was once a large and ancient group of land plants—phylum Lycophyta (ly-KOH-fy-tuh)—exists now as a much smaller group that includes the club mosses. Once, ancient club mosses grew into huge trees—up to 35 meters tall—and some produced Earth's first forests. The fossilized remains of these forests exist today as huge beds of coal.

Today, club mosses are small plants that live in moist woodlands and near streambeds and marshes. *Lycopodium,* the common club moss shown in **Figure 22–14,** looks like a miniature pine tree. For this reason it is also called "ground pine."

Horsetails The only living genus of Arthrophyta (ahr-THROH-fy-tuh) is *Equisetum,* which is a plant that grows about a meter tall. Like the club mosses, *Equisetum* has true leaves, stems, and roots. Its leaves are arranged in distinctive whorls at joints along the stem. *Equisetum* is called horsetail, or scouring rush, because its stems look similar to horses' tails and contain crystals of abrasive silica. During Colonial times, horsetails were commonly used to scour pots and pans.

CHECKPOINT *What chemical makes the stems of* Equisetum *abrasive?*

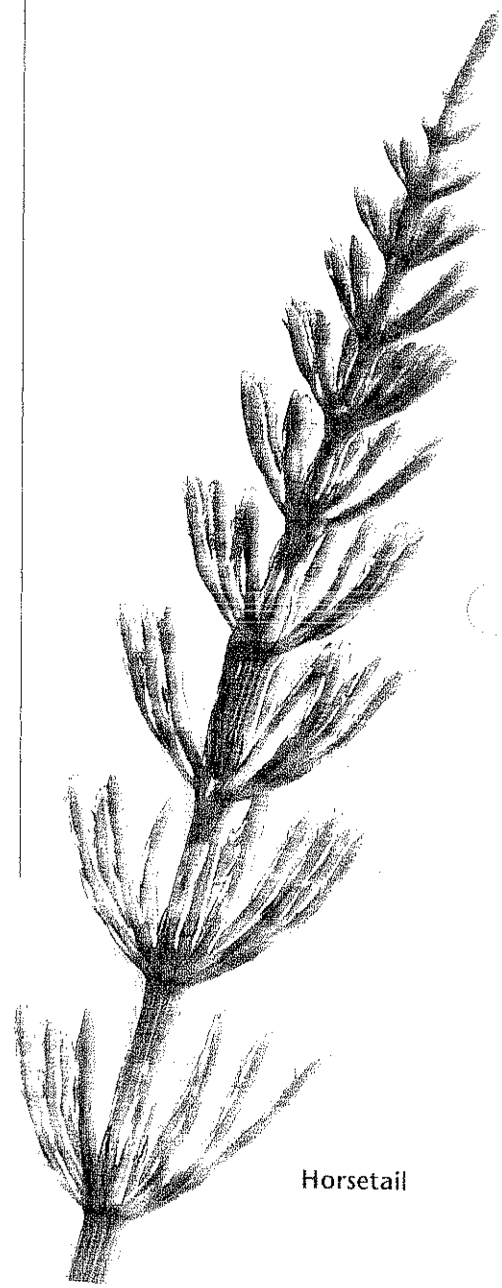
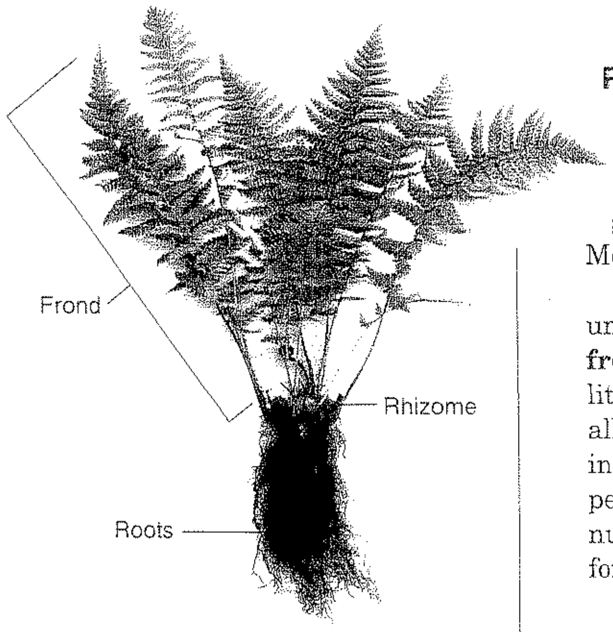


Figure 22–14 **Club mosses and horsetails are seedless vascular plants.** The club moss *Lycopodium* (left) looks like a tiny pine tree growing on the forest floor. The only living genus of Arthrophyta is *Equisetum,* or horsetail (above).



▲ **Figure 22–15** Ferns are easily recognized because of their delicate leaves, which are called fronds. Fronds grow from a rhizome, which grows horizontally through the soil. **Applying Concepts** *Is the plant shown a sporophyte or a gametophyte?*

Ferns Ferns, members of phylum Pterophyta (tehr-OH-fy-tuh), probably evolved about 350 million years ago, when great club moss forests covered the ancient Earth. Ferns have survived during the Earth's long history in numbers greater than any other group of spore-bearing vascular plants. More than 11,000 species of ferns are living today.

Ferns have true vascular tissues, strong roots, creeping or underground stems called **rhizomes,** and large leaves called **fronds,** shown in **Figure 22–15.** Ferns can thrive in areas with little light. They are most abundant in wet, or at least seasonally wet, habitats around the world. They are often found living in the shadows of forest trees, where direct sunlight hardly penetrates the forest's leafy umbrella. Ferns are found in great numbers in the rain forests of the Pacific Northwest. In tropical forests, some species grow as large as small trees.

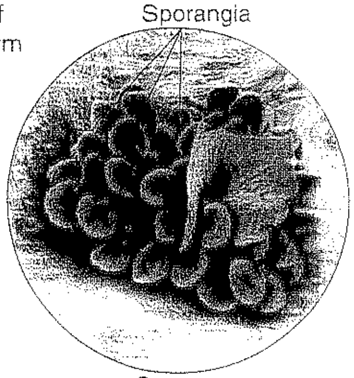
Life Cycle of Ferns

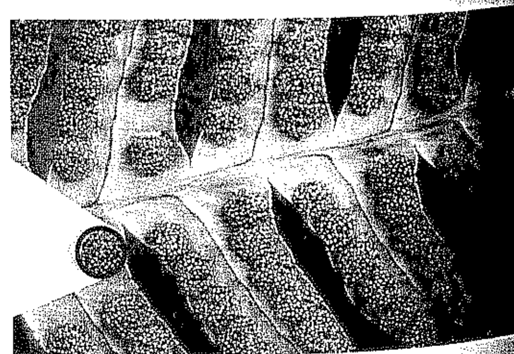
The large plants we recognize as ferns are actually diploid sporophytes. **Ferns and other vascular plants have a life cycle in which the diploid sporophyte is the dominant stage.** Fern sporophytes produce haploid spores on the underside of their fronds in tiny containers called **sporangia** (spoh-RAN-jee-uh; singular: sporangium). Sporangia are grouped into clusters called **sori** (SOH-ry; singular: sorus), shown in **Figure 22–16.** Spores released from sporangia may be carried by wind and water over long distances.

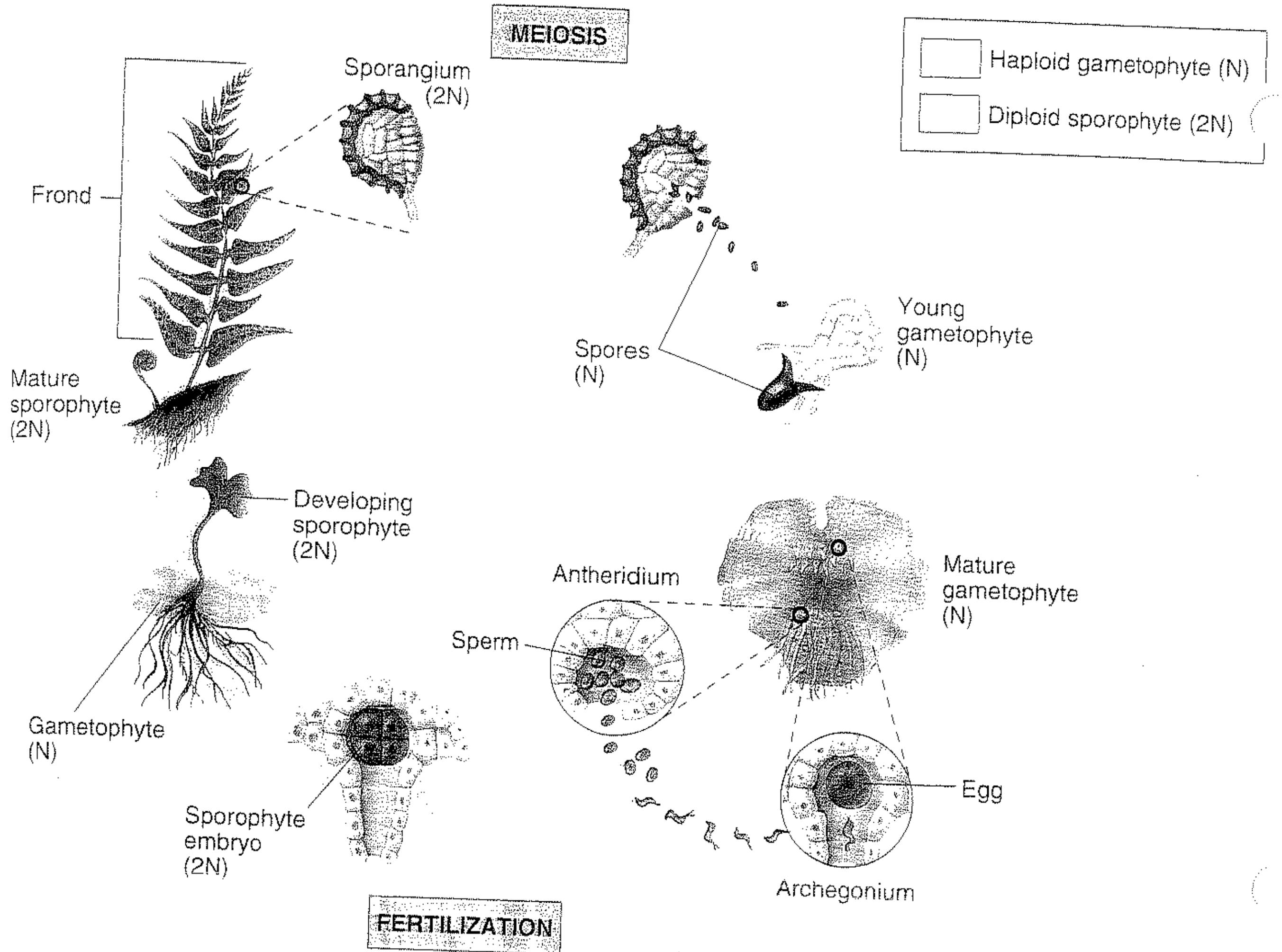
When the spores germinate, they develop into haploid gametophytes. The small gametophyte first grows a set of rootlike rhizoids. It then flattens into a thin, heart-shaped, green structure that is the mature gametophyte. Although it is tiny, the gametophyte grows independently of the sporophyte.

The antheridia and archegonia are found on the underside of the gametophyte. As in bryophytes, fertilization requires at least a thin film of water, allowing the sperm to swim to the eggs. The diploid zygote produced by fertilization immediately begins to grow into a new sporophyte plant. As the sporophyte grows, the gametophyte withers away. Fern sporophytes often live for many years. In some species, the fronds produced in the spring die in the fall, but the rhizomes live through the winter and sprout again the following spring.

▶ **Figure 22–16** Many clusters of sporangia—each called a sorus—form on the underside of fern leaves. In each sporangium, cells undergo meiosis to produce spores. **Inferring** *Are these spores haploid or diploid?*







▲ **Figure 22–17** **In the life cycle of a fern, the dominant and recognizable stage is the diploid sporophyte.** The tiny, heart-shaped gametophyte grows close to the ground and relies on dampness for the sperm it produces to fertilize an egg. The young sporophyte grows from the gametophyte.

22–3 Section Assessment

1. **Key Concept** What are the two types of vascular tissue? Describe the function of each.
2. **Key Concept** What are the three phyla of seedless vascular plants? Give an example of each.
3. **Key Concept** What is the dominant stage of the fern life cycle? What is the relationship of the fern gametophyte and sporophyte?
4. **Critical Thinking Inferring** The size of plants increased dramatically with the evolution of vascular tissue. How might these two events be related?

iTEXT **Assessment** Use iText to review the important concepts in Section 22–3.

ALTERNATIVE ASSESSMENT

Making a Photo Essay
Find out more about club mosses, horsetails, and ferns. Use this information along with photographs of these plants to put together a two-page photo essay about seedless vascular plants.

22–4 Seed Plants

Guide for Reading

Key Concepts
- What adaptations allow seed plants to reproduce without standing water?
- What are the four groups of gymnosperms?

Vocabulary
gymnosperm
angiosperm
cone
flower
pollen grain
pollination
seed
embryo
seed coat

Reading Strategy: Building Vocabulary As you read, make notes about the meaning of each term listed above. After you have read the section, draw a concept map to show the relationship among these terms.

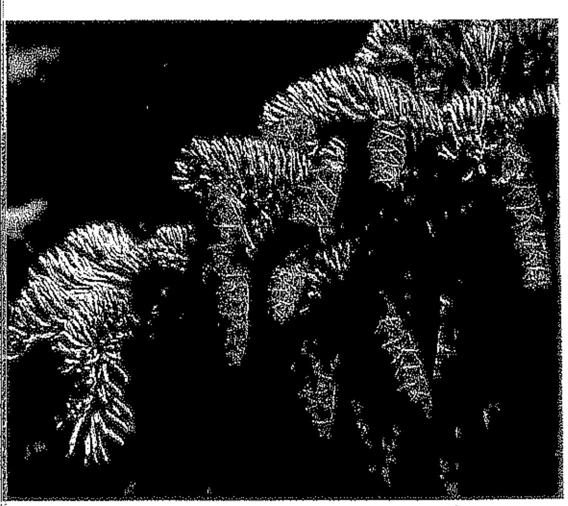
Whether they are acorns, pine nuts, dandelion seeds, or kernels of corn, seeds can be found everywhere. Seeds are so common, in fact, that their importance may be overlooked. Over millions of years; plants with a single trait—the ability to form seeds—became the most dominant group of photosynthetic organisms on land.

Seed plants are divided into two groups: gymnosperms and angiosperms. **Gymnosperms** (JIM-noh-spurmz) bear their seeds directly on the surfaces of cones, whereas **angiosperms** (AN-jee-oh-spurmz), which are also called flowering plants, bear their seeds within a layer of tissue that protects the seed. Gymnosperms include the conifers, such as pines and spruces, as well as palmlike plants called cycads, ancient ginkgoes, and the very weird gnetophytes. Angiosperms include grasses, flowering trees and shrubs, and all wildflowers and cultivated species of flowers. The angiosperms are discussed in Section 22–5. This section begins by exploring some of the reasons that seed plants became so successful.

Reproduction Free From Water

Like all plants, seed plants have a life cycle that alternates between a gametophyte stage and a sporophyte stage. Unlike mosses and ferns, however, seed plants do not require water for fertilization of gametes. As a result, seed plants can live just about anywhere—from moist habitats that are often dominated by seedless plants, to dry and cold habitats where most seedless plants cannot survive. **Adaptations that allow seed plants to reproduce without water include flowers or cones, the transfer of sperm by pollination, and the protection of embryos in seeds.**

Cones and Flowers The gametophytes of seed plants grow and mature within sporophyte structures called **cones**, which are the seed-bearing structures of gymnosperms, and **flowers**, which are the seed-bearing structures of angiosperms. The cones of a common gymnosperm are shown in **Figure 22–18**. The gametophyte generations of seed plants live inside these reproductive structures.



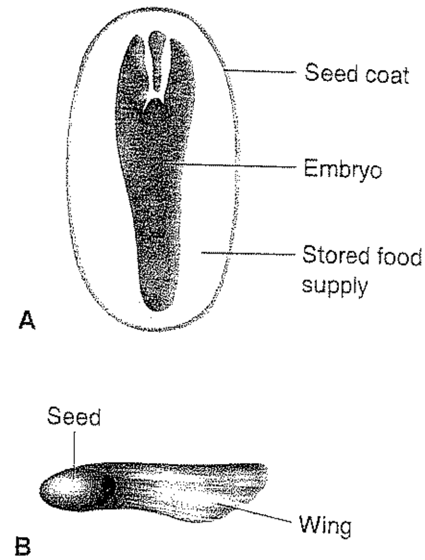
◀ **Figure 22–18** **Adaptations that allow seed plants to reproduce without water include reproduction in flowers or cones, the transfer of sperm by pollination, and the protection of embryos in a seed.** Gymnosperms, such as this spruce tree, bear their seeds on the scales of cones.

Pollen In seed plants, the entire male gametophyte is contained in a tiny structure called a **pollen grain.** Sperm produced by this gametophyte do not swim through water to fertilize the eggs. Instead, the pollen grain is carried to the female gametophyte by wind, insects, birds, small animals, or sometimes even bats. The transfer of pollen from the male gametophyte to the female gametophyte is called **pollination.**

Seeds A **seed** is an embryo of a plant that is encased in a protective covering and surrounded by a food supply. An **embryo** is the early developmental stage of the sporophyte plant. The seed's food supply provides nutrients to the embryo as it grows. The **seed coat** surrounds and protects the embryo and keeps the contents of the seed from drying out. Seeds may also have special tissues or structures that aid in their dispersal to other habitats. Some seed coats are textured so that they stick to the fur or feathers of animals. Other seeds are contained in fleshy tissues that are eaten and dispersed by animals.

After fertilization, the zygote contained within a seed grows into a tiny plant—the embryo. The embryo often stops growing while it is still small and contained within the seed. The embryo can remain in this condition for weeks, months, or even years. When the embryo begins to grow again, it uses nutrients from the stored food supply. As a result of this strategy, seeds can survive long periods of bitter cold, extreme heat, or drought—beginning to grow only when conditions are once again right.

CHECKPOINT *What is a pollen grain?*



▲ **Figure 22–19** This cross section shows the internal structure of the seed of a pine tree. **Predicting** *How might the food stored in the seed affect the reproductive success of the pine tree?*

Quick Lab

How do seeds differ from spores?

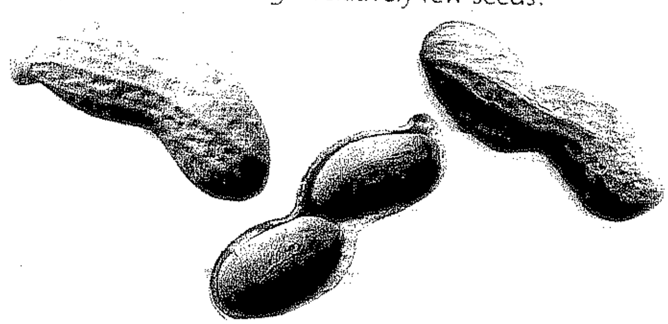
Materials Fern frond with sori, microscope, scalpel, microscope slide, coverslip, dropper pipette, peanuts in the shell, brown paper bag, hand lens

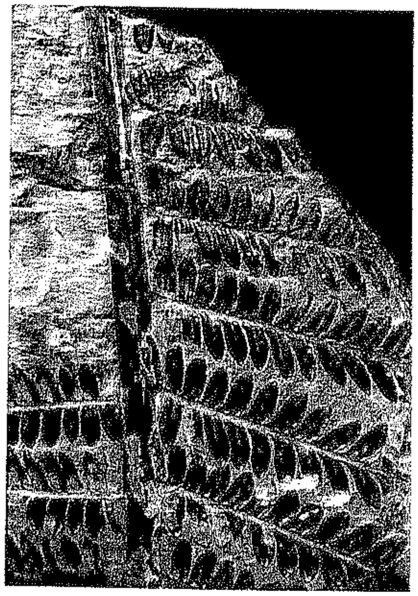
Procedure

1. Use a scalpel to scrape sori from the underside of a fern frond onto a microscope slide. Add a drop of water and a coverslip and examine the slide under the low power objective of a microscope. Sketch a few spores. **CAUTION:** *Use care with the scalpel.*
2. **CAUTION:** *Do not perform Steps 2 and 3 if you are allergic to nuts.* Open a peanut shell. Separate the two halves, or cotyledons, of a seed. Examine both halves with a hand lens and sketch the embryo.
3. Rub the nut on brown paper and hold the paper up to the light. A bright spot indicates lipids.

Analyze and Conclude

1. **Observing** What evidence did you observe that nutrients are stored in peanut seeds?
2. **Predicting** A spore and a seed are deposited in an area where the soil is poor in nutrients. Based on your observations in this activity, which is more likely to survive in a nutrient-poor environment—the spore or the seed? Explain.
3. **Formulating Hypotheses** What are the advantages of a plant disseminating millions of tiny spores as it reproduces? What are the advantages of a plant disseminating a relatively few seeds?





▲ **Figure 22–20** Seed ferns are part of the fossil record. They represent a link between ferns that do not form seeds and seed plants. This ancient plant had leaves that resemble the leaves of modern ferns. **Comparing and Contrasting** *If this plant were alive, what structures would distinguish it from a fern?*

Evolution of Seed Plants

The ancestors of seed plants evolved a variety of new adaptations that enabled them to survive in many places in which most mosses and ferns could not—from frigid mountains to scorching deserts. The most important of these adaptations was the seed.

Mosses and ferns underwent major adaptive radiations during the Carboniferous and Devonian periods, 300 to 400 million years ago. During these periods, land environments were much wetter than they are today. Tree ferns and other seedless plants grew into lush forests that covered much of Earth. Over a period of millions of years, however, continents became much drier, making it harder for seedless plants to survive and reproduce. For that reason, many moss and fern species became extinct. They were replaced by seed plants with adaptations that equipped them to deal with drier conditions.

Fossils of seed-bearing plants exist from almost 360 million years ago. As shown in **Figure 22–20**, some of these early seed plants outwardly resembled ferns. Seed fern fossils document several evolutionary stages in the development of the seed.

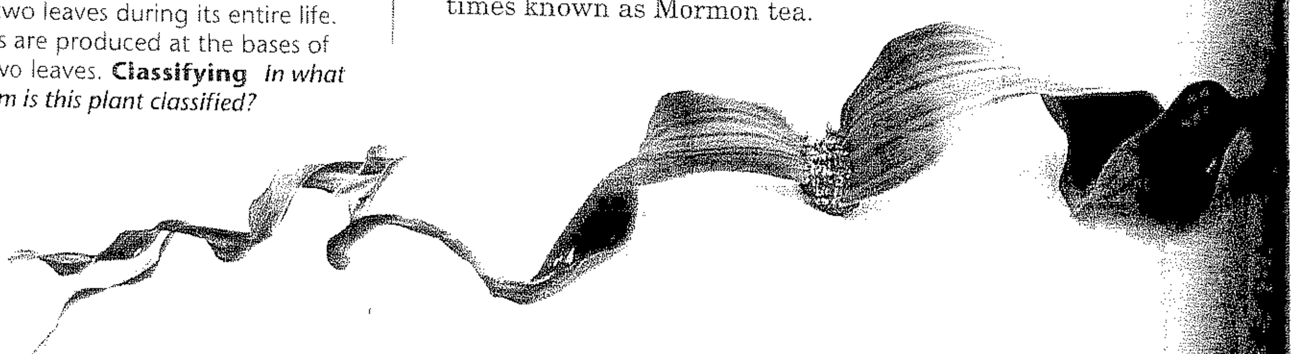
The early seed plants reached every landmass on Earth. Together with now-extinct seed ferns and other seedless vascular plants, seed plants formed dense forests and swamps that spread over much of what is now the eastern United States. Their remains now exist in the form of coal deposits.

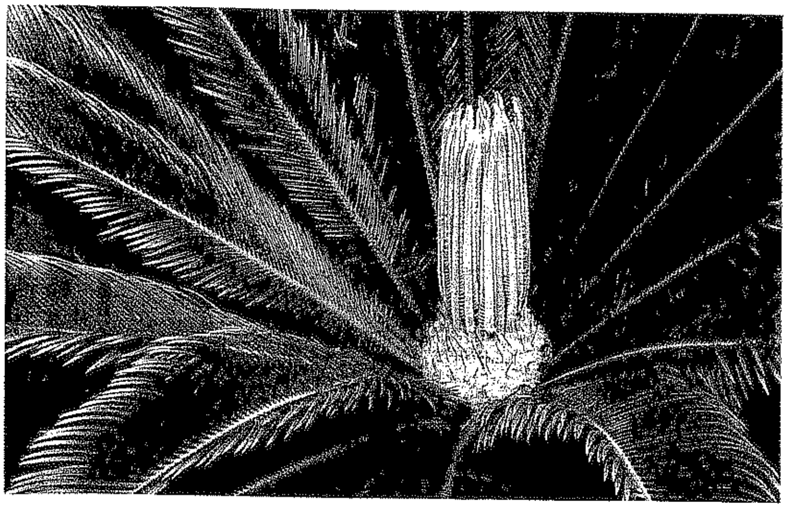
Gymnosperms—Cone Bearers

The most ancient surviving seed plants are the gymnosperms. **Gymnosperms include gnetophytes, cycads, ginkgoes, and conifers.** These plants all reproduce with seeds that are exposed—gymnosperm means "naked seed."

Gnetophytes About 70 present-day species of the phylum Gnetophyta (nee-TOH-fy-tuh) are known, placed in just three genera. The reproductive scales of these plants are clustered into cones. *Welwitschia,* an inhabitant of the Namibian desert in southwestern Africa, is one of the most remarkable gnetophytes. It has only two huge leathery leaves, shown in **Figure 22–21**, which grow continuously and spread across the ground. The genus *Ephedra* grows in the American southwest and is sometimes known as Mormon tea.

Figure 22–21 The *Welwitschia* plant (below), a type of gnetophyte, is an odd desert plant that produces only two leaves during its entire life. Cones are produced at the bases of the two leaves. **Classifying** *In what phylum is this plant classified?*





Cycads Cycads, members of the phylum Cycadophyta (si-kad-OH-fy-tuh), are beautiful palmlike plants that reproduce with large cones, as shown in **Figure 22–22.** Cycads first appeared in the fossil record during the Triassic Period, 225 million years ago. Huge forests of cycads thrived when dinosaurs roamed Earth. Today, only nine genera of cycads exist. Cycads can be found growing naturally in tropical and subtropical places such as Mexico, the West Indies, Florida, and parts of Asia, Africa, and Australia.

Ginkgoes Ginkgoes were common when dinosaurs were alive, but today the phylum Ginkgophyta (ging-KOH-fy-tuh) contains only one species, *Ginkgo biloba*. The living ginkgo species looks similar to its fossil ancestors, so it is truly a living fossil. In fact, *Ginkgo biloba,* also shown in **Figure 22–22**, may be one of the oldest seed plant species alive today. Ginkgo trees were carefully cultivated in China, where they were often planted around temples. Ginkgoes are now often planted in urban settings in the United States, where their toughness and resistance to air pollution make them popular shade trees.

CHECKPOINT *How many different species of ginkgoes exist?*

Conifers By far the most common gymnosperms, with more than 500 known species, are the conifers. The phylum Coniferophyta (koh-nif-er-OH-fy-tuh) includes pines, spruces, firs, cedars, sequoias, redwoods, and yews. Some conifers, such as the bristlecone pine tree at right, can live for more than 4000 years. Other species, such as giant redwoods, can grow to more than 100 meters in height.

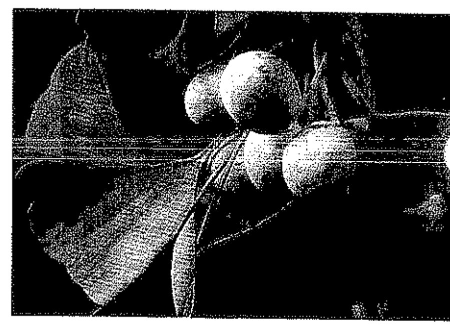


Figure 22–22 **Cycads, ginkgoes, and conifers are gymosperms.** Cycads (top left) produce seeds in reproductive structures that look like giant pinecones. The bristlecone pine (top right) is a conifer that can live for thousands of years. The ginkgo tree (bottom) is sometimes called a "living fossil" because it has changed little over millions of years.

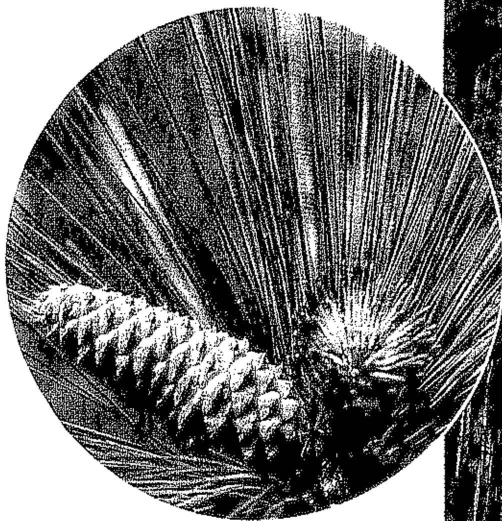


Figure 22–23 These longleaf pines in North Carolina grow in an area that receives abundant rainfall. Yet water sinks quickly through the sandy soil, limiting the availability of water to tree roots. In this environment, the pines' water-conserving needles (inset) are an adaptation that contributes to the trees' survival. **Predicting** *What might happen to a tree with large, flat leaves planted in this environment? Explain.*

Ecology of Conifers Today, conifers thrive in a wide variety of habitats: on mountains, in sandy soil, and in cool, moist areas such as the temperate rain forest of the Pacific Northwest. Surprisingly, conifer leaves have specific adaptations to dry conditions. How did these adaptations develop? Scientists have hypothesized that more than 250 million years ago, when conifers evolved, climate conditions were dry and cool. In response to these conditions, most conifers developed leaves that are long and thin, like the pine needles in **Figure 22–23**. This shape reduces the surface area from which water can be lost by evaporation. Another water-conserving adaptation is the thick, waxy layer that covers conifer leaves. In addition, the openings of leaves that allow for gas exchange are located in cavities below the surface of the leaves, also reducing water loss.

Most conifers are "evergreens"—that is, they retain their leaves throughout the year. The needles of most conifer species remain on the plant for 2 to 14 years. Older needles are gradually replaced by new needles, so the trees never become bare. However, not all species are evergreen. Larches and bald cypresses, for example, lose their needles every fall.

22–4 Section Assessment

1. **Key Concept** What are the main characteristics of seed plants?
2. **Key Concept** What are the different groups of gymnosperms?
3. What major change in Earth's climate favored the evolution of seed plants?
4. **Critical Thinking Applying Concepts** Pollination is a process that occurs only in seed plants. What process in seedless plants is analogous to pollination?

iTEXT Assessment Use iText to review the important concepts in Section 22–4.

ALTERNATIVE ASSESSMENT

Creative Writing
Suppose you could visit Earth as it was about 300 million years ago, when gymnosperms were the dominant plants and angiosperms had not yet developed. Write a story that describes a forest landscape of this period.

22–5 Angiosperms—Flowering Plants

Flowering plants, or angiosperms, are members of the phylum Anthophyta (an-THOH-fy-tuh). Flowering plants first appeared during the Cretaceous Period, about 135 million years ago, making their origin the most recent of all plant phyla. Flowering plants originated on land and quickly came to dominate Earth's plant life. The vast majority of living plant species reproduce with flowers.

Guide for Reading

Key Concepts

- What are the characteristics of angiosperms?
- What are monocots and dicots?
- What are the three categories of plant life spans?

Vocabulary

fruit
monocot
dicot
cotyledon
annual
biennial
perennial

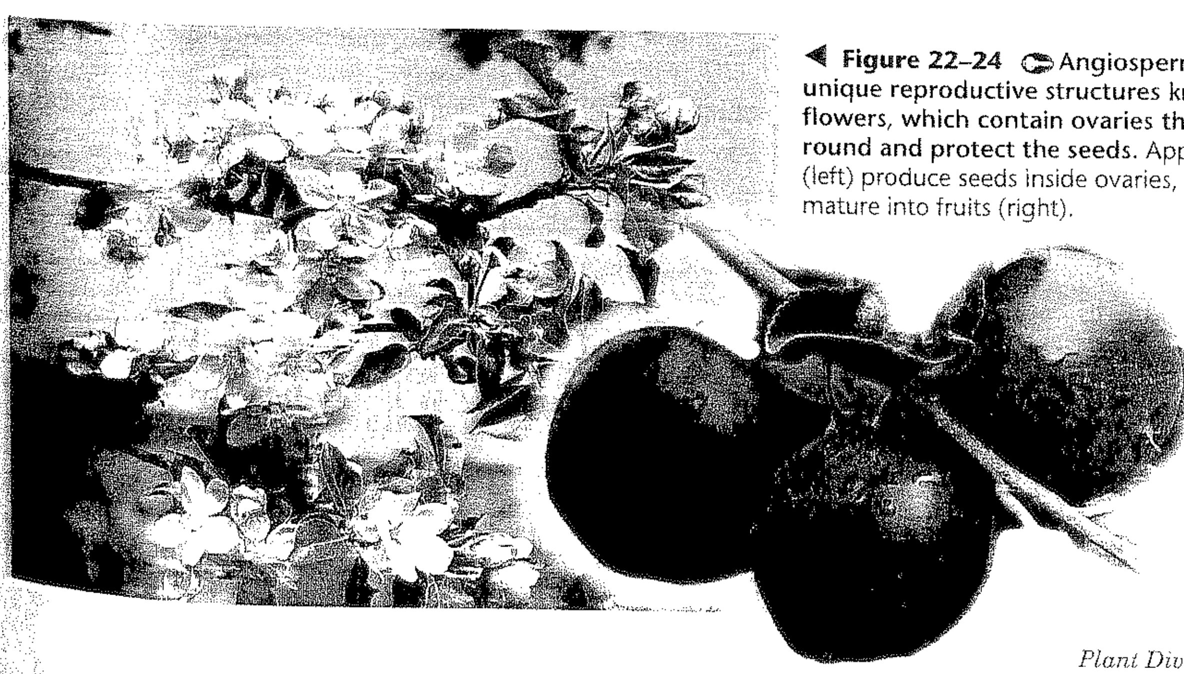
Reading Strategy: Finding Main Ideas
Angiosperms are the most diverse group of plants. As you read, make notes of the ways by which their diversity can be organized.

Flowers and Fruits

Angiosperms have unique reproductive organs known as flowers. In general, flowers are an evolutionary advantage to plants because they attract animals such as bees, moths, or hummingbirds, which then transport pollen from flower to flower. This means of pollination is much more efficient than the wind pollination of most gymnosperms.

Flowers contain ovaries, which surround and protect the seeds. The presence of an ovary gives angiosperms their name: Angiosperm means "enclosed seed." After pollination, the ovary develops into a fruit, which protects the seed and aids in its dispersal.

The unique angiosperm **fruit**—a thick wall of tissue surrounding the seed—is another reason for the success of these plants. When an animal eats a fruit, seeds from the core of the fruit generally enter the animal's digestive system. By the time these seeds leave the digestive system—ready to sprout—the animal may have traveled many kilometers. By using fruit to attract animals, flowering plants increase the ranges they inhabit, spreading seeds over hundreds of square kilometers.



◀ **Figure 22–24** **Angiosperms have unique reproductive structures known as flowers, which contain ovaries that surround and protect the seeds.** Apple flowers (left) produce seeds inside ovaries, which mature into fruits (right).

Diversity of Angiosperms

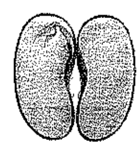
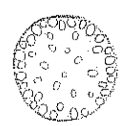
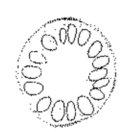
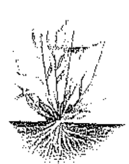
The angiosperms are an incredibly diverse group. Not surprisingly, there are many different ways of categorizing these plants. These include monocots and dicots; woody and herbaceous plants; and annuals, biennials, and perennials. As you read about each category, keep in mind that the categories can overlap. An iris, for example, is a monocot plant that is also an herbaceous perennial. These categories simply provide a way of appreciating and organizing the diversity of angiosperms.

Monocots and Dicots There are two classes within the angiosperms: the Monocotyledonae, or **monocots,** and the Dicotyledonae, or **dicots.** The general characteristics of both groups are shown in **Figure 22–25. Monocots and dicots are named for the number of seed leaves, or cotyledons, in the plant embryo. Monocots have one seed leaf, and dicots have two.** Other differences include the distribution of vascular tissue in stems, roots, and leaves, and the number of petals per flower. Monocots include corn, wheat, lilies, orchids, and palms. Dicots include roses, clover, tomatoes, oaks, and daisies.

CHECKPOINT *What is a cotyledon?*

Figure 22–25 **Monocots and dicots are named for the number of seed leaves, or cotyledons, in the plant embryo.** The table compares the characteristics of monocots and dicots.

Characteristics of Monocots and Dicots

	Monocots	Dicots
Seeds	Single cotyledon 	Two cotyledons 
Leaves	Parallel veins 	Branched veins 
Flowers	Floral parts often in multiples of 3 	Floral parts often in multiples of 4 or 5 
Stems	Vascular bundles scattered throughout stem 	Vascular bundles arranged in a ring 
Roots	Fibrous roots 	Taproot 

Careers in Biology

Botanical Illustrator

Job Description: work in a museum, outdoors, in a botanical garden, or at home to illustrate plants and organisms related to the plants

Education: two- or four-year college degree in an art school or other school noted for its art and design department

Skills: ability to observe nature; artistic talent; knowledge of biology; detail oriented; knowledge of the Internet, library, and museum research sources

Highlights: You provide illustrations that help people understand and appreciate biology. You have the pleasure of taking people of all ages on exciting visual adventures into the world of plants.

Linda Seabrooks Campbell is a professional botanical and science illustrator who finds great satisfaction in passing on her knowledge to students. "I take kids on nature hikes," she says, "and show them how to identify and make illustrations of plants."

Take It to the NET

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Woody and Herbaceous Plants The flowering plants can be subdivided into various groups according to the characteristics of their stems. One of the most important and noticeable stem characteristics is woodiness. Woody plants are made primarily of cells with thick cell walls that support the plant body. Woody plants include trees, shrubs, and vines. Shrubs are typically smaller than trees, and vines have stems that are long and flexible. Examples of woody vines are grapes and ivy. Examples of shrubs include blueberries, rhododendrons, and roses.

Plant stems that are smooth and nonwoody are characteristic of herbaceous plants. Herbaceous plants do not produce wood as they grow. Examples of herbaceous plants include dandelions, zinnias, petunias, and sunflowers.

Annuals, Biennials, and Perennials If you've ever planted a garden, you know that many flowering plants grow, flower, and die in a single year. Other types of plants continue to grow from year to year. The lifespan of plants is determined by a combination of genetic and environmental factors. Many long-lived plants continue growing despite yearly environmental fluctuations. However, harsh environmental conditions can shorten the life of other plants. **There are three categories of plant life spans: annual, biennial, and perennial.**

Word Origins

Annual comes from the Latin word *annus,* which means "year." The Latin prefix *bi-* means "two." **Based on the characteristics of perennials, what do you think the Latin prefix *per-* means?**

Figure 22–26 Categories of plant life spans include annuals, biennials, and perennials. Zinnias (left) are annual plants, which germinate, grow to maturity, set seed, and die in one growing season. Biennials such as the evening primrose (middle) grow roots, stems, and seeds in their first year, then produce flowers and seeds in their second year. Perennials such as peonies (right) live through many years.

Some plants grow from seed to maturity, flower, produce seeds, and die all in the course of one growing season. Flowering plants that complete a life cycle within one growing season are called **annuals.** Annuals include many garden plants, such as marigolds, petunias, pansies, and the zinnias in **Figure 22–26.** Wheat and cucumbers are also annuals.

Angiosperms that complete their life cycle in two years are called **biennials** (by-EN-ee-ulz). In the first year, biennials germinate and grow roots, very short stems, and sometimes leaves. During their second year, biennials grow new stems and leaves and then produce flowers and seeds. Once the flowers produce seeds, the plant dies. Evening primrose, parsley, celery, and foxglove are biennials.

Flowering plants that live for more than two years are called **perennials.** Perennials usually live through many years. Some perennials, such as peonies, asparagus, and many grasses, have herbaceous stems that die each winter and are replaced in the spring. Most perennials, however, have woody stems. Palm trees, sagebrush, maple trees, and honeysuckle are examples of woody perennials.

22–5 Section Assessment

1. **Key Concept** What reproductive structures are unique to angiosperms? Briefly describe the function of each.
2. **Key Concept** What are monocots and dicots?
3. **Key Concept** How do annuals, biennials, and perennials differ?
4. Compare the growth forms of plants with woody stems and those with herbaceous stems.
5. **Critical Thinking Forming Hypotheses** Which are more likely to be dispersed by animals—the seeds of an angiosperm or the spores of a fern? Explain your reasoning.

iTEXT Assessment Use iText to review the important concepts in Section 22–5.

ALTERNATIVE ASSESSMENT

Classifying
Prepare a display comparing two specific plants, one monocot and one dicot. On this display, write a brief summary of the basic differences between these two types of angiosperms.