Plant Diversity I: Bryophytes and Seedless Vascular Plants

Laboratory Objectives

After completing this lab topic, you should be able to:

1. Describe the distinguishing characteristics of bryophytes and seedless vascular plants.
2. Discuss the primitive and advanced features of bryophytes and seedless vascular plants relative to their adaptations to the land environment.
3. Recognize and identify representative members of each division of bryophytes and seedless vascular plants.
4. Describe in detail the life cycle of a moss and a fern, including the important structures and processes in each life cycle.
5. Identify fossil members and their extant counterparts in the seedless vascular plants.
6. Describe the general life cycle and alternation of generations in the bryophytes and the seedless vascular plants, and discuss the differences between the life cycles of the two groups of plants using examples.
7. Describe homospory and heterospory, including the differences in spores and gametophytes.
8. Discuss the ecological role and economic importance of these groups of plants.

Introduction

In the history of life on Earth, one of the most revolutionary events was the colonization of land, first by plants, then by animals. Evidence from comparisons of extant land plants and divisions of algae suggests that the first land plants were related to the green algae. These first colonists are thought to be most similar to the living, branched, multicellular green alga *Chara*. Once these primitive plants arrived on land over 500 million years ago, they faced new and extreme challenges in their physical environment. Only individuals that were able to survive the variations in temperature, moisture, gravitational forces, and substrate would thrive. Out of this enormous selective regime would come new and different adaptations and new and different life forms: the land plants.

Land plants generally have complex, multicellular plant bodies that are specialized for a variety of functions. Specialized structures have evolved for protection of the vulnerable stages of sexual reproduction. The plant body is often covered with a waxy cuticle that prevents desiccation. However, the waxy covering also prevents gas exchange, a problem solved by the presence of openings called **stomata** (sing., **stoma**). Some land plants have developed vascular tissue for efficient movement of materials throughout these

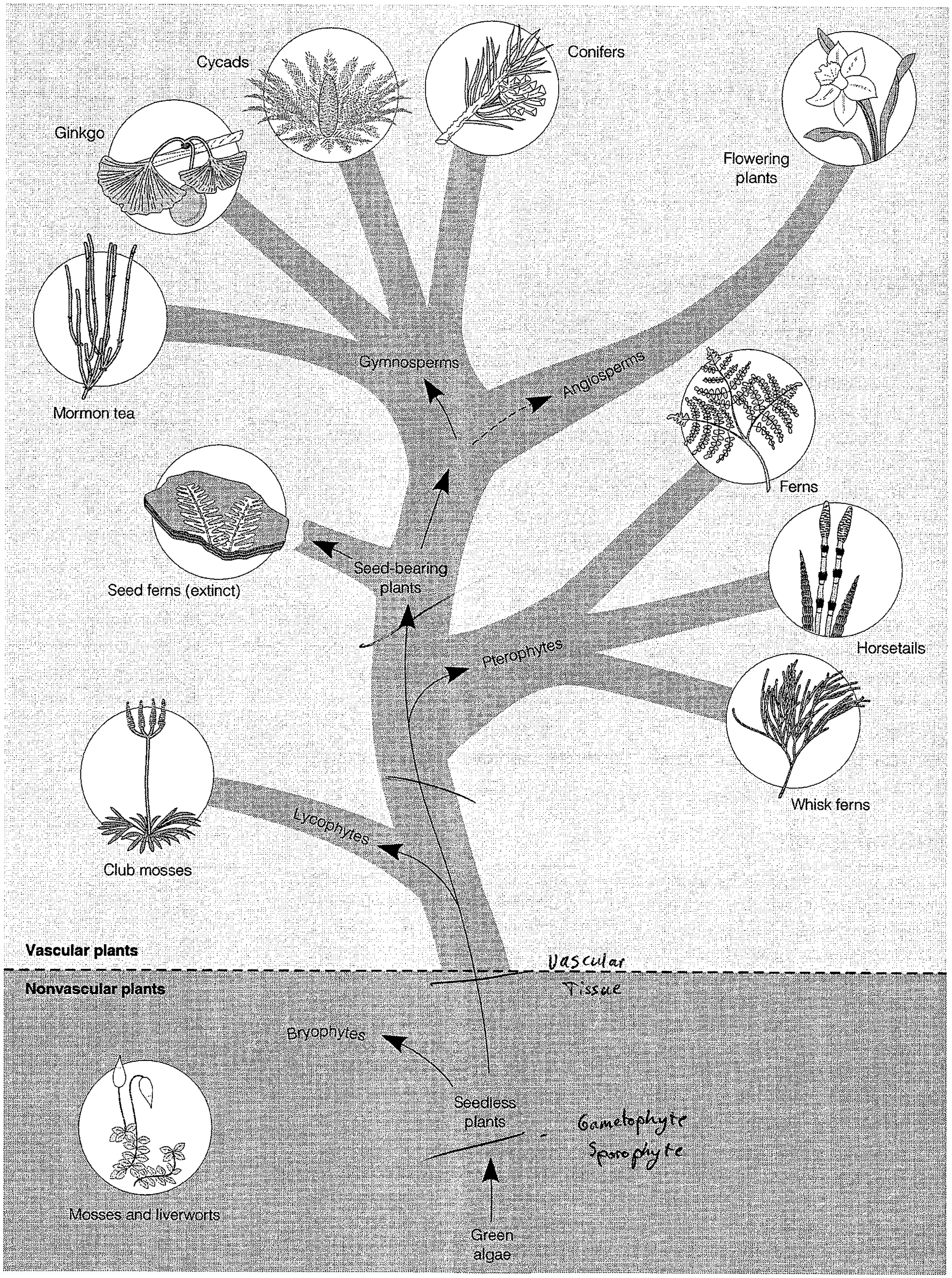
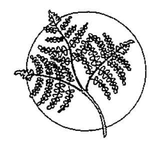
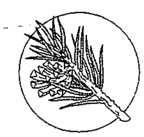
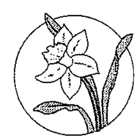

Cycads
Conifers
Ginkgo
Flowering plants
Mormon tea
Gymnosperms
Angiosperms
Ferns
Seed ferns (extinct)
Seed-bearing plants
Horsetails
Pterophytes
Whisk ferns
Lycophytes
Club mosses
Vascular plants
Vascular Tissue
Nonvascular plants
Bryophytes
Seedless plants
Gametophyte
Sporophyte
Mosses and liverworts
Green algae

Table 1
Classification of Land Plants

Classification	Common Name	Illustration
Nonvascular Plants		
Division Bryophyta	Mosses	
Division Hepatophyta	Liverworts	
Division Anthocerophyta	Hornworts	
Vascular Plants		
Seedless Plants		
Division Lycophyta	Club mosses	
Division Pterophyta	Ferns, horsetails, whisk ferns	
Seed Plants		
Gymnosperms		
Division Coniferophyta	Conifers	
Division Cycadophyta	Cycads	
Division Ginkgophyta	Ginkgo	
Division Gnetophyta	Gnetae	
Angiosperms		
Division Anthophyta	Flowering plants	

complex bodies, which are no longer bathed in water. As described in the following section, the reproductive cycles and reproductive structures of these plants are also adapted to the land environment.

In the two plant diversity labs, you will be investigating the diversity of land plants (Table 1 and Figure 1), some of which will be familiar to you (flowering plants, pine trees, and ferns) and some of which you may never have seen before (whisk ferns, horsetails, and liverworts). Remember as you view the classification that the designations *phylum* and *division* are equivalent taxonomic groupings. Botanists traditionally use division. You will study the bryophytes and seedless vascular plants in this lab topic, Plant Diversity I. *To maintain your perspective in the face of all this diversity—and to remember the major themes of these labs—bear in mind the questions that follow.*

( ) Figure 1.
Evolution of land plants. The bryophytes and vascular plants probably evolved from green algae over 460 million years ago. Seedless vascular plants dominated Earth 300 million years ago, and representatives of four divisions have survived until the present. Seed plants replaced the seedless plants, and today flowering plants are the most diverse and successful group in an amazing variety of habitats. The representatives studied in Plant Diversity I and II are indicated.

1. What are the special adaptations of these plants to the land environment?
2. How are specialized plant structures related to functions in the land environment?
3. What are the major trends in the plant kingdom as plant life evolved over the past 500 million years?
4. In particular, how has the fundamental reproductive cycle of alternation of generations been modified in successive groups of plants?

Plant Life Cycles

All land plants have a common sexual reproductive life cycle called **alternation of generations,** in which plants alternate between a haploid **gametophyte** generation and a diploid **sporophyte** generation (Figure 2). In living land plants, these two generations differ in their morphology. In all land plants except the bryophytes (mosses and liverworts), the diploid sporophyte generation is the dominant (more conspicuous) generation. The sporophyte generation undergoes meiosis to produce haploid **spores** in a protective, nonreproductive jacket of cells called the **sporangium.** The spores germinate to produce the haploid gametophyte, which produces **gametes** inside a jacket of cells forming **gametangia** (sing., **gametangium**). **Eggs** are produced in **archegonia** (sing., **archegonium**), and **sperm** are produced in **antheridia** (sing., **antheridium**). These haploid gametes are formed by mitosis. The gametes fuse, usually by the entrance of the sperm into the archegonium, forming a diploid **zygote,** the first stage of the diploid sporophyte generation.

Note that both gametes and spores are haploid in this life cycle. Unlike the animal life cycle, however, *the plant life cycle produces gametes by mitosis; spores are produced by meiosis.* The difference between these two cells is that

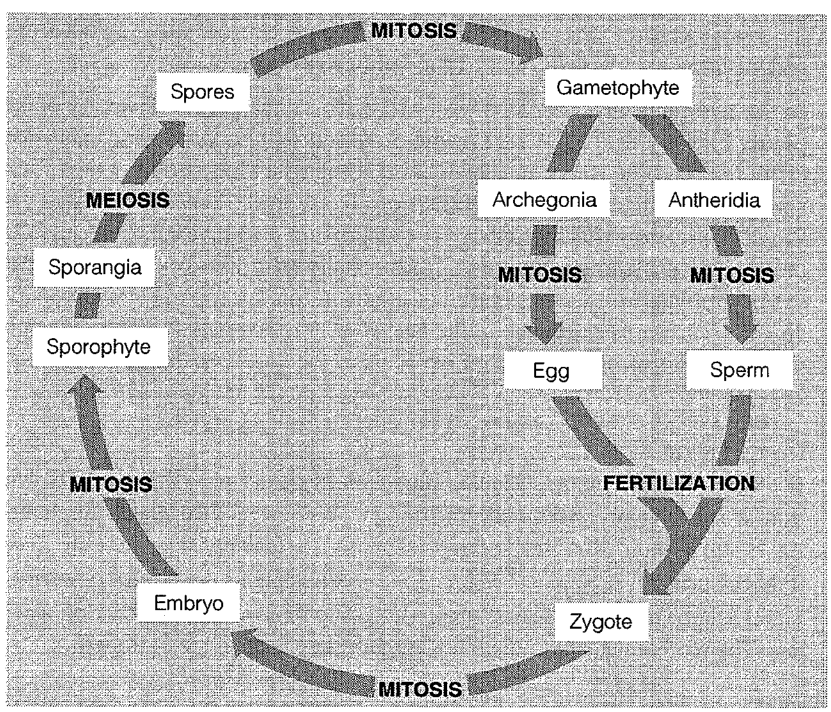


Figure 2.
Alternation of generations. In this life cycle, a diploid sporophyte plant alternates with a haploid gametophyte plant. Note that haploid spores are produced on the sporophyte by meiosis, and haploid gametes are produced in the gametophyte by mitosis. *Using a colored pencil, indicate the structures that are haploid, and with another color, note the structures that are diploid.*

gametes fuse with other gametes to form the zygote and restore the diploid number, while spores germinate to form a new haploid gametophyte plant.

Review the generalized diagram of this life cycle in Figure 2. *Using colored pencils, note the structures that are diploid and those that are haploid.* As you become familiar with variations of this life cycle through specific examples, you will want to continue referring to this general model for review.

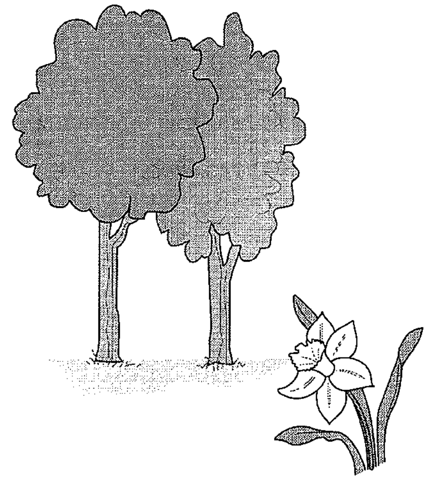
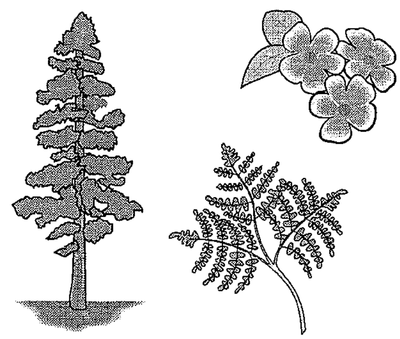
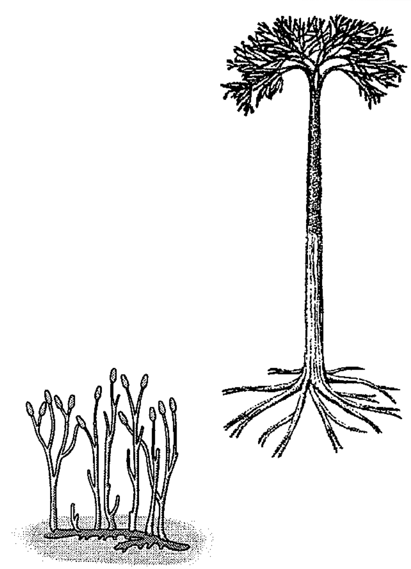
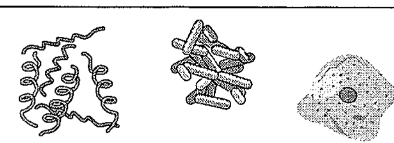
Major trends in the evolution of this life cycle include the increased importance of the sporophyte as the photosynthetic and persistent plant that dominates the life cycle; the reduction and protection of the gametophyte within the body of the sporophyte; and the evolution of seeds and then flowers.

Bryophytes and Seedless Vascular Plants

In this lab topic, terrestrial plants will be used to illustrate how life has undergone dramatic changes during the past 500 million years. Not long after the transition to land, plants diverged into at least two separate lineages. One gave rise to the bryophytes, a group of mostly nonvascular plants, including the mosses, and the other to the vascular plants (see Figure 1). Bryophytes first appear in the fossil record dating over 400 million years ago and remain unchanged, whereas the vascular plants have undergone enormous diversification. As you review the evolution of land plants, refer to the geological time chart for an overview of the history of life on Earth (Figure 3, on the next page).

EXERCISE 1
Bryophytes

The bryophytes are composed of three divisions of related plants that share some key characteristics and include mosses (Bryophyta) and liverworts (Hepatophyta). The third division, hornworts (Anthocerophyta), will not be seen in lab. (See again Figure 1 and Table 1.) The term *bryophytes* does not refer to a taxonomic category; rather, bryophytes are an ancient group of plants that appear to have evolved into several different groups independently and did not give rise to any other living groups of plants. They are small plants generally lacking **vascular tissue** (specialized cells for the transport of material), although water-conducting tubes appear to be present in some mosses. (However, these tubes may be unrelated to the vascular tissue in vascular plants.) The life cycle for the bryophytes differs from all other land plants because the gametophyte is the dominant and conspicuous plant. Because bryophytes are nonvascular, they are restricted to moist habitats and have never attained the size and importance of other groups of plants. The gametophyte plants remain close to the ground, enabling the motile sperm to swim from the antheridium to the archegonium and fertilize the egg. They have a cuticle but lack stomata on the surface of the **thallus** (plant body), which is not organized into roots, stems, and leaves.

Years Ago (millions)	Era / Period / Epoch	Life on Earth	
	CENOZOIC		
	Quaternary		
1.8	Recent Pleistocene	• Origin of agriculture and artificial selection; *H. sapiens*	
	Tertiary		
5	Pliocene	• Large carnivores; hominoid apes	
23	Miocene	• Forests dwindle; grassland spreads	
35	Oligocene	• Anthropoid apes	
57	Eocene	• Diversification of mammals and flowering plants	
65	Paleocene	• Specialized flowers; sophisticated pollinators and seed distributors	
	MESOZOIC		
145	Cretaceous	• Flowering plants established and diversified; many modern families present; extinction of many dinosaurs	
208	Jurassic	• Origin of birds; reptiles dominant; cycads and ferns abundant; first modern conifers and immediate ancestors of flowering plants	
245	Triassic	• First dinosaurs and mammals; forests of gymnosperms and ferns; cycads	
	PALEOZOIC		
290	Permian	• Diversification of gymnosperms; origin of reptiles; amphibians dominant	
363	Carboniferous	• First treelike plants; giant woody lycopods and sphenopsids form extensive forests in swampy areas; evolution of early seeds (seed ferns) and first stages of leaves	
409	Devonian	• Diversification of vascular plants; sharks and fishes dominant in the oceans	
439	Silurian	• First vascular plants	
510	Ordovician	• Diversification of algae and plants invade land	
570	Cambrian	• Diversification of major animal phyla	
	PRECAMBRIAN		
	Precambrian	• Origin of bacteria, archaea, and eukaryotes	
Earth is about 4.6 billion years old			

Bryophytes are not important economically, with the exception of sphagnum moss, which in its harvested and dried form is known as *peat moss*. Peat moss is absorbent, has an antibacterial agent, and was reportedly once used as bandages and diapers. Today peat moss is used primarily in the horticultural industry.

Lab Study A. Bryophyta: Mosses

Materials

living examples of mosses
prepared slides of *Mnium* archegonia and antheridia
colored pencils

Introduction

The mosses are the most common group of bryophytes, occurring primarily in moist environments but also found in dry habitats that are periodically wet. Refer to Figure 4 on the next page as you investigate the moss life cycle, which is representative of the bryophytes.

Procedure

1. Examine living colonies of mosses on demonstration. Usually you will find the two generations, gametophyte and sporophyte, growing together.
2. Identify the leafy **gametophytes** and the dependent **sporophytes**, which appear as elongated structures growing above them. Tug gently at the sporophyte and notice that it is attached to the gametophyte. Recall that the sporophyte develops and matures while attached to the gametophyte and receives its moisture and nutrients from the gametophyte.
3. The gametes are produced by the gametophyte in **gametangia**, which protect the gametes but are not readily visible without a microscope. Observe under the microscope's low-power lens prepared slides containing long sections of heads of the unisex moss *Mnium*, which contain the gametangia. One slide has been selected to show the **antheridia** (male); the other is a rosette of **archegonia** (female). Sperm-forming tissue will be visible inside the antheridia. On the archegonial slide, look for an archegonium. The moss archegonium has a very long neck and rounded base. It will be difficult to find an entire archegonium in any one section. Search for a single-celled **egg** in the base of the archegonium.
4. Refer to Figure 4 as you follow the steps of fertilization through formation of the gametophyte in the next generation. The sperm swim

( ) **Figure 3.**
Geological time chart. The history of life can be organized into time periods that reflect changes in the physical and biological environment. Refer to this table as you review the evolution of land plants in Plant Diversity I and II.

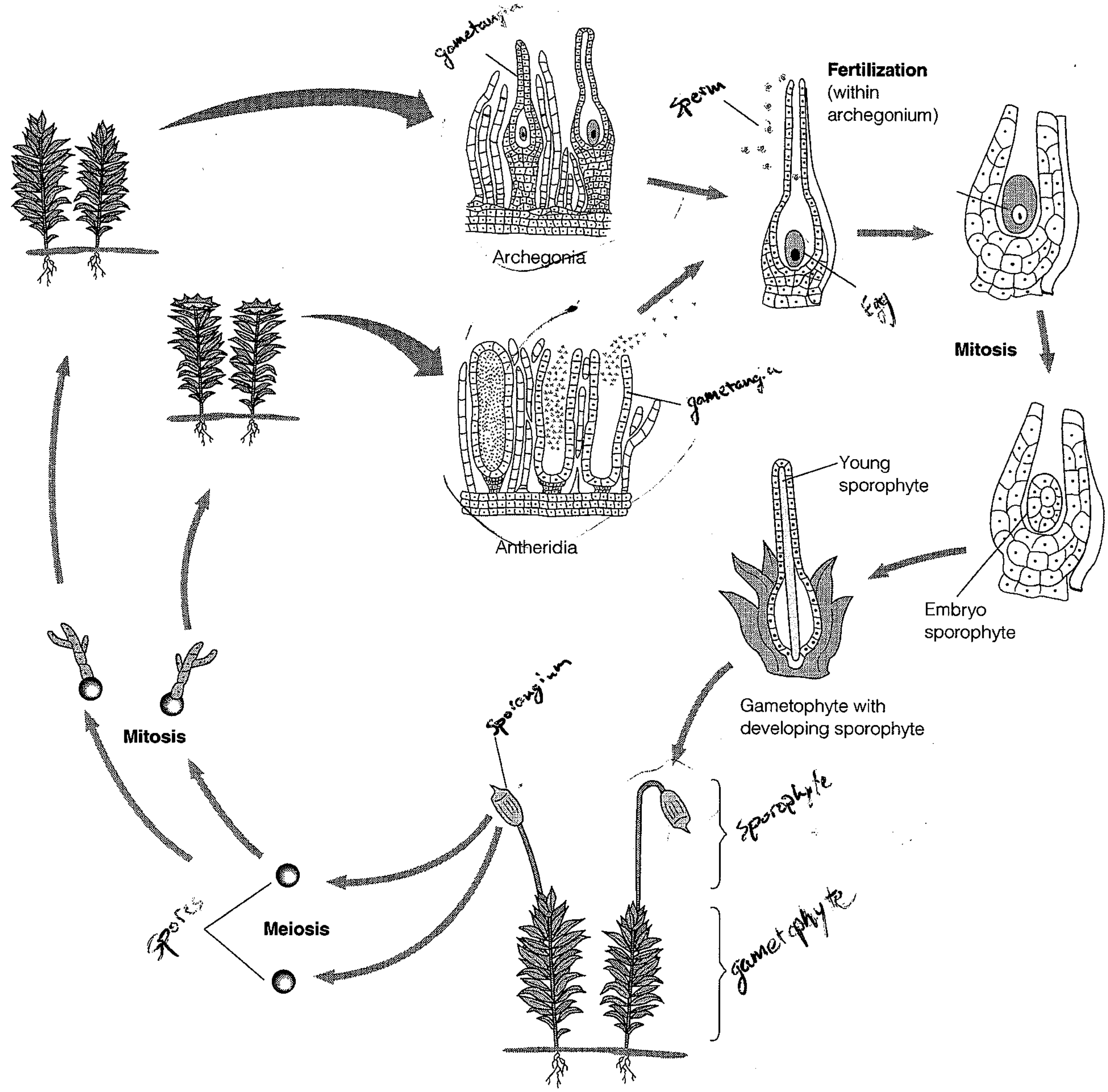


Figure 4.
Moss life cycle. The leafy moss plant is the gametophyte, and the sporophyte is dependent on it, deriving its water and nutrients from the body of the gametophyte. Review this variation of alternation of generations and label the structures described in Lab Study A. *Using colored pencils, highlight the haploid and diploid structures in different colors. Circle the processes of mitosis and meiosis.*

through a film of water to the archegonium and swim down the neck to the egg, where fertilization takes place. The diploid zygote divides by mitosis and develops into an embryonic sporophyte within the archegonium. As the sporophyte matures, it grows out of the gametophyte but remains attached, deriving water and nutrients from the gametophyte body. **Spores** develop in the **sporangium** at the end of the sporophyte. The spores are discharged from the sporangium and in a favorable environment develop into new gametophytes.

Results

1. Review the structures and processes observed and then label the moss life cycle diagram in Figure 4.
2. Using colored pencils, indicate if structures are haploid or diploid and circle the processes of mitosis and meiosis.

Discussion

Refer to Figure 2, the generalized diagram of the plant life cycle.

1. Are the spores produced by the moss sporophyte formed by meiosis or mitosis? Are they haploid or diploid? meiosis
2. Do the spores belong to the gametophyte or sporophyte generation?
3. Are the gametes haploid or diploid? Are they produced by meiosis or mitosis? mitosis
4. Is the dominant generation for the bryophytes the gametophyte or the sporophyte? gamatophyte
5. Can you suggest any ecological role for bryophytes?
6. What feature of the life cycle differs for bryophytes compared with all other land plants? sporophyte stage

Lab Study B. Hepatophyta: Liverworts

Materials

living liverworts

Introduction

Liverworts are so named because their bodies are flattened and lobed. Early herbalists believed that these plants were beneficial in the treatment of liver disorders. Although less common than mosses, liverworts can be found along streams on moist rocks, but because of their small size, you must look closely to locate them.

Procedure

Examine examples of liverworts on demonstration. Liverworts have a flat **thallus** (plant body). Note the **rhizoids**, rootlike extensions on the lower surface. Observe the **pores** on the surface of the leaflike thallus. These openings function in gas exchange; however, they are always open since they lack guard cells. On the upper surface of the thallus you should see circular cups called **gemmae cups**, which contain flat disks of green tissue called **gemmae.** The gemmae are washed out of the cups when it rains, and they grow into new, genetically identical liverworts.

Results

Sketch the overall structure of the liverwort in the margin of your laboratory manual. Label structures where appropriate.

Discussion

1. Is the plant you observed the gametophyte or sporophyte?

2. Are the gemmae responsible for asexual or sexual reproduction? Explain.

   Asexual, it produces an identical offspring

3. Why are these plants, like most bryophytes, restricted to moist habitats, and why are they always small?

   Require water to reproduce, lack vascular tissue.

4. In this lab topic, you are asked to complete tables that summarize features advantageous to the adaptation of plant groups to the land environment. You may be asked to compare these derived (advanced) features with others that have changed little (primitive) in the evolution of land plants. For example, for bryophytes, motile sperm might be considered a primitive feature, while the cuticle would be considered advanced.

   Complete Table 2, relating the features of bryophytes to their success in the land environment. Refer to the lab topic introduction for assistance.

Table 2
Primitive and Advanced Features of Bryophytes as They Relate to Adaptation to Land

Primitive Features	Advanced Features
Motile sperm	cuticle

EXERCISE 2
Seedless Vascular Plants

Seedless, terrestrial plants are analogous to the first terrestrial vertebrate animals, the amphibians, in their dependence on water for external fertilization and development of the unprotected, free-living embryo. Both groups were important in the Paleozoic era but have undergone a steady decline in importance since that time. Seedless plants were well suited for life in the vast swampy areas that covered large areas of the Earth in the Carboniferous period but were not suited for the drier areas of the Earth at that time or for later climatic changes that caused the vast swamps to decline and disappear. The fossilized remains of the swamp forests are the coal deposits of today (Figure 3).

Although living representatives of the seedless vascular plants have survived for millions of years, their limited adaptations to the land environment have restricted their range. All seedless vascular plants have vascular tissue, which is specialized for conducting water, nutrients, and photosynthetic products. Their life cycle is a variation of alternation of generations, in which the sporophyte is the dominant plant; the gametophyte is usually independent of the sporophyte. These plants have stomata and structural support tissue. However, since they still retain the primitive feature of motile sperm that require water for fertilization, the gametophyte is small and restricted to moist habitats.

Economically, the only important members of this group are the ferns, a significant horticultural resource.

The divisions included in the seedless vascular plants are Lycophyta and Pterophyta (see again Table 1 and Figure 1).

Lab Study A. Lycophyta: Club Mosses

Materials

living *Selaginella* and *Lycopodium*
preserved *Selaginella* with microsporangia and megasporangia
prepared slide of *Selaginella* strobilus, l.s.

Introduction

Living members of Lycophyta are usually found in moist habitats, including bogs and streamsides. However, one species of *Selaginella*, the resurrection plant, inhabits deserts. It remains dormant throughout periods of low rainfall, but then comes to life—resurrects—when it rains. During the Carboniferous period, lycophytes were not inconspicuous parts of the flora but rather formed the forest canopy; they were the ecological equivalent of today's oaks, hickories, and pines.

Bryophytes and most seedless vascular plants produce one type of spore (**homospory**), which gives rise to the gametophyte by mitosis. One advanced feature occasionally seen in seedless vascular plants is the production of two kinds of spores (**heterospory**). Large spores called **megaspores** divide by mitosis to produce the female gametophyte. The numerous small spores, **microspores**, produce the male gametophytes by mitosis. Heterospory and separate male and female gametophytes, as seen in *Selaginella*, are unusual in seedless vascular plants, but characteristic of seed-producing vascular plants.

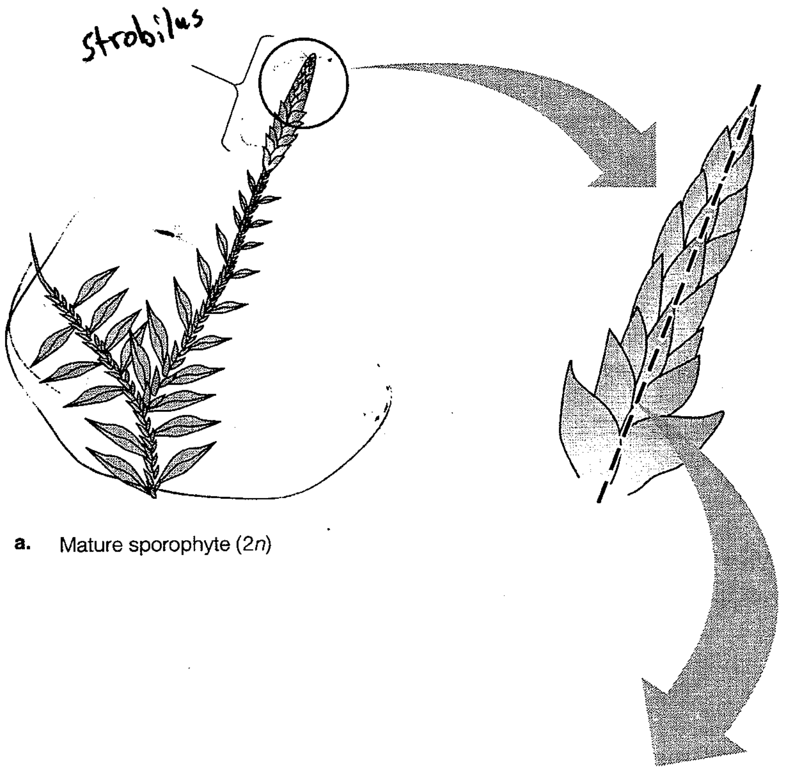
Procedure

1. Examine living club mosses, *Selaginella* and *Lycopodium*. Are they dichotomously branched? (The branches would split in two, appearing to form a Y.) Locate sporangia, which may be present either clustered at the end of the leafy stem tips, forming **strobili**, or **cones**, or dispersed along the leafy stems. Note that these plants have small leaves, or bracts, along the stem. No
2. Examine preserved strobili of *Selaginella*. Observe the round sporangia clustered in sporophylls (leaflike structures) at the tip of the stem. These sporangia contain either four megaspores or numerous microspores. Can you observe any differences in the sporangia or spores?
3. Observe the prepared slide of a long section through the strobilus of *Selaginella*. Begin your observations at low power. Are both microspores and megaspores visible on this slide? Yes

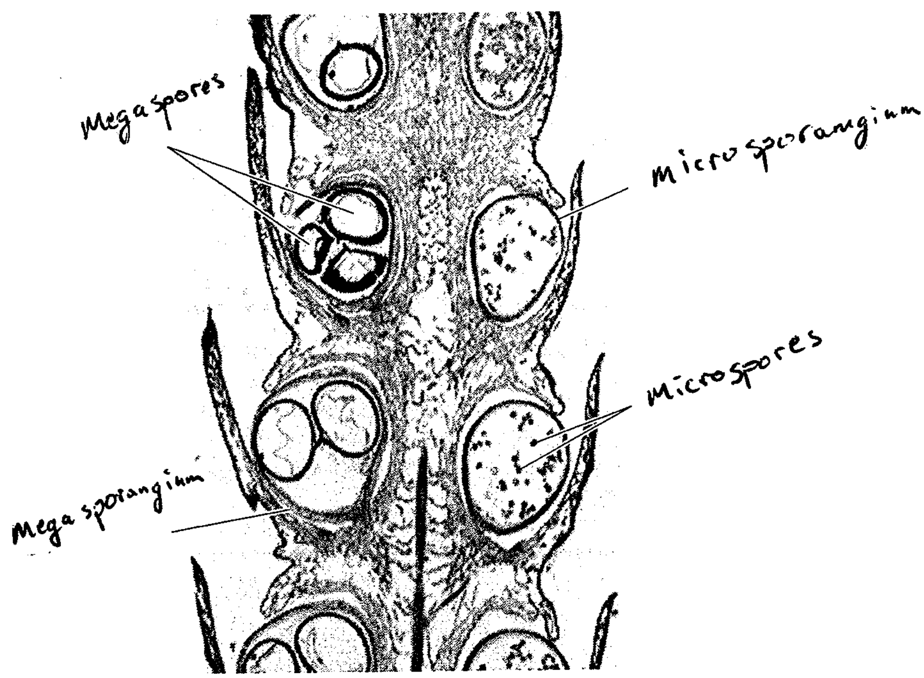
   How can you distinguish these spores? yes

   male female

4. Identify the **strobilus**, **microsporangium**, **microspores**, **megasporangium**, and **megaspores** and label Figure 5.



a. Mature sporophyte (2n)



b.

Figure 5.
Selaginella. (a) The leafy plant is the sporophyte. The sporangia are clustered at the tips in strobili. (b) Photomicrograph of a longitudinal section through the strobilus of *Selaginella*.

Results

1. Sketch the overall structure of the club mosses in the margin of your lab manual. Label structures where appropriate.
2. Review Figure 5 of *Selaginella*. Using a colored pencil, highlight the structures that are haploid and part of the gametophyte generation.

Discussion

1. Are these leafy plants part of the sporophyte or the gametophyte generation? Do you have any evidence to support your answer?

   ~~gametophyte, there is a sporophyte attached to it~~ sporophyte, determine if it has a strobilus

2. What features would you look for to determine if this were a seedless vascular plant? vascular tissue, a sporophyte

3. Are microspores and megaspores produced by mitosis or meiosis? (Review the life cycle in Figure 2.) meiosis

4. Will megaspores divide to form the female gametophyte or the sporophyte? gametophyte

Having trouble with life cycles? Return to the introduction and review the generalized life cycle in Figure 2. Reread the introduction to the study of seedless vascular plants. The key to success is to determine where meiosis occurs and to remember the ploidal level for the gametophyte and the sporophyte.

Lab Study B. Pterophyta: Ferns, Horsetails, and Whisk Ferns

Materials

living and/or preserved horsetails (*Equisetum*)
living and/or preserved whisk ferns (*Psilotum*)
living ferns

Introduction

If a time machine could take us back 400 million years to the Silurian period, we would find that vertebrate animals were confined to the seas, and early vascular plants had begun to diversify on land (Table 3). By the Carboniferous period, ferns, horsetails, and whisk ferns grew alongside the lycophytes. Until recently, these three groups of seedless vascular plants were placed in separate divisions: Pterophyta (ferns), Sphenophyta (horsetails), and Psilophyta (whisk ferns). Strong evidence from molecular biology now reveals a close relationship among these three groups, supporting a common ancestor for the group and their placement in one division, Pterophyta.

Psilophytes (**whisk ferns**) are diminutive, dichotomously branched (repeated Y branches), photosynthetic stems that reproduce sexually by aerial spores. Today, whisk ferns can be found in some areas of Florida and in the tropics. Sphenophytes (**horsetails**) have green jointed stems with occasional clusters of leaves or branches. Their cell walls contain silica that give the stem a rough texture. These plants were used by pioneers to scrub dishes—thus their name, scouring rushes. In cooler regions of North America, horsetails grow as weeds along roadsides. **Ferns** are the most successful group of seedless vascular plants, occupying habitats from the desert to tropical rain forests. Most ferns are small plants that lack woody tissue. An exception is the tree ferns found in tropical regions. Many cultivated ferns are available for home gardeners.

In this lab study you will investigate the diversity of pterophytes, including whisk ferns, horsetails, and a variety of ferns. The plants on demonstration are sporophytes, the dominant generation in seedless vascular plants. You will investigate the life cycle of a fern in Lab Study C, Fern Life Cycle.

Procedure

1. Examine a living **whisk fern** (*Psilotum nudum*) on demonstration. This is one of only two extant genera of psilophytes.
2. Observe the spherical structures on the stem. If possible, cut one open and determine the function of these structures. Note the dichotomous branching, typical of the earliest land plants.
3. Examine the **horsetails** (*Equisetum* sp.) on demonstration. Note the ribs and ridges in the stem. Also examine the nodes or joints along the stem where branches and leaves may occur in some species. Locate the **strobili** in the living or preserved specimens on demonstration. These are clusters of **sporangia**, which produce **spores.**
4. Examine the living **ferns** on demonstration. Note the deeply dissected leaves, which arise from an underground stem called a **rhizome**, which functions like a root to anchor the plant. Roots arise from the rhizome. Observe the dark spots, or **sori** (sing. **sorus**), which are clusters of sporangia, on the underside of some leaves, called **sporophylls**.

Results

1. Sketch the overall structure of the whisk fern, horsetail, and fern in the margin of your lab manual. Label structures where appropriate.
2. Are there any leaves on the whisk fern? On the horsetails?
3. Are sporangia present on the whisk fern? On the horsetails? On the ferns?

Discussion

1. Are the spores in the sporangia produced by mitosis or meiosis?

meiosis

2. Are the sporangia haploid or diploid? Think about which generation produces them.

3. Once dispersed, will these spores produce the gametophyte or sporophyte generation?

Lab Study C. Fern Life Cycle

Materials

living ferns
living fern gametophytes with archegonia and antheridia
living fern gametophytes with young sporophytes attached
stereoscopic microscope
compound microscope
prepared slide of fern gametophytes with archegonia, c.s.
colored pencils
Protoslo®

Introduction

In the previous Lab Study you examined the features of the fern sporophyte. In this lab study you will examine the fern life cycle in more detail, beginning with the sporophyte.

Procedure

1. Examine the sporophyte leaf with sori at your lab bench. Make a water mount of a sorus and examine the sporangia using a dissecting microscope. You will find the stalked **sporangia** in various stages of development. Find a sporangium still filled with **spores** and another that has discharged its spores. The sporangia contain cells in different stages of meiosis, leading to spores that are seen in different stages of maturation. These stages will not be distinguishable to you under the microscope.
2. Refer to Figure 6 as you observe the events and important structures in the life cycle of the fern. The haploid spores of ferns fall to the ground and grow into heart-shaped, **gametophyte** plants. All seedless terrestrial plants depend on an external source of water for a sperm to swim to an egg to effect fertilization and for growth of the resulting sporophyte plant. The sexual organs, which bear male and female gametes, are borne on the underside of the gametophyte. Egg cells are borne in urn-like structures called **archegonia**, and sperm cells are produced in globular structures called **antheridia.** Archegonia are usually found around the notch of the heart-shaped gametophyte, while antheridia occur over most of the undersurface.

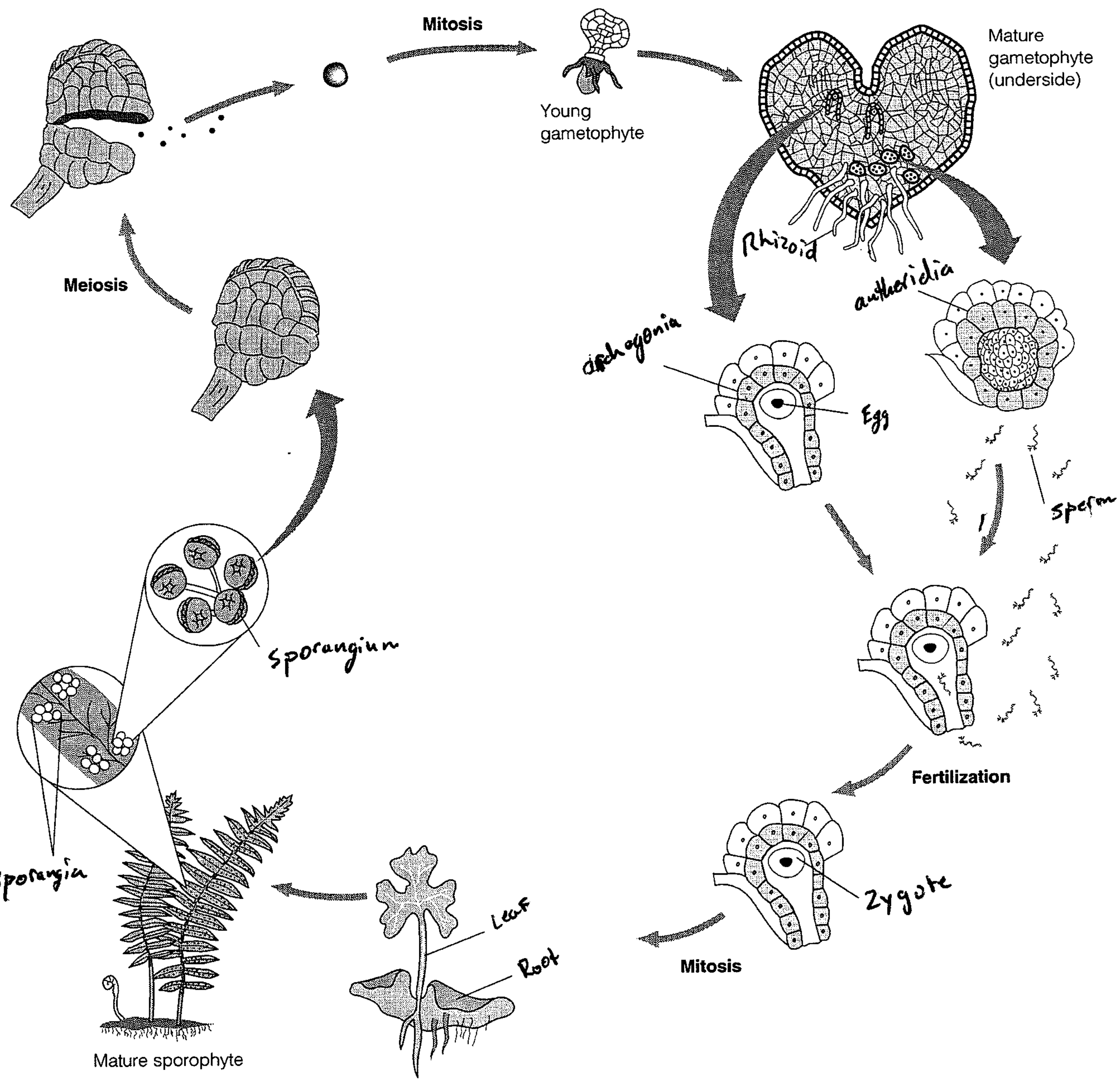


Figure 6.
Fern life cycle. The familiar leafy fern plant is the sporophyte, which alternates with a small, heart-shaped gametophyte. Review this life cycle, a variation of alternation of generations, and label the structures and processes described in Lab Study C. *Using colored pencils, highlight the haploid and diploid structures in different colors.*

3. To study whole gametophytes, make a slide of living gametophytes. View them using the stereoscopic microscope or the scanning lens on the compound microscope. Note their shape and color and the presence of **rhizoids**, rootlike multicellular structures. Locate archegonia and antheridia. Which surface will you need to examine? Sketch in the margin of your lab manual any details not included in Figure 6.

4. If you have seen antheridia on a gametophyte, remove the slide from the microscope. Gently but firmly press on the coverslip with a pencil eraser. View using the compound microscope first on intermediate and then on high power. Look for motile **sperm** swimming with a spiral motion. Each sperm has two flagella. Add a drop of Protoslo to slow down movement of sperm.
5. Observe the cross section of a fern gametophyte with archegonia. Each archegonium encloses an **egg,** which may be visible on your slide.
6. Make a wet mount of a fern gametophyte with a **young sporophyte** attached. Look for a young **leaf** and **root** on each sporophyte.

   Share slides of living gametophytes with archegonia, antheridia and sperm, and sporophytes until everyone has observed each structure.

Results

1. Review the structures and processes observed, and then label the stages of fern sexual reproduction outlined in Figure 6.
2. Using colored pencils, circle those parts of the life cycle that are sporophytic (diploid). Use another color to encircle the gametophytic (haploid) stages of the life cycle. Highlight the processes of meiosis and mitosis.

Discussion

Refer to Figure 2, the generalized diagram of the plant life cycle, and Figure 6, a representation of the fern life cycle.

1. Are the spores produced by the fern sporophyte formed by meiosis or mitosis? meiosis
2. Do the spores belong to the gametophyte or the sporophyte generation?
3. Are the gametes produced by mitosis or meiosis?

   Mitosis
4. Are the archegonia and antheridia haploid or diploid? Think about which generation produces them. haploid
5. Is the dominant generation for the fern the gametophyte or the sporophyte? sporophyte
6. Can you suggest any ecological role for ferns?

Lab Study D. Fossils of Seedless Vascular Plants

Materials

fossils of extinct lycophytes (*Lepidodendron, Sigillaria*)
fossils of extinct sphenophytes (*Calamites*)
fossils of extinct ferns

Introduction

If we went back in time 300 million years to the Carboniferous period, we would encounter a wide variety of vertebrate amphibians moving about vast swamps dominated by spore-bearing forest trees. Imagine a forest of horsetails and lycophytes the size of trees, amphibians as large as alligators, and enormous dragonflies and roaches! Seedless plants were at their peak during this period and were so prolific that their carbonized remains form the bulk of Earth's coal deposits. Among the most spectacular components of the coal-swamp forest were tree ferns, 100-foot-tall trees belonging to the fossil genera *Lepidodendron* and *Sigillaria,* and 60-foot-tall horsetails assigned to the fossil genus *Calamites* (Figures 3 and 7).

Procedure

Examine flattened fossil stems of *Lepidodendron, Sigillaria, Calamites,* and fossil fern foliage, all of which were recovered from coal mine tailings. Compare these with their living relatives, the lycophytes (club mosses), sphenophytes (horsetails), and ferns, which today are diminutive plants found in restricted habitats.

Results

1. For each division of seedless vascular plants, describe those characteristics that are similar for both living specimens and fossils. For example, do you observe dichotomous branching and similar shape and form of leaves, stems, or sporangia? Refer to the living specimens or your sketches.

   Lycophytes:

   Sphenophytes:

   Ferns:

2. Sketch in the margin of your lab manual the overall structure of the fossils. How would you recognize these fossils at a later date? Label structures where appropriate.

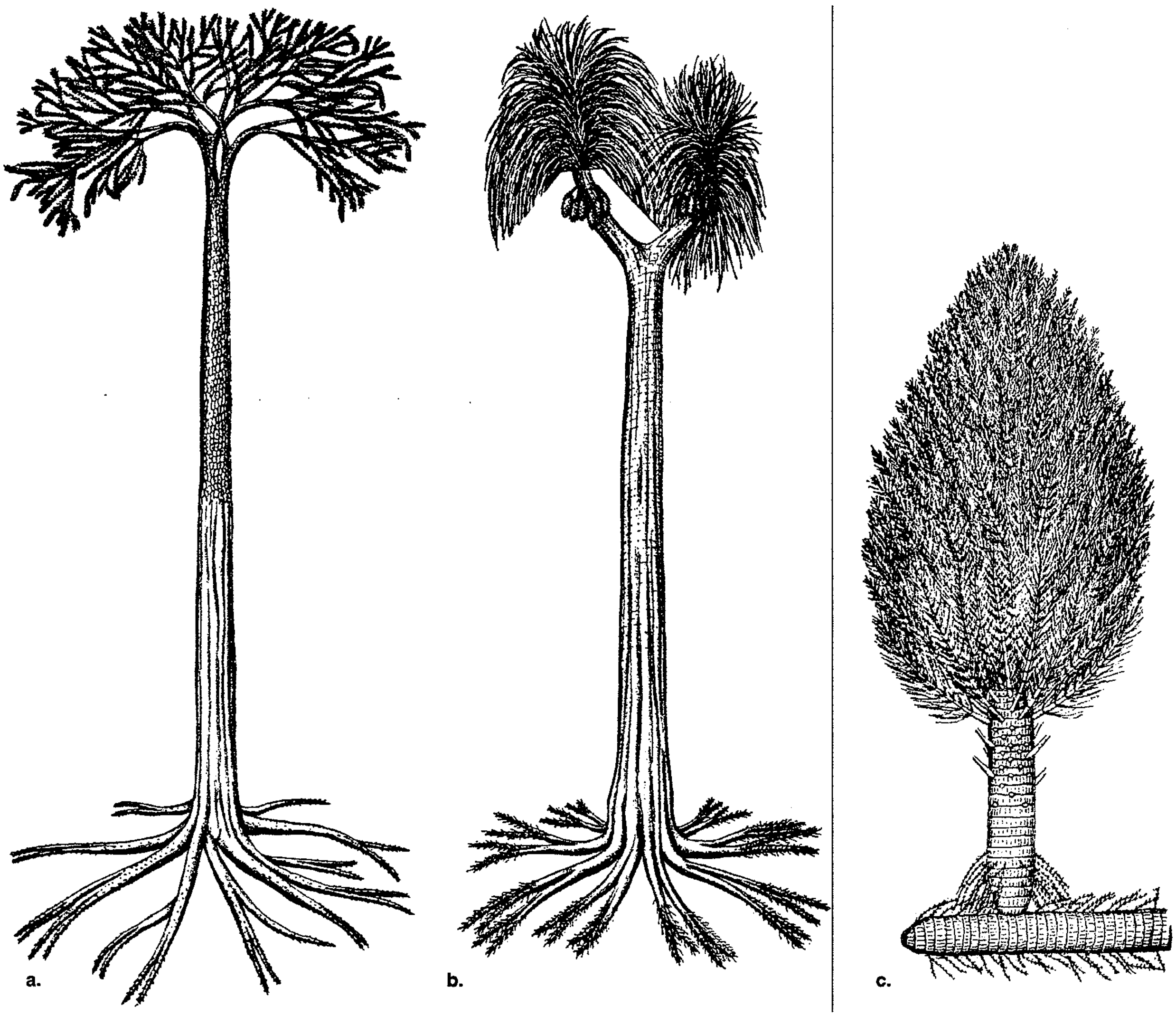


Figure 7.
Seedless vascular plants of the Carboniferous period. Reconstruction of the lycophytes (a) *Lepidodendron* and (b) *Sigillaria.* (c) *Calamites* was a relative of horsetails.

Discussion

The lycophytes, sphenophytes, and ferns were once the giants of the plant kingdom and dominated the landscape. Explain why they are presently restricted to certain habitats and are relatively small in stature.

Questions for Review

1. Complete Table 3, indicating the primitive and advanced features of seedless vascular plants relative to success in land environments. Recall that in this context the term *primitive* means an ancestral trait, while the term *advanced* indicates a derived trait, or adaptation, to land. For example, traits shared with the bryophytes (such as sperm requiring water for fertilization) are primitive, while the presence of vascular tissue is advanced.

Table 3
Primitive and Advanced Features of Seedless Vascular Plants as They Relate to Adaptation to Land

Primitive Features	Advanced Features

2. For each of the listed features, describe its contribution, if any, to the success of land plants.

   gametangium

   cuticle

   rhizoid

   motile sperm

   vascular tissue

   gemma

3. Complete Table 4. Identify the function of the structures listed. Indicate whether they are part of the gametophyte or sporophyte generation, and provide an example of a plant that has this structure.

Table 4
Structures and Functions of the Bryophytes and Seedless Vascular Plants

Structure	**Function**	**Sporophyte/ Gametophyte**	**Example**
Antheridium			
Archegonium			
Spore			
Gamete			
Rhizome			
Gemma			
Sporangium			
Strobilus			
Sorus			

4. What is the major difference between the alternation of generations in the life cycles of bryophytes and seedless vascular plants?

Applying Your Knowledge

1. The fossil record provides little information about ancient mosses. Do you think that bryophytes could ever have been large tree-sized plants? Provide evidence from your investigations to support your answer.

2. On a walk through a botanical garden, you notice a small leafy plant that is growing along the edge of a small stream in a shady nook. You hypothesize that this plant is a lycophyte. What information can you gather to test your hypothesis?

3. German scientists studied air pollution from heavy metals (cadmium, copper, lead, nickel, and zinc) by analyzing the concentration of these metals in moss samples. They compared mosses collected between 1845 and 1974, which were preserved as herbarium specimens, with mosses collected in 1991. In general, the 1991 mosses had lower heavy metal concentrations. These results were attributed to increased air pollution controls. Based on your knowledge of the structure of the moss gametophyte, can you suggest one or more reasons why mosses are particularly useful indicators of air pollution?

4. Heterospory occasionally occurs in lycophytes and ferns, and in all seed plants. Botanists are convinced that heterospory must have originated more than once in the evolution of plants. Can you suggest one or more advantages that heterospory might provide to plants?

References

Herpin, U., B. Markert, V. Wechert, J. Berklekamp, K. Friese, U. Siewers, and H. Lieth. "Retrospective Analysis of Heavy Metal Concentrations at Selected Locations in the Federal Republic of Germany Using Moss Materials from a Herbarium," *Science of the Total Environment*, 1997, vol. 205, pp. 1–12.

Mauseth, J. D. *Botany: An Introduction to Plant Biology*, 2nd ed. Philadelphia, PA: Saunders College Publishing, 1995.

Moore, R., W. D. Clark, and D. Vodopich. *Botany*, 2nd ed. Dubuque, IA: WCB/McGraw-Hill, 1998.

Raven, P. H., R. F. Evert, and S. E. Eichhorn. *Biology of Plants*, 6th ed. New York: W. H. Freeman Publishers, 1999.

Websites

Links to images of horsetails:

http://www.wisc.edu/botit/systematics/Phyla/Sphenophyta/Sphenophyta.html

Links to images of whisk ferns:

http://www.wisc.edu/botit/systematics/Phyla/Psilophyta/Psilophyta.html

Links to images of lycophytes:

http://www.wisc.edu/botit/systematics/Phyla/Lycophyta/Lycophyta.html

Photo Credits

5b: ©James W. Richardson/Visuals Unlimited.

Art Credits

3, 7: Adapted from James D. Mauseth, *Botany: An Introduction to Plant Biology*, fig. 23.3, p. 667 (Sudbury, MA: Jones and Bartlett Publishers, 1991), www.jbpub.com. Reprinted with permission.

Plant Anatomy

Laboratory Objectives

After completing this lab topic, you should be able to:

1. Identify and describe the structure and function of each cell type and tissue type.
2. Describe the organization of tissues and cells in each plant organ.
3. Relate the function of an organ to its structure.
4. Describe primary and secondary growth and identify the location of each in the plant.
5. Relate primary and secondary growth to the growth habit (woody or herbaceous).
6. Discuss adaptation of land plants to the terrestrial environment as illustrated by the structure and function of plant anatomy.
7. Apply your knowledge of plants to the kinds of produce you find in the grocery store.

Introduction

Vascular plants have been successful on land for over 400 million years, and their success is related to their adaptations to the land environment. An aquatic alga lives most often in a continuously homogeneous environment: The requirements for life are everywhere around it, so relatively minor structural adaptations have evolved for functions such as reproduction and attachment. In contrast, the terrestrial habitat, with its extreme environmental conditions, presents numerous challenges for the survival of plants. Consequently, land plants have evolved structural adaptations for functions such as the absorption of underground water and nutrients, the anchoring of the plant in the substrate, the support of aerial parts of the plant, and the transportation of materials throughout the relatively large plant body. In angiosperms, the structural adaptations required for these and other functions are divided among three vegetative plant organs: stems, roots, and leaves. Unlike animal organs, which are often composed of unique cell types (for example, cardiac muscle fibers are found only in the heart, osteocytes only in bone), plant organs have many tissues and cell types in common, but they are organized in different ways. The structural organization of basic tissues and cell types in different plant organs is directly related to their different functions. For example, leaves function as the primary photosynthetic organ and generally have thin, flat blades that maximize light absorption and gas exchange. Specialized cells of the root epidermis are long extensions that promote one of the root functions, absorption. The interrelationship of structure and function is a major theme in biology, and you will continue to explore it in this lab topic.

Use the figures in this lab topic for orientation and as a study aid. Be certain that you can identify all items by examining the living specimens and microscope slides. These, and not the diagrams, will be used in the laboratory evaluations.

Summary of Basic Plant Tissues and Cell Types

Following is a review of plant tissues and the most common types of cells seen in plant organs, as well as their functions. Other specialized cells will be described as they are discussed in lab. Refer back to this summary as you work through the exercises.

Dermal Tissue: Epidermis

The **epidermis** forms the outermost layer of cells, usually one cell thick, covering the entire plant body. The epidermal cells are often flattened and rectangular in shape. Specialized epidermal cells include the **guard cells** of the stomata, hairs called **trichomes,** and unicellular **root hairs.** Most epidermal cells on aboveground structures are covered by a waxy **cuticle,** which prevents water loss. The epidermis provides protection and regulates movement of materials.

Ground Tissue: Parenchyma, Collenchyma, and Sclerenchyma

Parenchyma cells are the most common cell in plants and are characteristically thin-walled with large vacuoles. These cells may function in photosynthesis, support, storage of materials, and lateral transport.

Collenchyma cells are usually found near the surface of the stem, leaf petioles, and veins. These living cells are similar to parenchyma cells but are characterized by an uneven thickening of cell walls. They provide flexible support to young plant organs.

Sclerenchyma cells have thickened cell walls that may contain lignin. They provide strength and support to mature plant structures and may be dead at functional maturity. The most common type of sclerenchyma cells are long, thin **fibers.**

Vascular Tissue: Xylem and Phloem

Xylem cells form a complex vascular tissue that functions in the transport of water and minerals throughout the plant and provides support. **Tracheids** and **vessel elements** are the primary water-conducting cells. Tracheids are long, thin cells with perforated tapered ends. Vessel elements are larger in diameter, open-ended, and joined end to end, forming continuous transport systems referred to as **vessels.** Parenchyma cells are present in the xylem and function in storage and lateral transport. Fibers in the xylem provide additional support.

Phloem tissue transports the products of photosynthesis throughout the plant as part of the vascular tissue system. This complex tissue is composed of living, conducting cells called **sieve-tube members,** which lack a nucleus and have **sieve plates** for end walls. The cells are joined end to end throughout the plant. Each sieve-tube member is associated with one or more adjacent **companion cells,** which are thought to regulate sieve-tube member function. Phloem parenchyma cells function in storage and lateral transport, and phloem fibers provide additional support.

Meristematic Tissue: Primary Meristem, Cambium, and Pericycle

Primary meristems consist of small, actively dividing cells located in buds of the shoot and in root tips of plants. These cells produce the primary tissues along the plant axis throughout the life of the plant.

Vascular cambium is a lateral meristem also composed of small, actively dividing cells that are located between the xylem and phloem vascular tissue. These cells divide to produce secondary growth, which results in an increase in girth.

Pericycle is a layer of meristematic cells just outside the vascular cylinder in the root. These cells divide to produce lateral branch roots.

EXERCISE 1
Plant Morphology

Materials

living bean or geranium plant
squirt bottle of water
paper towel

Introduction

As you begin your investigation of the structure and function of plants, you need an understanding of the general shape and form of the whole plant. In this exercise, you will study a bean or geranium plant, identifying basic features of the three vegetative organs: roots, stems, and leaves. In the following exercises, you will investigate the cellular structure of these organs as viewed in cross sections. Refer to the living plant for orientation before you view your slides.

Procedure

1. Working with another student, examine a living **herbaceous** (nonwoody) plant and identify the following structures in the shoot (stems and leaves):
   a. **Nodes** are regions of the stem from which leaves, buds, and branches arise and which contain meristematic tissue (areas of cell division).
   b. **Internodes** are the regions of the stem located between the nodes.
   c. **Terminal buds** are located at the tips of stems and branches. They enclose the shoot apical meristem, which gives rise to leaves, buds, and all primary tissue of the stem. Only stems produce buds.
   d. **Axillary,** or **lateral, buds** are located in the leaf axes at nodes; they may give rise to lateral branches.
   e. Leaves consist of flattened **blades** attached at the node of a stem by a stalk, or **petiole.**

2. Observe the root structures by gently removing the plant from the pot and loosening the soil from the root structure. You may need to rinse a few roots with water to observe the tiny, active roots. Identify the following structures:
   a. **Primary** and **secondary roots.** The primary root is the first root produced by a plant embryo and may become a long taproot. Secondary roots arise from meristematic tissue deep within the primary root.
   b. Root tips consist of a **root apical meristem** that gives rise to a **root cap** (protective layer of cells covering the root tip) and to all the primary tissues of the root. A short distance from the root tip is a zone of **root hairs** (specialized epidermal cells), the principal site of water and mineral absorption.

Results

1. Label Figure 1.
2. Sketch in the margin of your lab manual any features not included in this diagram that might be needed for future reference.

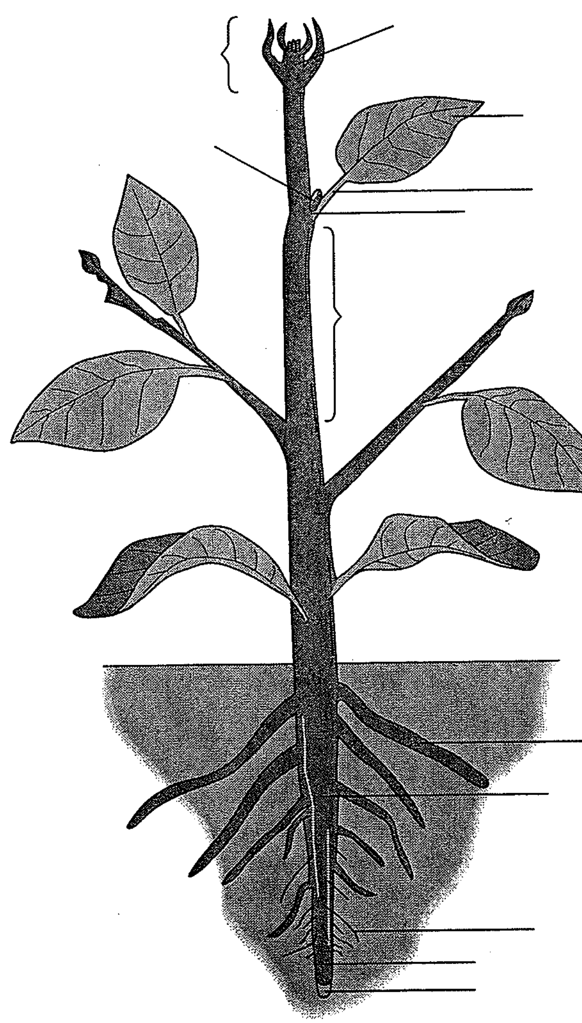


Figure 1.
A herbaceous plant. The vegetative plant body consists of roots, stems, and leaves. The buds are located in the axils of the leaves and at the shoot tip. The roots also grow from meristem tissues in the root tip. Label the diagram based on your observations of a living plant and the structures named in Exercise 1.

Discussion

1. Look at your plant and discuss with your partner the possible functions of each plant organ. Your discussion might include evidence observed in the lab today or prior knowledge. Describe proposed functions (more than one) for each organ.

   Stems:

   Roots:

   Leaves:

2. Imagine that you have cut each organ—roots, stems, and leaves—in cross section. Sketch the overall shape of that cross section in the margin of your lab manual. Remember, you are not predicting the internal structure, just the overall shape.

EXERCISE 2
Plant Primary Growth and Development

Materials

prepared slides of *Coleus* stem (long section)
compound microscope

Introduction

Plants produce new cells throughout their lifetime as a result of cell divisions in meristems. Tissues produced from apical meristems are called **primary tissues,** and this growth is called **primary growth.** Primary growth occurs along the plant axis at the shoot and the root tip. Certain meristem cells divide in such a way that one cell product becomes a new body cell and the other remains in the meristem. Beyond the zone of active cell division, new cells become enlarged and specialized for specific functions (resulting, for example, in vessels, parenchyma, and epidermis). The investigation of the genetic and biochemical basis of this cell differentiation continues to be an area of exciting biological research.

In this exercise, you will examine a longitudinal section through the tip of the stem, observing the youngest tissues and meristems at the apex, then moving down the stem, where you will observe more mature cells and tissues.

Procedure

1. Examine a prepared slide of a longitudinal section through a terminal bud of *Coleus*. Use low power to get an overview of the slide; then

increase magnification. Locate the **apical meristem**, a dome of tissue nestled between the **leaf primordia**, young developing leaves. Locate the axillary **bud primordia** between the leaf and the stem.

2. Move the specimen under the microscope so that cells may be viewed at varying distances from the apex. The youngest cells are at the apex of the bud, and cells of increasing maturity and differentiation can be seen as you move away from the apex. Follow the early development of vascular tissue, which differentiates in relation to the development of primordial leaves.
   a. Locate the narrow, dark tracks of **undifferentiated vascular tissue** in the leaf primordia.
   b. Observe changes in cell size and structure of the vascular system as you move away from the apex and end with a distinguishable vessel element of the **xylem,** with its spiral cell wall thickening in the older leaf primordia and stem. You may need to use the highest power on the microscope to locate these spiral cell walls.

Results

1. Label Figure 2, indicating the structures visible in the young stem tip.
2. Modify the figure or sketch details in the margin of the lab manual for future reference.

Discussion

1. Describe the changes in cell size and structure in the stem tip. Begin at the youngest cells at the apex and continue to the xylem cells.

2. The meristems of plants continue to grow throughout their lifetime, an example of **indeterminate growth.** Imagine a 200-year-old oak tree, with active meristem producing new buds, leaves, and stems each year. Contrast this with the growth pattern in humans.

EXERCISE 3

Cell Structure of Primary Tissues

All **herbaceous** (nonwoody) flowering plants produce a complete plant body composed of primary tissue, derived from apical primary meristem. This plant body consists of *organs*—roots, stems, leaves, flowers, fruits, and seeds—and *tissue systems*—**dermal** (epidermis), **ground** (parenchyma), and **vascular** (xylem and phloem). In this exercise, you will investigate the cellular structure and organization of plant organs and tissues by examining microscopic slides. You will make your own thin cross sections of stems, and view prepared slides of stems, roots, and leaves. Woody stems will be examined in Exercise 4.

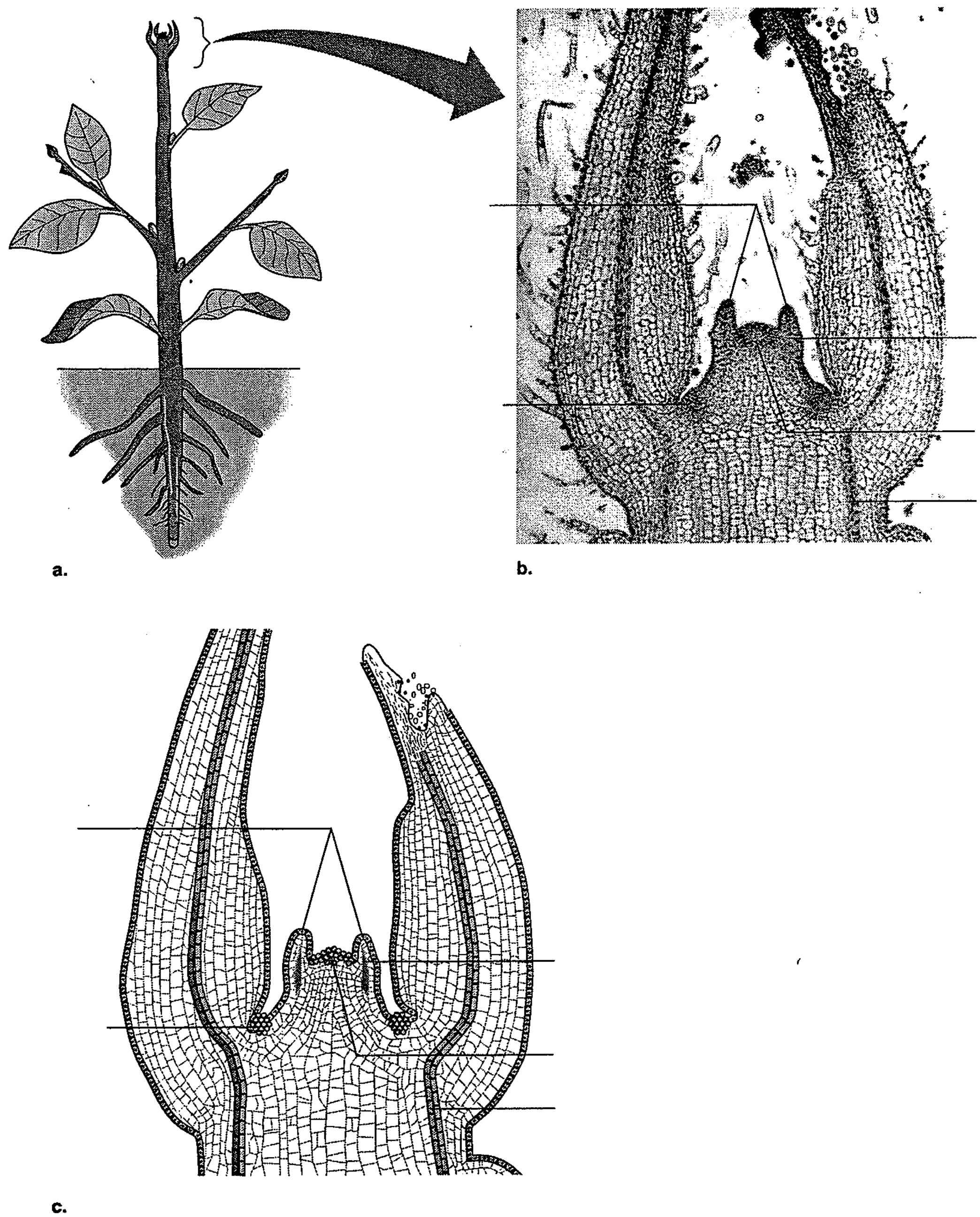


Figure 2.
***Coleus* stem tip.** (a) Diagram of entire plant body. (b) Photomicrograph of a longitudinal section through the terminal bud. (c) Line diagram of the growing shoot tip with primordial leaves surrounding the actively dividing apical meristem. The most immature cells are at the tip of the shoot and increase in stages of development and differentiation farther down the stem. Label the cells and structures described in Exercise 2.

Lab Study A. Stems

Materials

prepared slide of herbaceous dicot stem
dropper bottle of distilled water
small petri dish with 50% ethanol
dropper bottle of 50% glycerine
dropper bottle of 0.2% toluidine blue stain
nut-and-bolt microtome
warm paraffin
living plant for sections
new single-edged razor blade
forceps
microscope slides
coverslips
compound microscope
dissecting needles

Introduction

A stem is usually the main stalk, or axis, of a plant and is the only organ that produces buds and leaves. Stems support leaves and conduct water and inorganic substances from the root to the leaves and carbohydrate products of photosynthesis from the leaves to the roots. Most herbaceous stems are able to photosynthesize. Stems exhibit several interesting adaptations, including water storage in cacti, carbohydrate storage in some food plants, and thorns that reduce herbivory in a variety of plants.

You will view a prepared slide of a cross section of a stem, and, working with another student, you will use a simple microtome—an instrument used for cutting thin sections for microscopic study—to make your own slides. You will embed the stem tissue in paraffin and cut thin sections. You will stain your sections with toluidine blue, which will help you distinguish different cell types. This simple procedure is analogous to the process used to make prepared slides for subsequent lab studies.

Read through the procedure and set up the materials before beginning.

Procedure

1. Embed the sections of the stem.
   a. Using a new single-edged razor blade, cut a 0.5 cm section of a young bean stem.
   b. Obtain a nut-and-bolt microtome. The nut should be screwed just into the first threads of the bolt. Using forceps, carefully hold the bean stem upright inside the nut.
   c. Pour the warm paraffin into the nut until full. Continue to hold the top of the stem until the paraffin begins to harden. While the paraffin completely hardens, continue the exercise by examining the prepared slide of the stem.
2. Examine a prepared slide of a cross section through the herbaceous dicot stem.
3. Identify the **dermal tissue system,** characterized by a protective cell layer covering the plant. It is composed of the **epidermis** and the

cuticle. Occasionally, you may also observe multicellular **trichomes** on the outer surface of the plants.

4. Locate the **ground tissue system,** background tissue that fills the spaces between epidermis and vascular tissue. Identify the **cortex region** located between the vascular bundles and the epidermis. It is composed mostly of **parenchyma,** but the outer part may contain **collenchyma** as well.
5. Next find the **pith region,** which occupies the center of the stem, inside the ring of vascular bundles; it is composed of parenchyma. In herbaceous stems, these cells provide support through turgor pressure. This region is also important in storage.
6. Now identify the **vascular system,** a continuous system of xylem and phloem providing transport and support. In your stems and in many stems, the **vascular bundles** (clusters of xylem and phloem) occur in rings that surround the pith; however, in some groups of flowering plants, the vascular tissue is arranged in a complex network.
7. Observe that each bundle consists of phloem tissue toward the outside and xylem tissue toward the inside. A narrow layer of vascular cambium, which may become active in herbaceous stems, is situated between the xylem and the phloem. Take note of the following information as you make your observations.

   Phloem tissue is composed of three cell types:

   a. Dead, fibrous, thick-walled **sclerenchyma cells** that provide support for the phloem tissue and appear in a cluster as a **bundle cap.**
   b. **Sieve-tube members,** which are large, living, elongated cells that lack a nucleus at maturity. They become vertically aligned to form sieve tubes, and their cytoplasm is interconnected through sieve plates located at the ends of the cells. Sieve plates are not usually seen in cross sections.
   c. **Companion cells,** which are small, nucleated parenchyma cells connected to sieve-tube cells by means of cytoplasmic strands.

   Xylem tissue is made up of two cell types:

   a. **Tracheids,** which are elongated, thick-walled cells with closed, tapered ends. They are dead at functional maturity, and their lumens are interconnected through pits in the cell walls.
   b. **Vessel elements,** which are cylindrical cells that are large in diameter and dead at functional maturity. They become joined end to end, lose their end walls, and form long, vertical vessels.

   Vascular cambium is a type of tissue that is located between the xylem and the phloem and which actively divides to give rise to secondary tissues.
8. Complete the Results section below for this slide, then return to step 9 to prepare and observe your own handmade sections of stem preparations.
9. Cut the stem sections in the hardened paraffin.

   a. Support the nut-and-bolt microtome with the bolt head down and, using the razor blade, carefully slice off any excess paraffin extending above the nut. Be careful to slice in a direction away from your body and to keep your fingers away from the edge of the razor blade (Figure 3).

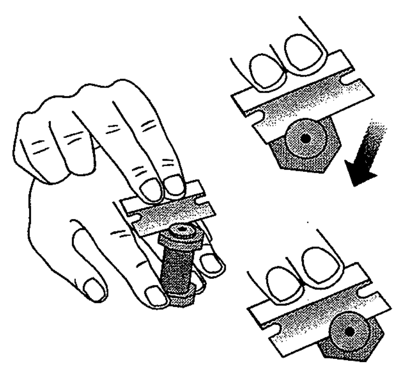


Figure 3.
Using the nut-and-bolt microtome. A piece of stem is embedded in paraffin in the bolt. As you twist the bolt up, slice thin sections to be stained and viewed. Slide the entire blade through the paraffin to smoothly slice thin sections. Follow the directions in Exercise 3, Lab Study A carefully.

Be careful to keep fingers and knuckles away from the razor blade. Follow directions carefully.

b. Turn the bolt *just a little,* to extend the stem/paraffin above the edge of the nut.

c. Produce a thin section by slicing off the extension using the full length of the razor blade, beginning at one end of the blade and slicing to the other end of the blade (see Figure 3).

d. Transfer each section to a small petri dish containing 50% ethanol.

e. Continue to produce thin sections of stem in this manner. The thinnest slices may curl, but this is all right if the stem section remains in the paraffin as you make the transfer. Cell types are easier to identify in very thin sections or in the thin edges of thicker sections.

10. Stain the sections.

a. Leave the sections in 50% ethanol in the petri dish for 5 minutes. The alcohol *fixes,* or preserves, the tissue. Using dissecting needles and forceps, carefully separate the tissue from the surrounding paraffin.

b. Using forceps, move the stem sections, free of the paraffin, to a clean slide.

c. Add several drops of toluidine blue to cover the sections. Allow the sections to stain for 10 to 15 seconds.

d. Carefully draw off the stain by placing a piece of paper towel at the edge of the stain.

e. Rinse the sections by adding several drops of distilled water to cover the sections. Draw off the excess water with a paper towel. Repeat this step until the rinse water no longer looks blue.

f. Add a drop of 50% glycerine to the sections and cover them with a coverslip, being careful not to trap bubbles in the preparation.

g. Observe your sections using a compound microscope. Survey the sections at low or intermediate power, selecting the specimens with the clearest cell structure. You may have to study more than one specimen to see all structures.

11. Follow steps 3–7 above and identify all structures and cells. Incorporate your observations into the Results section (4, following).

Results

1. Label the stem section in Figure 4b and c.
2. Were any epidermal trichomes present in your stem?
3. Note any features not described in the procedure. Sketch these in the margin of your lab manual for future reference. Return to Procedure step 9 in this lab study and complete the preparation of hand sections of the bean stem.
4. Compare your hand sections with the prepared slide. Modify Figure 4 or sketch your hand section in the margin. Is there any evidence of vascular cambium and secondary growth (Exercise 4)? Compare your results with those of other students.

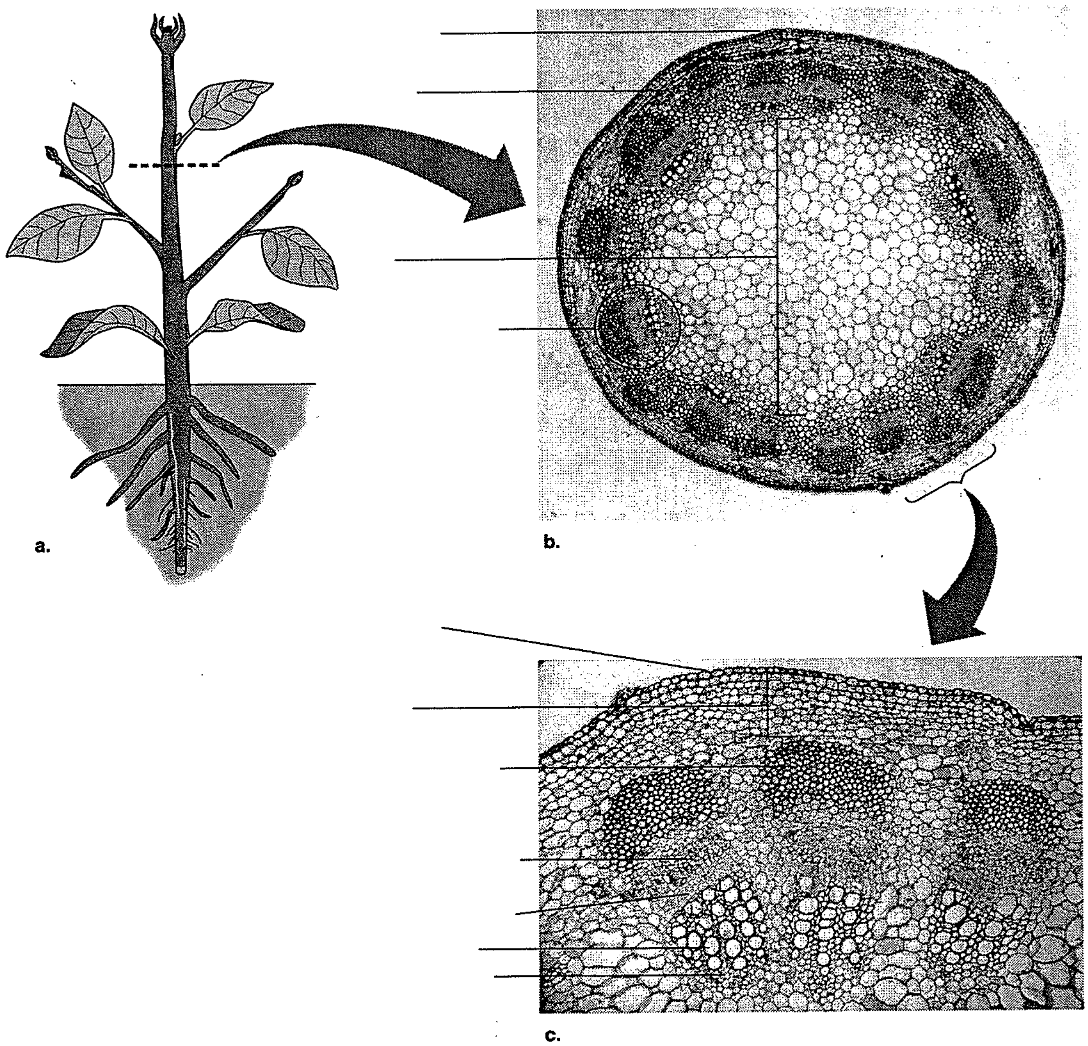


Figure 4.
Stem anatomy. (a) Diagram of whole plant. (b) Photomicrograph of cross section through the stem portion of the plant. (c) Enlargement of one vascular bundle as seen in cross section of the stem.

The functions of cells were described in the Summary of Basic Plant Tissues and Cell Types, which appeared near the beginning of this lab topic.

Discussion

1. Which are larger and more distinct, xylem cells or phloem cells?

2. What types of cells provide support of the stem? Where are these cells located in the stem?

3. For the cells described in your preceding answer, how does their observed structure relate to their function, which is support?

4. What is the function of xylem? Of phloem?

5. The pith and cortex are made up of parenchyma cells. Describe the many functions of these cells. Relate parenchyma cell functions to their observed structure.

6. What differences did you observe in the prepared stem sections and your hand sections? What factors might be responsible for these differences?

Lab Study B. Roots

Materials

prepared slide of buttercup (*Ranunculus*) root (cross section)
demonstration of fibrous roots and taproots
colored pencils
compound microscope

Introduction

Roots and stems often appear to be similar, except that roots grow in the soil and stems above the ground. However, some stems (rhizomes) grow underground, and some roots (adventitious roots) grow aboveground. Roots and stems may superficially appear similar, but they differ significantly in their functions.

What are the primary functions of stems?

Roots have four primary functions:

1. anchorage of the plant in the soil
2. absorption of water and minerals from the soil
3. conduction of water and minerals from the region of absorption to the base of the stem
4. starch storage to varying degrees, depending on the plant

Hypothesis

Our working hypothesis for this investigation is that the *structure* of the plant body is related to particular *functions.*

Prediction

Based on our hypothesis, make a prediction about the similarity of root and stem structures that you expect to observe (if/then).

You will now test your hypothesis and predictions by observing the external structure of roots and their internal cellular structure and organization in a prepared cross section. This activity is an example of collecting evidence from observations rather than conducting a controlled experiment.

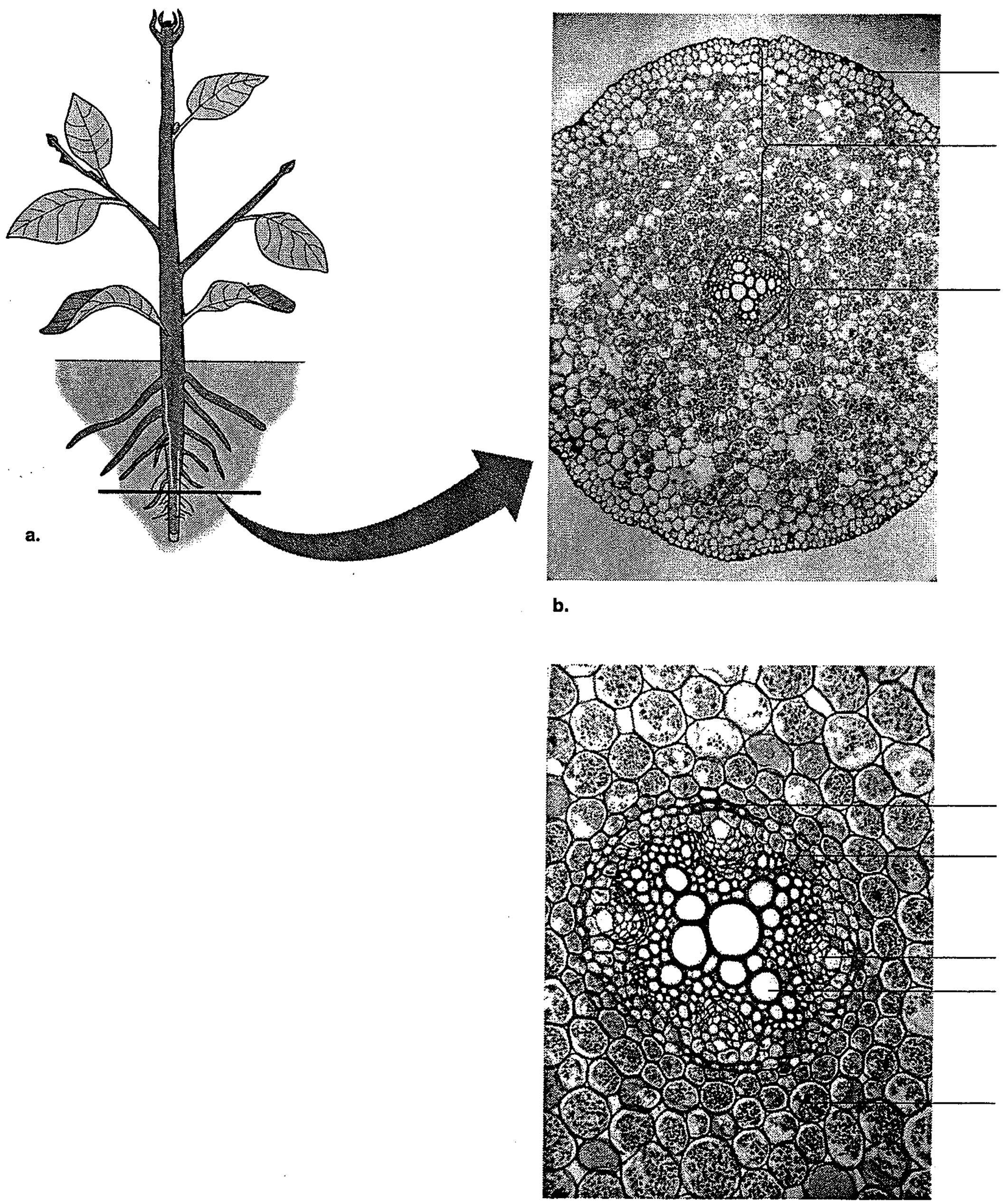
Procedure

1. Examine the external root structure. When a seed germinates, it sends down a **primary root,** or **radicle,** into the soil. This root sends out side branches called lateral roots, and these in turn branch out until a root system is formed.

   If the primary root continues to be the largest and most important part of the root system, the plant is said to have a **taproot** system. If many main roots are formed, the plant has a **fibrous root** system. Most grasses have a fibrous root system, as do trees with roots occurring within 1 m of the soil surface. Carrots, dandelions, and pine trees are examples of plants having taproots.

   a. Observe examples of fibrous roots and taproots on demonstration in the laboratory.

   b. Sketch the two types of roots in the margin of your lab manual.



a.

b.

c.

Figure 5.
Cross section of the buttercup root. (a) Whole plant. (b) Photomicrograph of a cross section of a root. (c) Enlargement of the vascular cylinder. Label the root based on your observations of a prepared microscope slide.

2. Examine the internal root structure.
   a. Study a slide of a cross section through a buttercup (*Ranunculus*) root. Note that the root lacks a central pith. The vascular tissue is located in the center of the root and is called the **vascular cylinder** (Figure 5b).
   b. Look for a cortex. The **cortex** is primarily composed of large parenchyma cells filled with numerous purple-stained organelles. Which of the four functions of roots listed in the introduction to this lab study do you think is related to these cortical cells and their organelles?
   c. Identify the following tissues and regions and label Figure 5b and c accordingly: **epidermis,** parenchyma of **cortex, vascular cylinder, xylem, phloem, endodermis,** and **pericycle.** The endodermis and the pericycle are unique to roots. The endodermis is the innermost cell layer of the cortex. The walls of endodermal cells have a band called the **Casparian strip**—made of **suberin,** a waxy material—that extends completely around each cell, as shown in Figure 6. This strip forms a barrier to the passage of anything moving between adjacent cells of the endodermis. All water and dissolved materials absorbed by the epidermal root hairs and transported inward through the cortex must first pass through the living cytoplasm of endodermal cells before entering the vascular tissues. The pericycle is a layer of dividing cells immediately inside the endodermis; it gives rise to lateral roots.

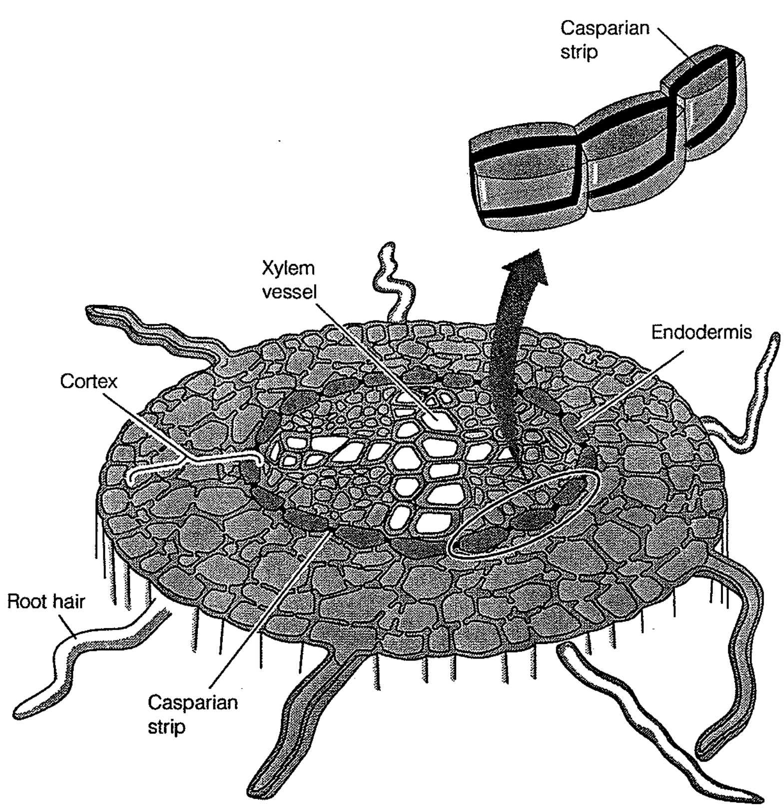


Figure 6.
Root endodermis. The endodermis is composed of cells surrounded by a band containing *suberin,* called the *Casparian strip* (seen in enlargement), that prevents the movement of materials along the cells' walls and intercellular spaces into the vascular cylinder. Materials must cross the cell membrane before entering the vascular tissue.

Results

1. Review Figure 5 and note comparable structures in Figure 6.
2. Using a colored pencil, highlight the representations of structures or cells found in the root but not seen in the stem.

Discussion

1. Suggest the advantage of taproots and of fibrous roots under different environmental conditions.

2. Did your observations support your hypothesis and predictions?

3. Compare the structure and organization of roots and stems. How do these two organs differ?

4. Explain the relationship of structure and function for two structures or cells found only in roots.

5. Note that the epidermis of the root lacks a cuticle. Can you explain why this might be advantageous?

6. What is the function of the endodermis? Why is the endodermis important to the success of plants in the land environment?

Lab Study C. Leaves

Materials

prepared slide of lilac (*Syringia*) leaf
slides
compound microscope
coverslips
dropper bottles of water
leaves of purple heart (*Setcreasia*) kept in saline and DI water

Introduction

Leaves are organs especially adapted for photosynthesis. The thin blade portion provides a very large surface area for the absorption of light and the uptake of carbon dioxide through stomata. The leaf is basically a layer of parenchyma cells (the **mesophyll**) between two layers of epidermis. The loose arrangement of parenchyma cells within the leaf allows for an extensive surface area for the rapid exchange of gases. Specialized epidermal cells called guard cells allow the exchange of gases and evaporation of water at the leaf surface. Guard cells are photosynthetic (unlike other epidermal cells), and are capable of changing shape in response to complex environmental and physiological factors. Current research indicates that the opening of the stomata is the result of the active uptake of K^+ and subsequent changes in turgor pressure in the guard cells.

In this lab study, you will examine the structure of a leaf in cross section. You will observe stomata on the leaf epidermis and will study the activity of guard cells under different conditions.

Procedure

1. Before beginning your observations of the leaf cross section, compare the shape of the leaf on your slide with Figure 7a and b on the next page.
2. Observe the internal leaf structure.
   a. Examine a cross section through a lilac leaf and identify the following cells or structures: **cuticle, epidermis** (upper and lower), parenchyma with chloroplasts (**mesophyll**), **vascular bundle** with **phloem** and **xylem,** and **stomata** with **guard cells** and **substomatal chamber.**
   b. The vascular bundles of the leaf are often called **veins** and can be seen in both cross section and longitudinal sections of the leaf. Observe the structure of cells in the central midvein. Is xylem or phloem on top in the leaf?

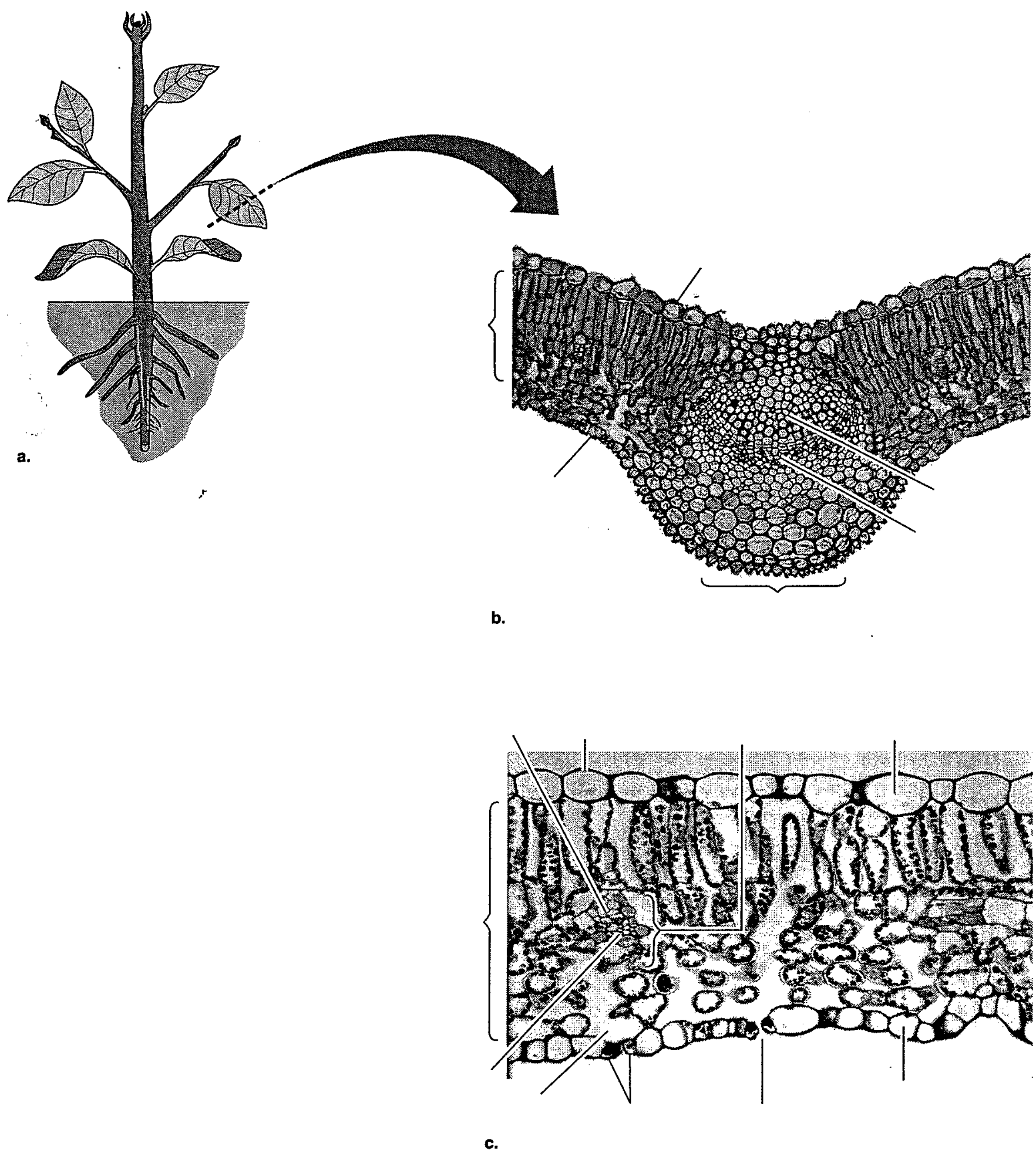


Figure 7.
Leaf structure. (a) Whole plant. (b) Photomicrograph of a leaf cross section through the midvein. (c) Photomicrograph of a leaf cross section adjacent to the midvein.

c. Observe the distribution of stomata in the upper and lower epidermis. Where are they more abundant?

d. Label the cross section of the leaf in Figure 7.

3. Observe the leaf epidermis and stomata.
   a. Obtain two *Setcreasia* leaves, one placed in saline for an hour and the other placed in distilled water for an hour.
   b. Label two microscope slides, one "saline" and the other "H_2O."
   c. To remove a small piece of the lower epidermis, fold the leaf in half, with the lower epidermis to the inside. Tear the leaf, pulling one end toward the other, stripping off the lower epidermis (Figure 8). If you do this correctly, you will see a thin purple layer of lower epidermis at the torn edge of the leaf.
   d. Remove a small section of the epidermis from the leaf in *DI water* and mount it in water on the appropriate slide, being sure that the outside surface of the leaf is facing up. View the slide at low and high power on your microscope, and observe the structure of the stomata. Sketch your observations in the margin of your lab manual.
   e. Remove a section of the epidermis from the leaf in *saline* and mount it on the appropriate slide in a drop of the *saline*. Make sure that the outside surface of the leaf is facing up. View the slide with low power on your microscope, and observe the structure of the stomata. Sketch your observations in the margin of your lab manual.

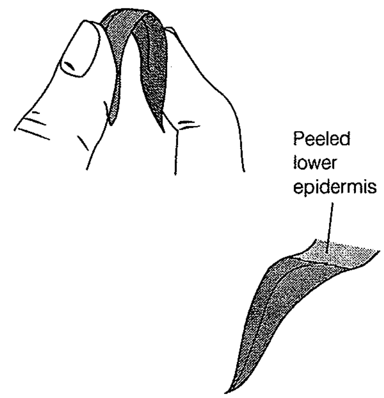


Figure 8.
Preparation of leaf epidermis peel. Bend the leaf in half and peel away the lower epidermis. Remove a small section of lower epidermis and make a wet mount.

Results

1. Review the leaf cross section in Figure 7.
2. Describe the structure of the stomata on leaves kept in DI water.

3. Describe the structure of the stomata on leaves kept in saline.

Discussion

1. Describe the functions of leaves.

2. Provide evidence from your observations of leaf structure to support the hypothesis that structure and function are related. Be specific in your examples.

3. Explain the observation that more stomata are found on the lower surface of the leaf than on the upper.

4. Explain the differences observed, if any, between the stomata from leaves kept in DI water and those kept in saline. Utilize your knowledge of osmosis to explain the changes in the guard cells. (In this activity, you stimulated stomatal closure by changes in turgor pressure due to saline rather than K^+ transport.)

EXERCISE 4

Cell Structure of Tissues Produced by Secondary Growth

Materials

prepared slides of basswood (*Tilia*) stem
compound microscope

Introduction

Secondary growth arises from meristematic tissue called cambium. Vascular cambium and cork cambium are two types of cambium. The vascular cambium is a single layer of meristematic cells located between the secondary phloem and secondary xylem. Dividing cambium cells produce a new cell at one time toward the xylem, at another time toward the phloem. Thus, each cambial cell produces files of cells, one toward the inside of the stem, another toward the outside, resulting in an increase in stem girth (diameter). The secondary phloem cells become differentiated into sclerenchyma fiber cells, sieve-tube members, and companion cells. Secondary xylem cells become differentiated into tracheids and vessel elements. Certain cambial cells produce parenchyma ray cells that can extend radially through the xylem and phloem of the stem.

The cork cambium is a type of meristematic tissue that divides, producing cork tissue to the outside of the stem and other cells to the inside. The cork cambium and the secondary tissues derived from it are called periderm. The periderm layer replaces the epidermis and cortex in stems and roots with secondary growth. These layers are continually broken and sloughed off as the woody plant grows and expands in diameter.