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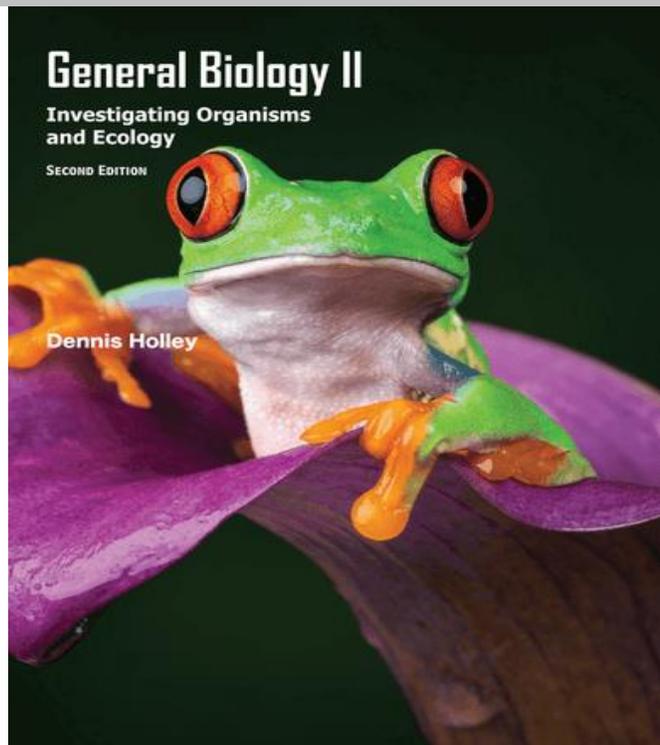
## GENERAL BIOLOGY II: Investigating Organisms and Ecology 2e

Dennis Holley

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### About Holley 2e:

**Research-based:** This book is based on current educational research and best educational practices, not tradition.

**Understandable:** This book is content (idea) driven and not terms and terminology driven (tradition). Terms and scientific names are used when and where appropriate to illustrate and explain the concepts and ideas inherent in a particular chapter.

**Readable:** Presented in a single-column format, the chapters in this book are written more similar to a magazine article than a dry, stilted entry in an encyclopedia. This allows for easier student reading which, in turn, increases reading comprehension.

**Appropriate level:** Many, if not most, of the students that take introductory biology courses come with only a fair to poor biology background. This problem is compounded by college biology textbooks that are written at a higher technical level than necessary, especially introductory texts intended for majors. This textbook, however, takes such student deficiencies into account as it is written at an appropriate technical level.

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Organisms and Ecology

DENNIS HOLLEY

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# PREFACE

Greetings biology student and welcome to the always astonishing, sometimes strange, and occasionally even bizarre realm of life and living things.

*Biology gives you a brain. Life turns it into a mind.*

—Jeffery Eugenides

**B**iology or any scientific endeavor should be thought of as consisting of two phases: the first being the *Investigation* and *Exploration* phase and the final is the *Accumulation* phase. Biologists attempt to answer questions about life and living things by actively investigating organisms through experimentation and by discovering new organisms through exploration. Investigation and exploration lead to the accumulation of facts and information. These accumulated facts and information lead to even more questions that, in turn, lead to more investigation resulting in even more facts and information being accumulated. And the cycle continues.

In this course, you will confront the facts and concepts of biology in your textbook (*Accumulation*). However, you will also be challenged to think, act, and work like a biologist (*Investigation*) at certain points in your textbook, and especially in the laboratory segment of this course. As you investigate, you will use the same information, develop the same scientific skills, and employ the same scientific processes as do professional biologists.

## Science Process Skills

### *Organizing Information*

- Classify
- Sequence
- Describe
- Summarize
- Explain
- Definition and proper use of terminology
- Accessing and using reference materials
- Reading comprehension

***Critical Thinking***

- Critical and creative thinking
- Observe
- Infer
- Compare and contrast
- Recognize cause and effect
- Formulate and use models

***Experimentation***

- Experimental design
- Formulate hypothesis/prediction
- Establish variables and controls
- Collect and organize data
- Accurate measurement
- Analyze data
- Draw reasonable conclusions

**Graphics and Numbers**

- Make and interpret graphs
- Construct and interpret tables
- Interpret scientific illustrations
- Calculate and compute

**Communication**

- Brainstorming
- Collaboration
- Communicating

Developing and using these skills effectively is very important if you are biology major, but even if you are not majoring in a scientific field, mastering these skills will help you function as a clear-thinking and scientifically literate citizen of a society that grows ever more science-based and technologically oriented.

**Approach and Organization**

***Approach*** Biology textbooks and related curricular materials at all levels have come under harsh but justified criticism by various scientific and educational groups in the past decade. From the inception of this text, it has been the goal to write a general biology program that acts on the criticisms and recommendations of those authorities and is based on current educational research. This textbook has been designed and written to be:

- **Readable and Interesting.** The goal has been to write a textbook in which the chapters read more like an interesting magazine or newspaper article and less like a dry and detailed technical

entry from an encyclopedia. Increasing reader interest increases readability and to aid in that goal, I include out-of-the-ordinary things in each chapter that would not normally be found in general biology texts. I have also taken a different approach than other zoology books in that while I firmly believe that evolution is driving force and cornerstone of all things biological, I did not make the theoretical and often speculative aspects of origins and patterns of evolution the focal point of each chapter. Instead, I opted for a more concrete “here-and-now” approach in which our focus is mainly on animal systematics, phyla and class characteristics, and ecology. Hopefully, less emphasis on the theoretical translates into a work that is more relevant to you the student.

- **Understandable.** As I wrote this textbook, I tried to avoid the “Huh? Factor” as much as possible. That is; you as a student should not be obliged to reread a passage several times all the while armed with a biological dictionary to understand what you just read. The chapters of this textbook are centered on concepts and ideas. Specific facts, terms and terminology, and scientific names are used only when necessary and appropriate to illustrate and explain the concepts and ideas inherent in a particular chapter. This textbook is concept (idea) driven, not terminology (definitions) driven.
- **Connected.** Living things are all around us, on us and possibly in us, and they affect our daily lives directly and indirectly in ways we are continuing to uncover. In an attempt to connect you the reader directly to the living things around you, each chapter concludes with a discussion on how the organisms encountered in that chapter connect to humans economically, environmentally, medically, and even culturally.
- **Personable** Many textbooks are written by teams of writers, some of which are anonymous. As a result, the reader (student) lacks a personal connection with the author(s). Again, this text is different. First, this text was written in entirety only by the name you see stamped on the front of this book—Dennis Holley. Secondly, I have attempted to write each chapter in the tone of enthusiastic and passionate, but caring and concerned teacher speaking directly to you the student. Hopefully, I have succeeded.

**Organization** A quick glance at the table of contents reveals that what the science of biology is all about and how it works is detailed in Chapter 1. With this foundation in place, in *Unit One* you will encounter primitive life forms ranging from viruses to bacteria and from protists to fungi. In *Unit Two* you will immerse yourself in the green world all around us as you delve into the origins of different types of plants and their body structures as well as their responses and reproduction. In *Unit Three* you will explore the varied realms of the animal kingdom from sponges to mammals and investigate why animals do what they do as you learn about animal behavior. Finally, in *Unit Four* you will examine the ecological principles that unite and intertwine living things and the physical environment around them.

At the end of each chapter, you will find both a set of *Review and Reflect* questions that will test your critical thinking skills while reviewing the main concepts of that particular chapter and a set of *Create and Connect* challenges that will help you develop and use important science process skills. Some or all of these questions and challenges may be assigned by the instructor as part of the assessment package for this course. In these assignments, you will be asked to write everything from formal scientific reports to essays to posi-

tion papers to short stories. The exact format and details will be given with each assignment. Consult the appendix on scientific writing for guidelines and suggestions for correct scientific writing.

I believe this textbook represents a major paradigm shift in the way college biology textbooks are written and presented because it was written by a teacher (not a research scientist) for students. I have labored to make this textbook accurate, understandable, and interesting so that you can and will read it. And if you do indeed bother to read it, I guarantee that you will gather not only a wealth of information but also a never-ending respect for those amazing creatures with which we share this planet.

## **A Personal Note from the Author**

I am a biologist to the core, always have been, and always will be. My interest in all things living is broad and generic. If it's a living creature—plant, animal, or microbe—I find it fascinating. How did I get this way? Understanding parents and a nurturing habitat are to blame. My mother was constantly contending with tadpoles in jars, aquariums of fish, mice in cages, and occasionally rewashing the clothes she had just hung out to dry because my flock of pigeons flew too low overhead. She pretended to make a fuss but encouraged my every adventure. My father helped me build cages and traps and was quite adept at capturing and helping me rear the many kinds of small animals that constantly caught my attention and interest.

I was blessed with growing up in a very small rural village where my family's acreage was only several blocks from a meandering stream aptly known by the locals as "Muddy Creek." This brook was shaded by many huge overhanging trees and was full of snails, fish, frogs, turtles, and even beavers and muskrats. Many inquisitive hours were spent around and in that stream.

Two events sealed my fate and set me on my course. In my early high school years, my parents finally gave in to my pestering and bought me a small, simple microscope (which they couldn't afford even though it cost only around \$30). This amazing black beauty came complete with a wooden box of slides and a few dissecting instruments. Once I dove into the microscopic world, I was hooked on all things biological. Later, I stumbled on Paul de Kruif's 1926 book, *Microbe Hunters* and was inspired to get the education that would allow me to become a professional biologist. At that point, I didn't know exactly what I wanted to do professionally, but I did know my future would have something to do with biology.

I eagerly devoured every biology course I could take in college, and while I flirted for a time with the idea of becoming a marine biologist, I eventually became an educator. For nearly forty years, high schools and universities have actually paid me for merely doing what I love—teaching biology and teaching others how to teach biology and science. I am a very inquiry-oriented, hands-on type of teacher whose philosophy as an educator is best and most simply articulated in the words of Louis Agassiz:

*Study nature, not books.*

My love of all things biological continues unabated to this day. As such, I would consider the day poorly spent were I not to stumble upon at least several biological "WOW! Moments" (*WoMos*) during the course of that day. Such moments are not hard to find for they are everywhere. You just have to be receptive to them. Stop, look, and appreciate the natural world around you

## PREFACE

I would like to dedicate this book to my parents for their nurturing and understanding, my wife and family for their patience and support, and to my students—past and present—who have taught me more than they will ever know.

*Dennis Holley*

As a teacher there is nothing more I enjoy professionally than “talking shop,” so please feel free to contact me if we might be of any assistance in your biological endeavors either in the classroom or laboratory. Also, I certainly want to address any complaints or problems you have with the book, and I am anxious for feedback and input from you regarding any suggestions you might have for future editions. Please contact me through the book website at [www.generalbiologytextbook.com](http://www.generalbiologytextbook.com).



## CHAPTER 9

# ANGIOSPERM ARCHITECTURE: FORM AND FUNCTION OF FLOWERING PLANTS

*Creatures from a planet without flowers would think we must be mad with joy the whole time to have such things about us.*

—Iris Murdock

### Introduction

**O**n closer examination, the roots, stems, and leaves of angiosperms can be seen as the truly amazing structures they really are. These structures form the vegetative organs of a plant, and although the word *organ* is not normally a word associated with plants, these structures most truly are organs. Working in harmony with each other, the roots, stems, and leaves of plants perform astonishing physical and chemical feats that far outstrip human capabilities.

In order to supply thirsty leaves, a giant redwood tree can absorb and transport 2,500 pounds of water a day from its roots upward through its stem to an unbelievable height of 300 feet or so. It does so in the face of tremendous gravitational forces clawing to pull the water back down. In the process, the tree expends the energy equivalent to launching a can of soda into near-earth orbit.

On a hot day, even a smallish tree can efficiently absorb, transport, and evaporate many gallons of water. The mighty oak can move water at the rate of an inch every 10 seconds. We humans, with all our

vaunted technology, would be hard pressed to construct plumbing systems as efficient and effective as those found in plants, especially since plants move tremendous amounts of their fluids often tremendous distances without mechanical pumps of any sort.

Furthermore, stems rival any skyscraper in their complexity. Some trees grow to be hundreds of feet tall and large enough in diameter that roadways have been built through them. And they do so without an internal skeleton of bone or steel girders. Rather, their support begins at the cellular level. Each plant cell with its thick, corrugated cell wall covering meshes with other cells top to bottom, side to side, and front to back to provide a rigid yet flexible support for the scaffolding of branches that reach to the sky.

However, the most remarkable of plant structures must surely be the leaves. These green chemical sorcerers take in water and minerals that come up from the roots and carbon dioxide that comes in from the air and using the power of sunlight in a process called photosynthesis, rearrange these molecules and convert them into the molecule called glucose. This exquisitely efficient chemical conjuring and the amazing molecules produced by it make life on this planet possible. Glucose is the fuel of life, for without it, plants would starve and perish and along with them, like a crashing house of cards, all animal life. The green finery of leaves makes animal life on this planet possible, including you dear reader.

## Angiosperm Cells and Tissues

The body of a plant or animal is organized in similar fashion. The basic building block of any creature's body is the cell. Cells are organized into tissues that perform particular functions, tissues are organized into organs, and organs are arranged into organ systems (**Figure 9.1**). When a plant embryo begins to develop, the first cells to form are meristem cells. Like animal stem cells, plant meristem cells are undifferentiated cells that can divide indefinitely and give rise to many different types of differentiated cells. Meristematic cells called *initials* remain within meristems as sources of new growth, enabling the plant to continue growing and replacing tissues throughout its life. When an initial divides by mitosis, one daughter cell remains an initial at the same location within the meristem. The other daughter cell, called a *derivative*, is pushed out of the meristem and either divides again or begins elongating and differentiating into a specific type of cell.

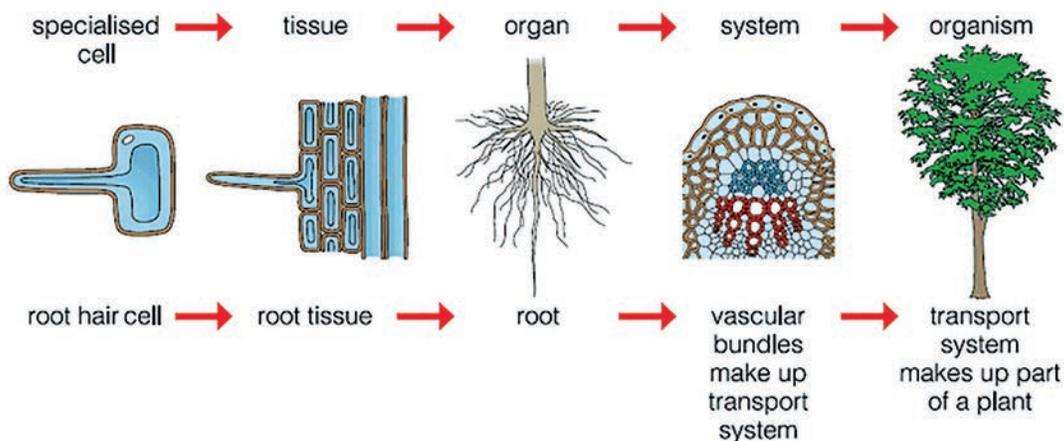


Figure 9.1

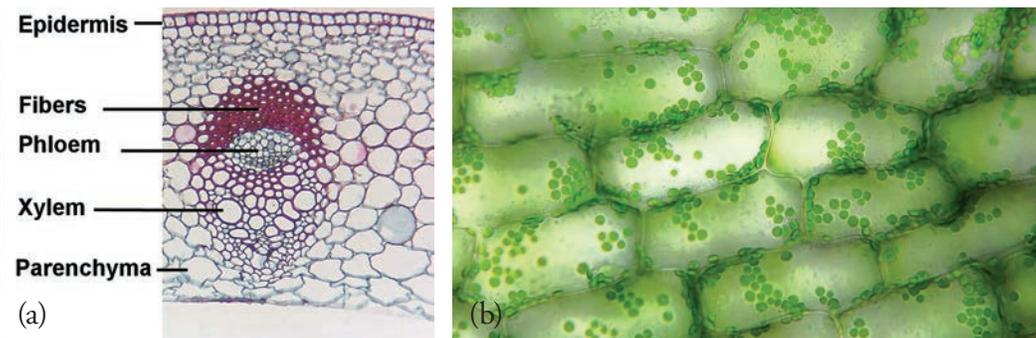
## Angiosperm Cell Types

The main types of differentiated cells that commonly occur in plants are: parenchyma cells, collenchyma cells, and sclerenchyma.

**Parenchyma cells** are the most numerous and most common type of living differentiated plant cell. They are the least specialized type of plant cell and usually undergo relatively little differentiation before become mature plant cells.

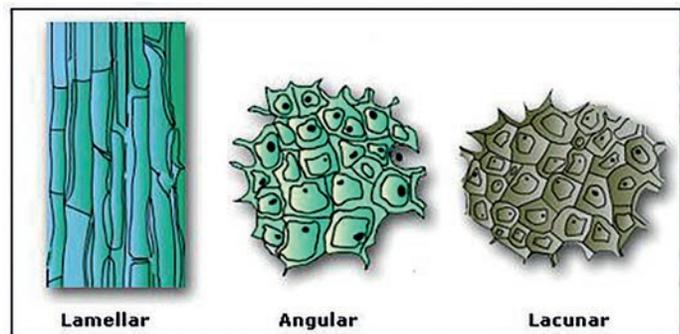
Parenchyma cells have thin primary cell walls and usually do not have secondary cell walls. Their thin cell walls enable them to grow into various shapes to fill the space available. As a result, they may be spherical, cubical, or elongated in shape. They often function to fill space or provide structure to parts of the plant that are often frequently replaced, such as leaves.

Besides serving as space-fillers and structural components, parenchyma cells also serve other purposes such as carrying out photosynthesis as well as food and water storage in roots, stems, and leaves. Specialized parenchyma cells that carry out photosynthesis are called *chlrenchyma cells* (**Figure 9.2**).



**Figure 9.2** Parenchyma Cells. (a) Stem cross-section showing large, thin-walled parenchyma cells used for storage of food and water and (b) Chlrenchyma cells showing chloroplasts within.

**Collenchyma cells** function mainly to provide flexible support. Collenchyma cells have mainly thin primary cell walls and are usually elongated but can grow into various shapes because they are alive at maturity and lack secondary walls. Unlike parenchyma cells, however, some collenchyma cells have primary cell walls that are thickened in some places by additional cellulose. Parenchyma and collenchyma cells provide flexible support as they become swollen or enlarged with water or **turgid**. There are three types of collenchyma cells based on where thickening of the cell wall occurs: lamellar, angular, and lacunar (**Figure 9.3**). In lamellar collenchyma, thickening occurs at the inner and outer tangential cell walls whereas thickening only in the corners is found in angular collenchyma while in lacunar collenchyma cell walls facing the cavity lumen or intracellular spaces are thickened. The additional

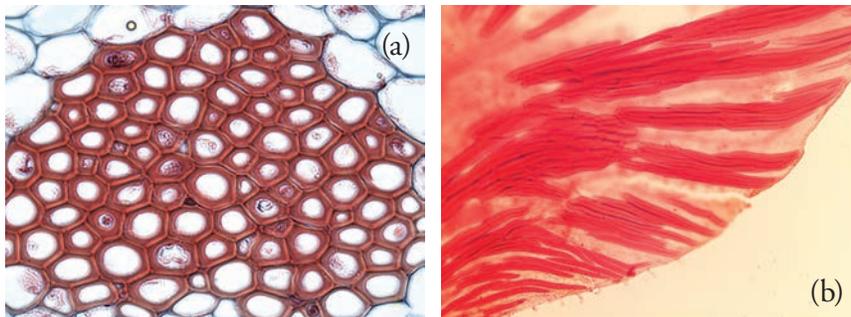


**Figure 9.3** Types of collenchyma cells

thickenings in the cell walls at various spots enable collenchyma cells to provide more support than parenchyma while remaining somewhat flexible.

**Sclerenchyma** cells have secondary walls often hardened with lignin and thus provide rigid support. Also unlike parenchyma and collenchyma cells, sclerenchyma cells are typically dead at maturity. They provide structural strength in regions of the plant that have stopped growing in length and no longer need to be flexible.

There are two main types of sclerenchyma cells: fibers and sclereids. *Fibers* are elongated cells with thick lignin-reinforced secondary walls. Usually occurring in groups (think cables), they enable stems to move in the wind without snapping. *Sclereids*, often called stone cells, are either elongated, cubical, or star-shaped and make structures such as nutshells and fruit pits rock-hard and inflexible (**Figure 9.4**).



**Figure 9.4** Sclerenchyma Cells. (a) Cross-section of fibers. This view is equivalent to looking at the end of a cable. Note the great thickness of the cell walls of the fibers compared to the thin-walled parenchyma cells surrounding them. (b) Long tapering sclereids supporting a leaf edge.

### *Angiosperm Tissue Types*

Botanists distinguish between two types of tissue: simple and complex. *Simple tissue* is composed of only one type of cell whereas a *complex tissue* is composed of several cell types, such as a mixture of parenchyma, sclerenchyma, and vascular cells. In vascular plants, various simple and complex tissues are organized into three types of *tissue systems* that are continuous throughout the plant: the dermal tissue system, the vascular tissue system, and the ground tissue system, all of which originate from meristematic cells (**Figure 9.5**).

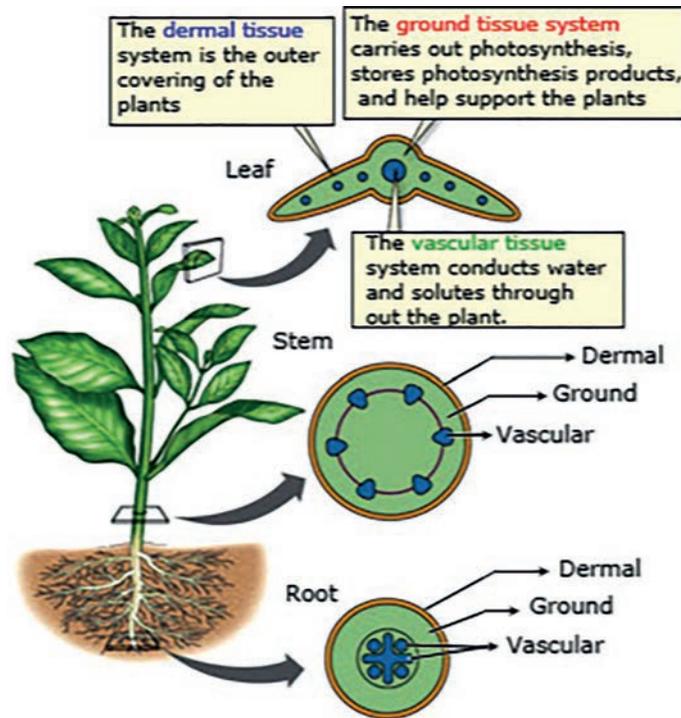
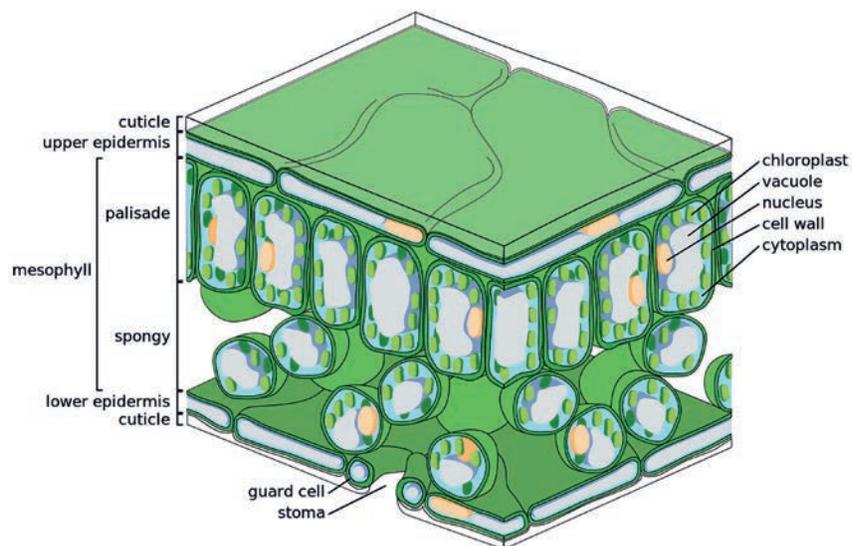


Figure 9.5

**Dermal Tissue System** The dermal tissue system is the thin protective outer covering of herbaceous and young woody plants. Dermal tissue consists of several layers of modified parenchyma cells called the *epidermis* (Gr. *epi*, over + *dermis*, skin) that function to protect the plant from physical damage and desiccation (drying). To control water loss, many plants stems and leaves produce a **cuticle** (Figure 9.2), a clear layer of wax and a fatty substance called *cutin* covering the epidermis (**Figure 9.6**). In woody plants, the epidermis of the stem and roots is replaced by a protective tissue known as *periderm* that consists of nonliving cork cells that protect the plant from physical damage and water loss.



**Figure 9.6** A section of plant leaf showing a layer of translucent cuticle over both the upper and lower surfaces. The epidermis consists of a single layer of flattened jigsaw puzzle-shaped cells.

Dermal cells can become modified into hair-like projections on the roots (root hairs) and the leaves (*trichomes*). Trichomes help shield the plant from excess sun and moisture loss and discourage herbivory (plant eating) (**Figure 9.7**).



**Figure 9.7** Epidermal Hairs. (a) Root hairs and (b) Scanning electron microscope image of the upper surface of a jasmine tobacco (*Nicotiana glauca*) leaf showing trichomes, epidermal cells, and tiny stomates (eye-like slits).

**Vascular Tissue System** The vascular tissue system is a continuous system of tubes and channels that serve to transport water and minerals from the roots to the leaves and move sugars and other organic nutrients (food) from the leaves to the rest of the plant. There are two types of vascular tissue: xylem and phloem. **Xylem** transports water and minerals from the roots up to the leaves, and **phloem** moves food from the leaves downward to other parts of the plant including the roots. In the roots, the vascular tissue is located in the *vascular cylinder*; in the stem, it forms *vascular bundles*; and in the leaves, it is found in *leaf veins* (Figure 9.5).

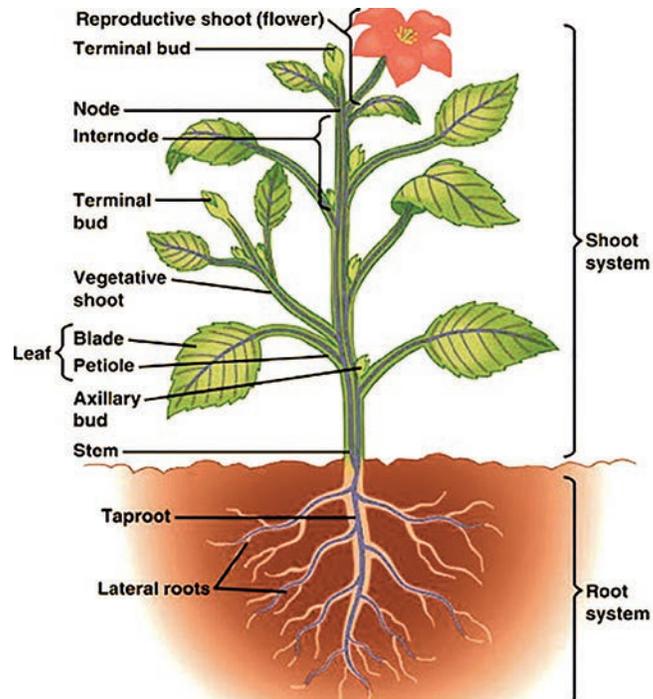
**Ground Tissue System** The ground tissue system consists of all the tissue other than the dermal tissue system and the vascular tissue system. Although parenchyma dominates, ground tissue also contains collenchyma and sclerenchyma cells. Ground tissue functions to carry out photosynthesis, store food, provide support and protection, and fill up any spaces not occupied by either dermal tissue or vascular tissue. Usually, ground tissue forms between the dermal and vascular tissues where it is known as *cortex*. However, it sometimes also appears to the inside of the vascular tissues, where it is called *pith*.

**Table 9.1**  
*Tissue Systems, Tissues, and Cell Types*

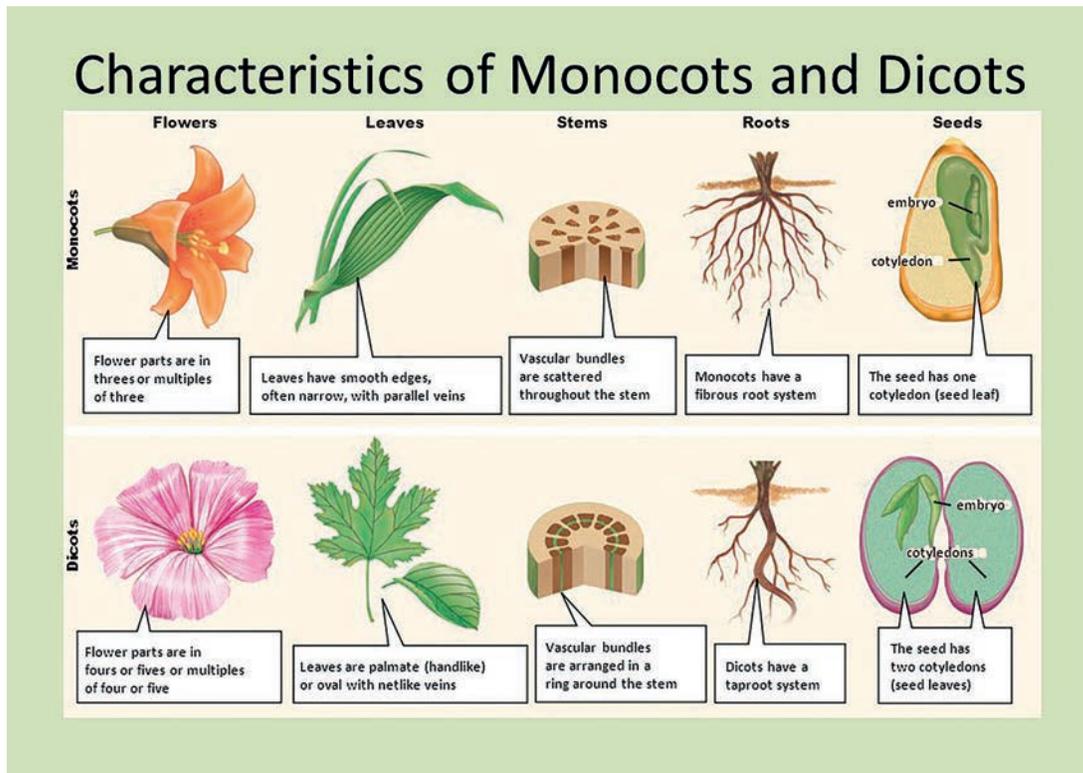
Tissue Systems	Tissues	Cell Types	Location	Main Functions of Cell Types
<b>Dermal</b>	Epidermis	Parenchyma and modified parenchyma	Outer layer of herbaceous plants	Protection; prevention of water loss
	Periderm	Cork and parenchyma	Outer layer of woody plants	Protection
<b>Ground</b>	Parenchyma	Parenchyma	Throughout the plant	Photosynthesis; food storage
	Collenchyma	Collenchyma	Beneath stem epidermis near vascular tissues; along veins in some plants	Flexible support in primary plant body
	Sclerenchyma	Fiber	Throughout the plant	Rigid support
		Sclerid	Throughout the plants	Rigid support and protection
<b>Vascular</b>	Xylem	Tracheid	Xylem of angiosperms	Conduct water and dissolved minerals
		Vessel Element	Xylem of angiosperms	Conduct water and dissolved minerals; support
	Phloem	Sieve-tube member	Phloem of angiosperms	Conduction of food and other organic molecules
		Companion cell	Phloem of angiosperms	Metabolic support for sieve-tube members

### Angiosperm Vegetative Organs

As plants evolved ever greater amounts of vascular tissue and began to live on land, vegetative organs (all plant parts except reproductive structures) developed to facilitate living in drier environs (**Figure 9.8**).



**Figure 9.8** The body of a plant consists of a root system and a shoot system. New branches, leaves or flowers develop from buds. The root system is connected to the stem system by vascular tissue (blue) that extends from the roots to the leaves.



**Figure 9.9** Flowering plants are either monocots or eudicots (dicots). Six morphological and anatomical features distinguish the two groups: number of flower parts, leaf venation, arrangement of vascular bundles in the stem, arrangement of roots, and the number of cotyledons in the seed. Additionally, monocots produce pollen with only one pore/slit whereas eudicots (dicots) produce pollen with three pores/slits.

There are morphological and anatomical differences in the vegetative organs of plants. Based on those differences, angiosperms may be divided into two groups: monocotyledons (monocots) and eudicotyledons (eudicots) (formerly monocotyledons [monocots]) (**Figure 9.9**). The eudicots are by far the largest group and include some of the most familiar plants—from asters to oak trees. The monocots include grasses, lilies, orchids, and palm trees, among others. Botanists recognize three basic organ systems in plants: roots, stems, and leaves.

## Roots

*To find water, a plant must position its roots with just as much precision as it does its leaves.*

—David Attenborough

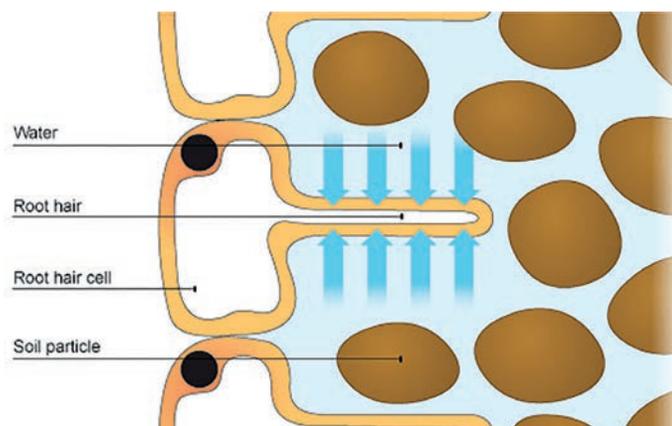
If the dark underground of Green World could by some impossible feat, be made transparent, one would be amazed at the profuse amount of plant growth and tissue hidden from our view. Branching, twining, overlapping, and even connecting, the roots of plants grow with as much vigor and riotous enthusiasm below ground as the stems, leaves, and flowers that soar above ground.

### Root Functions

In most vascular plants, the roots compose the underground portion of the plant of the sporophyte phase and as such, perform a number of vital functions: absorption, anchorage, food and water storage, and hormone production.

**Absorption** As we look out over the green carpet that covers a great deal of our planet, we are struck immediately by the intimate relationship between plants and water. Where there is no water there are no plants; the true desert areas of Earth are totally barren. All chemical reactions that take place within plant cells occur in a watery medium, and it is by means of water that all substances are transported to other parts of the plant. And although it is clear that water is only one of the many substances on which plants depend, it is the most basic and important one.

How do plants solve their water requirement problems? They do so with an intricate plumbing system that has its beginnings in the roots, where water is absorbed from the soil, continues through a complex of tubes in the stem which carry water upward to all parts of the plant, and ends with the water evaporating from the leaves into the surrounding air. Sounds simple enough, but how do roots take in the water in the first place?



**Figure 9.10** Water trapped in the spaces between soil particles diffuses into the root through the root hairs.

As we learned in an earlier chapter, molecules of gases and liquids move of their own accord from areas of high concentration to areas of low concentration through a process known as diffusion (The diffusion of water specifically is known as osmosis.). Molecules of water will diffuse from the soil (high concentration) into the plant's roots (low concentration) (**Figure 9.10**).

The gateway for water to enter the roots is through innumerable tiny hair-like growths known as root hairs (**Figure 9.11**). Root hairs can penetrate the tiniest cavities in the soil surrounding the plant, and wherever they encounter a bit of moisture, they absorb it. There are relatively few water molecules in a root hair cell but large numbers of molecules of dissolved substances. The water in the soil spaces around a plant usually contain only a small amount of dissolved minerals and many molecules of water. Thus, the concentration of water molecules is higher in the soil spaces and lower in the root hair cells. Because of this concentration difference and because the thin cell walls of root hairs are permeable to water, water moves in by osmosis.



**Figure 9.11** Root hairs are thin-walled single-celled trichomes extending from the root epidermis. They function to absorb water and mineral ions.

**Anchorage** Have you ever tried to pull a small sapling tree out of the ground? If so, you received a first-hand appreciation of the fact that roots tenaciously cling to the soil and function quite adequately as a plant's anchor.

The extent of a root system—the depth to which it penetrates the soil and the distance it spreads laterally—is dependent upon several factors, including the moisture, temperature, and composition of the soil. Typically, 50% to 90% of a plant's roots occur in the upper 30 cm (12 inches) of soil, the part of the soil richest in organic matter. Potato roots reach depths of 0.9 meters (3 feet) and grains such as wheat, barley, and oats can reach from 0.9 meters to 1.8 meters (3 to 6 feet). The taproot of alfalfa may extend to depths of up to 6 meters (20 ft) or more making it an ideal crop in dry areas of the Central Plains states.

Roots spread laterally as well, often to great distance from the plant. The roots of a 35-foot tall elm may have a radial spread of over 18 meters (60 feet) outward in all directions. The root system of corn plants often reaches a depth of 1.5 m (5 ft), with a lateral spread of about 1 meter (3.3 ft) on all sides of the plant. Even a small, herbaceous plant can have lateral roots extending outward to a radius of 0.9 meters (3 feet) around the stem. Most desert plants have shallow root systems that spread laterally rather than the more vertically oriented root systems of plants living in moist soil.

With extensive branching, the total length of all of a plant's roots can be quite large in comparison with the surface area of the aboveground portion of a plant. For instance, a single corn plant may have almost 457 meters (1,500 linear feet) of roots total. In an intensive study of the fibrous roots of winter rye, H.J. Dittmer found that one plant 51 cm (20 inches) tall, consisting of a clump of 80 shoots, had a total of 14 million roots—main roots, secondaries, tertiaries, and quaternaries. The total surface area of the root system was 372 square meters (4,000) square feet—equal to the floor space of two or three good-sized houses—or 130 times the surface area of the stems and leaves. If laid end to end, these roots would have had a length greater than the distance from New York City to Washington, D.C. or around 600 km (360 miles). Amazingly, all these roots occupied only about 6 liters (2 cubic feet) of soil. Such extensive root systems so thoroughly per-

meate the soil around them that they not only serve to secure the plant into the ground but they also become ecologically important in holding topsoil so that it does not get washed away by rains.

Once you understand and appreciate that the root system of a plant may extend deeper and further out than the plant it is attached to and that the roots can weigh as much as the stem and leaves, you will never look at plants the same way again, especially large trees.

**Food and Water Storage** Most roots are important storage organs, and some, such as those of the carrot, beet, radish, sweet potato, and sugar beet, are specifically adapted for the storage of food. Food molecules (glucose) manufactured above ground in photosynthesizing portions of the plant body move down the plant and into the storage tissues of the root where they are converted into starch and other stable carbohydrates. Sweet potatoes and yams, for example, have extra cambial cells that develop in the xylem portion of branch roots. These cambial cells produce numerous parenchyma cells that cause the organs to swell. Starches are then stored in the swollen areas of the root. Carrots, beets, and turnips have storage organs that are a combination of root and stem. The starches stored in the root may be used by the root itself, but more often they are eventually “digested” (converted) back to glucose and transported upwards through the vascular system to the above-ground parts.

Food storage occurs only in *perennial plants* (plants living three years or more) or *biennial plants*. In *biennial plants* (plants that complete their life cycle over a two-year period) such as the sugar beet and carrot, large food reserves accumulate in the storage regions of the root during the first summer. These food reserves are then used during the winter to keep the plant alive. What remains is used during the second spring to produce flowers, fruits, and seeds (**Figure 9.12**). *Annual plants* (plants that complete their life cycle in one year) have no such need for storage.

Some plants have also developed the ability to store water in their roots. Some plants in the family Cucurbitaceae—cucumbers, squashes (including pumpkins), luffas, and melons (including watermelon) produce huge water-storing roots. The plant will then use the stored water in times or seasons of low precipitation. Some cultures will harvest these water storage roots and use them for drinking water. Plants storing up to 72 kilograms (159 pounds) of water in a single major root have been found and documented.

**Hormone Production** Shoot growth and development depend on the hormones cytokinin and gibberellin produced in the roots and transported upward to the stem. Regulating stem growth and development from the root-based hormones allows for an integration of the growth processes in both systems. A plant must control the size of its shoot so that transpiration by its leaves does not exceed the absorptive capabilities of its roots. As the root system grows larger and more robust, hormonal integration allows for the export of even more cytokinin and gibberellin which, in turn, increases the growth of the shoot, and the two systems remain in balance.



**Figure 9.12** The carrot (*Daucus carota*) is a biennial plant that grows a rosette of leaves during the spring and summer, all the while building up the stout taproot that stores large amounts of sugars to power the flowering of the plant in the second year.

## Types of Root Systems

When a seed sprouts, the first organ to develop is the primary root that develops from the **radicle** that was present in the seed. The development of the embryonic root allows water to move into the seed which begins the conversion of food stored as starch back into usable food molecules of glucose. This little reserve of glucose, laid down when the seed was formed, sustains the embryonic stem and leaves until they can grow and develop sufficiently to make and transport food.

In most eudicots and gymnosperms, the primary root develops into a single prominent central *taproot*. Branching off the taproot are numerous and smaller *lateral* or *branch roots*. This pattern of root development is known as a *taproot system* (**Figure 9.13**).

Some trees, such as oak and many pines, drive massive taproots deep into the soil in the ongoing search for water and minerals, making such trees difficult to transplant. The record for depth of penetration by taproots belongs to the desert shrub mesquite (*Prosopis juliflora*) whose roots were found at a depth of 53.3 meters (over 175 feet) in an open pit mine. Plants like carrots, dandelions, beets, and radishes form shorter, fleshy taproots that function as food storage organs.

All monocots and some eudicots have a large mass of similarly sized and highly branched roots forming a *fibrous root system* (**Figure 9.14**). Fibrous root systems spread out in all directions. A botanist calculated the root length of a 2-year old couch grass (*Agropyrum cristatum*). Its fibrous root system had a total length of 500 km (310 mi), occupying a soil volume 2 m (6.6 ft) deep with a range of 1.2 m (4 ft) around the plant.

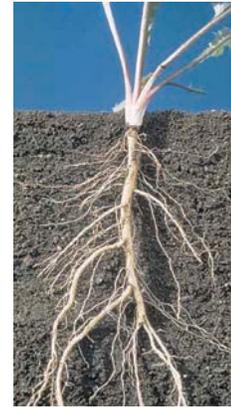
### Specialized Roots

The main functions of roots are to absorb, anchor, and store food. However, in many plants, roots have been modified through evolution to serve a number of other plant needs:

**Storage roots** These are thickened roots that accumulate nutrient molecules in large amounts. Storage roots may be categorized as fleshy—carrots, ginseng, and sugar beets—or tuberous—sweet potato, cassava, and yam.

**Aerial roots** Ivy and some other types of vines produce a type of adventitious root known as an *aerial root* to help them cling to objects such as walls and provide support for their climbing stems.

**Prop roots** and **buttress roots** Some modified roots provide additional support, stability, or anchorage for a plant. These are aerial roots that arise from a stem and subsequently grow into the soil. Among these are the prop roots grown by corn and *Ficus* (**Figure 9.15**).



**Figure 9.13** The central taproot and accompanying lateral roots of a dandelion (*Taraxacum*) plant.



**Figure 9.14** The network of roots in a fibrous root system does not arise as branches off the primary root but consists of many branching roots that arise from the base of the stem.



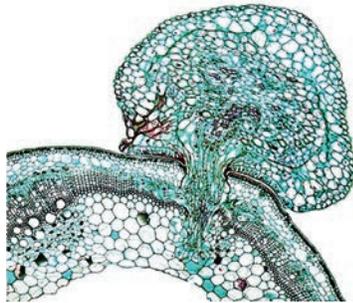
**Figure 9.15** Prop Roots. (a) Corn (*Zea mays*) prop roots stabilize the plant vertically; (b) Banyan tree (*Ficus benghalensis*) prop roots function as support pillars making it possible for the branches to extend horizontally great distances.

Providing support on a larger scale are *buttress roots*. Buttress roots are flared roots that extend outward from tree trunks in a fashion similar to the buttresses supporting the walls of medieval cathedrals. Some tropical trees develop huge buttress roots that help stabilize them in thin tropical soils (**Figure 9.16**).



**Figure 9.16** Buttresses are tension elements being larger on the side away from asymmetrical canopies.

**Haustorial roots** Haustorial roots are found on plants known as **epiphytes** (Gr. *epi*, upon + *phyton*, plant) that grow on other plants.



**Figure 9.17** Cross-section of a dodder plant (top) growing a haustorial root into the vascular tissue of a host plant.

Some epiphytes such as orchids have haustoria that secrete a kind of cement. The orchids take in no nourishment from their unintended hosts. Instead, they absorb the water they need directly from the moist air of their steamy rainforest habitat, and they fulfill their mineral requirements from leaves that fall and decompose near their roots. Other epiphytes are parasites that produce haustoria that grow into the stems (Dodder [*Cuscuta europaea*], mistletoe [Santalales]) or roots (Yellow rattle [*Rhinanthus*], Western Australian Christmas tree [*Nuytsia floribunda*]) of other plants where they siphon off water, minerals, and food (**Figure 9.17**).

**Box 9.1*****A Plant that Grows Roots into Itself?***

*Dischidia rafflesiana*, known commonly as the “flower pot plant” or the “ant plant,” is an epiphyte found in tropical habitats in China, India, and most areas of Indonesia. Some of its leaves are flattened and succulent (fleshy), but others develop into large, hollow pods (“flower pots”) (**Figure 9.18**).

These “pots” are structured in such a way as to allow them to collect organic debris and rainwater. Ants also find the hollow pots suitable living quarters and establish a thriving colony inside (hence their other common name “ant plant”). The activities of the ants along with the collecting organic debris from a rich source of needed minerals that the plant taps in a very unusual manner. Roots, formed at the node above the pot, grow downward *into* the pot, from which they absorb vital water and minerals. Very strange—a plant that grows roots down into itself to secure minerals from insect frass and dead bodies and decaying organic debris within it.



**Figure 9.18** *Dischidia* pots with one pot having been cut open to reveal the roots.

***Root Structure***

Roots have three major zones: the *meristematic zone*, the *elongation zone*, and the *maturation zone* (**Figure 9.19**). The tip of the root is an active growth zone known as the *apical meristem*. The fragile cells of the apical meristem are protected by a thick layer of cells known as the *root cap*. At the microscopic level, all soils contain sand grains, organic debris and other components that could easily damage the delicate apical meristem. The thick root cap provides a thick, protective barrier between the soil and the apical meristem. As the root grows downward, the root cap is constantly worn away by friction with soil particles and must be replaced by cells rapidly replicating at the base of the root cap.

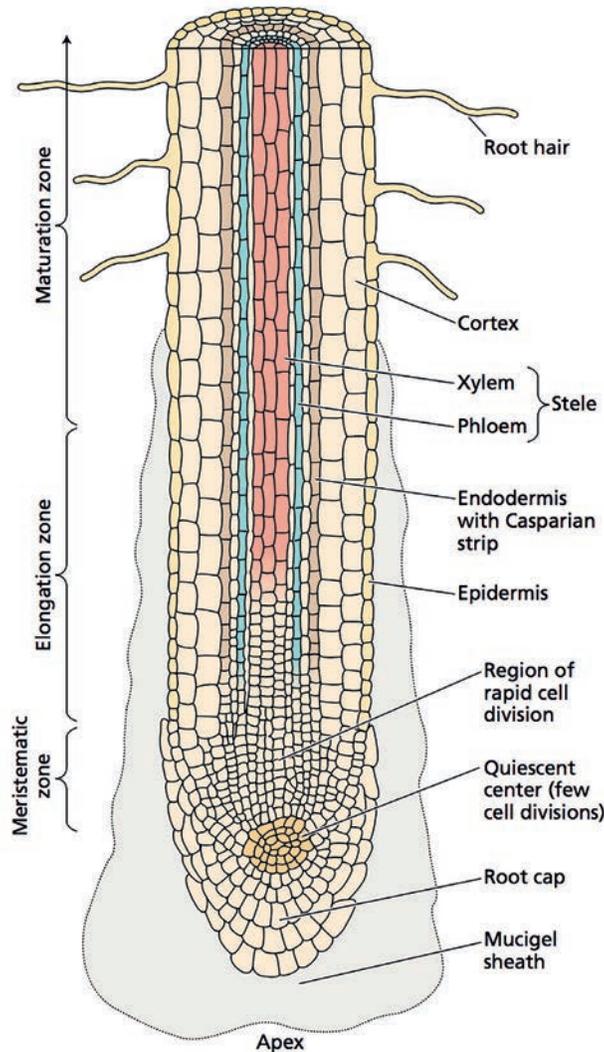


Figure 9.19

Root cap cells secrete a complex polysaccharide called *mucigel*, which helps lubricate the growth of the root through the soil matrix. Mucigel also causes the soil to release its nutrient ions permitting the ions to diffuse more rapidly toward the root. Furthermore, carbohydrate- and amino acid-rich mucigel foster the growth of soil bacteria around the root. The metabolism of these bacteria is believed to help release nutrients from the soil.

Above the meristematic zone is the *elongation zone*, a region in which many thread-like epidermal cells (root hairs) extend outward a short distance from the root. The multitude of root hairs increases the root's surface area permitting greater opportunity for absorption.

As the root tip grows downward, the elongation zone follows. The areas of root left behind lose their root hairs, mature, and become the maturation zone. Lateral roots (also known as branch roots or secondary roots) emerge in rows or randomly distributed on the parent root in the maturation zone. The amount of lateral root growth in a plant is often dependent on the microenvironment of the soil in which it grows. If

the parent root grows into rich, moist soils, numerous lateral roots will form, but if the soil is poor, hard, or dry, few if any lateral roots will form.

A root cut in cross-section (horizontally) reveals that internally the tissues of mature roots can be divided into three types: *epidermis*, *cortex*, and *vascular cylinder* (**Figure 9.20**).

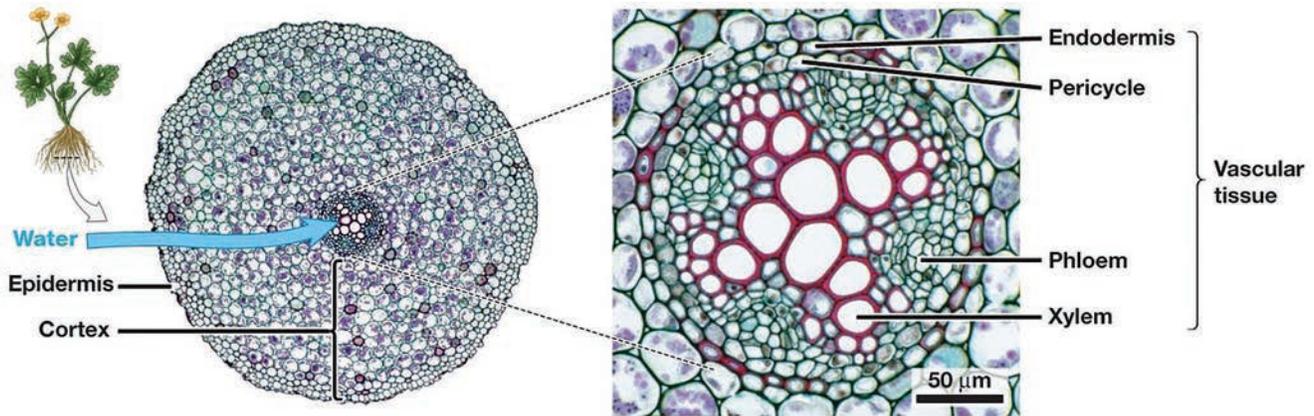


Figure 9.20

**Epidermis** The epidermis is a thin outer layer of cells that take in water and nutrients through **root hairs**. Root hairs are simple unbranched tubes with rounded ends produced as outgrowths of the epidermal cells in the elongation zone.

**Cortex** Just inside the epidermis is a thick layer of large loosely packed parenchyma cells known as the **cortex**. Much of the bulk of the root is cortex, and these thin-walled cells serve as the path across which water and minerals pass as they progress from the outside of the root toward the vascular cylinder in the center of the root. As roots mature, a considerable amount of starch (stored food) usually accumulates in the many intercellular spaces of the cortex.

At the inner boundary of the cortex is a single layer of cells known as the *endodermis*. The endodermis wraps the vascular cylinder and stretches up and down the entire length of the root. Water and nutrients entering the epidermis pass into the cortex cells and move easily through and around them.

Each endodermis cell is surrounded on four sides by a waterproof strip called the *Casparian strip*. Visualize a brick with a thick, sticky rubber band wrapped around its middle. The strips around the individual cells touch each other and stick together like the mortar between the bricks in a wall (**Figure 9.21**). The Casparian strips are not permeable to water. Thus water and nutrients cannot move around the endodermis cells, only through them. Endodermal cells use active transport to pump dissolved nutrients into the vascular cylinder. As these dissolved nutrients build up inside the vascular cylinder, water moves through the endodermal cells by osmosis to equalize the relative concentration of water molecules in the tissues. This active transport of nutrients coupled with the osmosis of water and the sealing of the spaces between endodermis cells by the Casparian strip results in a one-way flow of water and nutrients into the vascular cylinder.

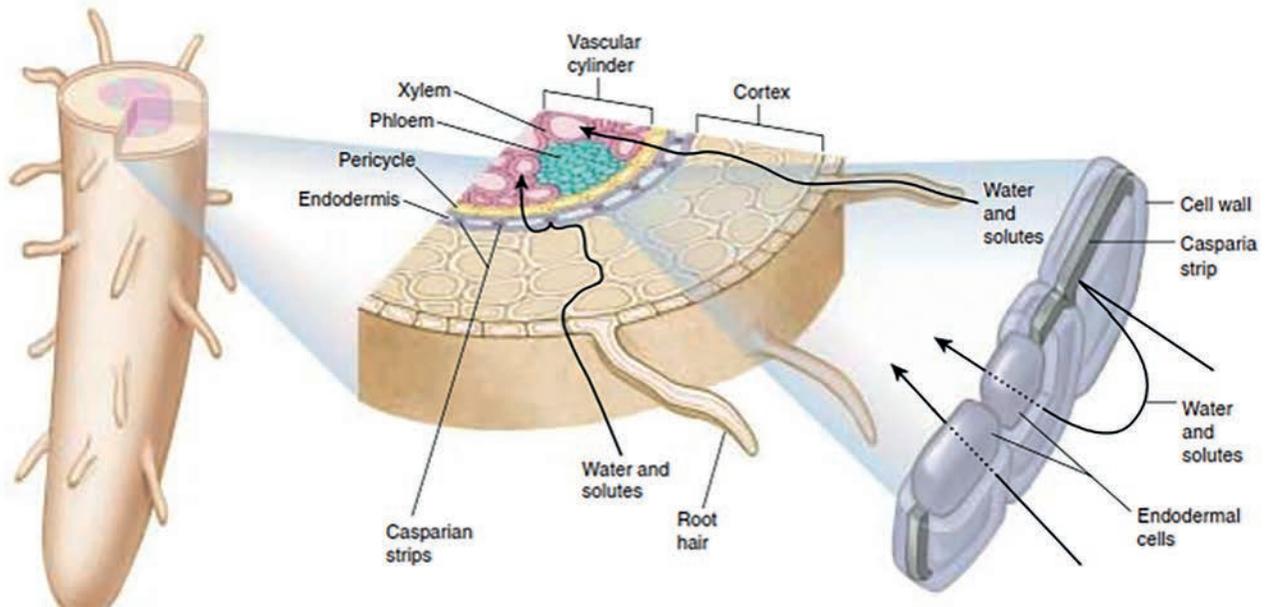


Figure 9.21

**Vascular Cylinder** The vascular cylinder (fluid-conducting tubes) is divided from the cortex and completely surrounded by one to several layers of cells called the *pericycle*. The pericycle plays several important roles. In most seed plants, lateral roots arise from the pericycle, and in those whose roots undergo secondary growth, such as woody eudicots, the pericycle gives rise to covering and vascular tissues (**Figure 9.22**).

The center of the vascular cylinder is occupied by tube-like cells of two types: xylem which conducts water and minerals up the root and into the stem and phloem which conducts food molecules down from the leaves and into the root. Collectively the xylem, phloem, pericycle, and endodermis at the core of a root are called the *stele*. As more nutrients are pumped into the vascular cylinder, more molecules of water follow. Because neither can move back into the cortex, pressure known as **root pressure** builds up inside the vascular cylinder. This increased pressure forces water into the xylem. As root pressure in the vascular cylinder forces more water into the xylem, and as more and more water moves from the cortex into the vascular cylinder, the water in the xylem is forced upward into the stem. In short plants such as grasses and strawberries, root pressure alone is sufficient to push water all the way up from roots to leaves. In tall plants such as trees, however, root pressure alone is not enough to move water from the roots into the leaves and as we will see later, additional forces come into play.

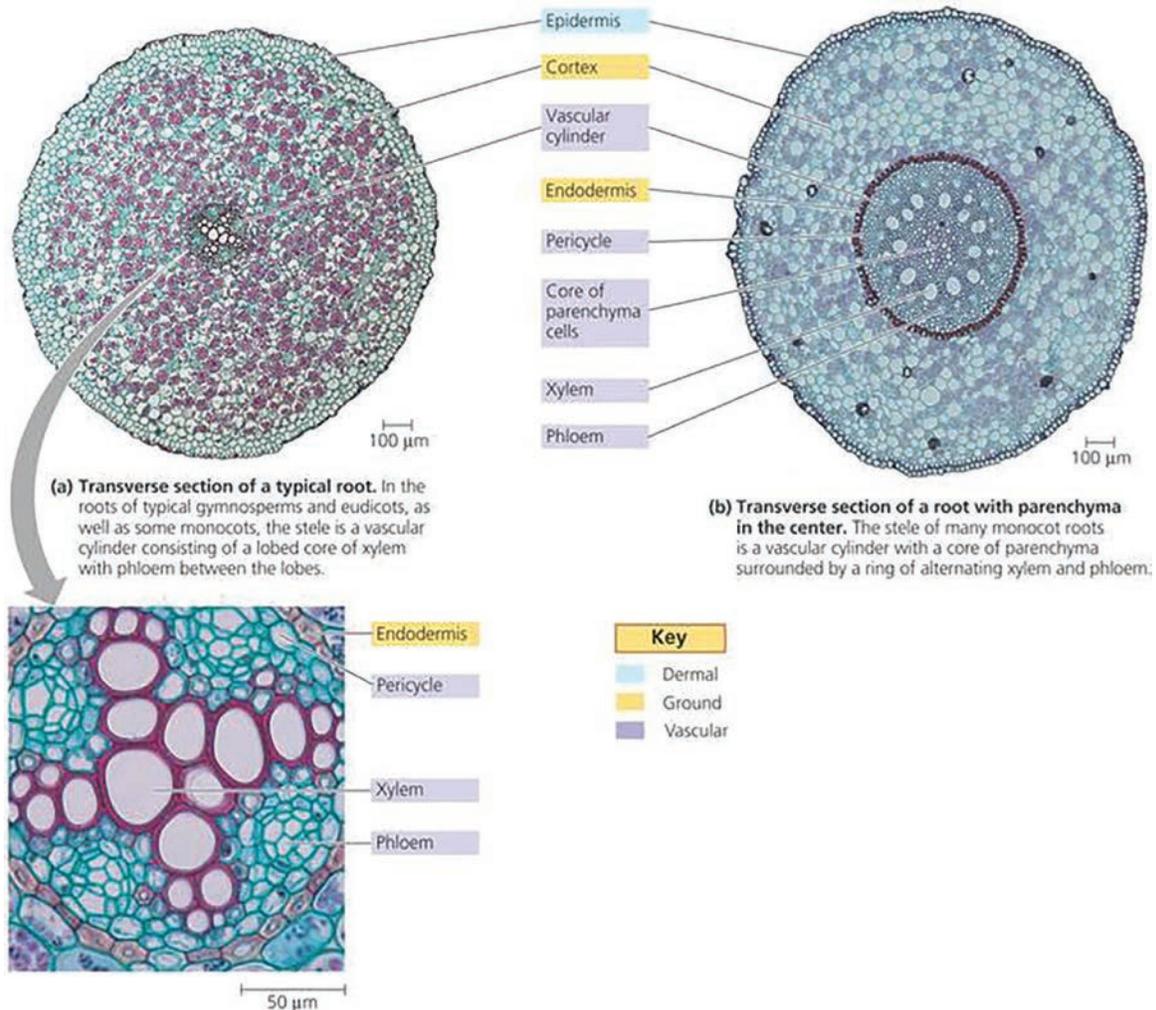


Figure 9.22 Although monocot and eudicot roots contain the same primary tissues, the arrangement of those tissues varies greatly between the two.

## STEMS

*Knowing trees, I understand the meaning of patience. Knowing grass I can appreciate persistence.*

—Hal Borland

The citizens of Green World drape and display their finery of leaves and flowers across support structures known as stems. Stems come in a wide variety of forms varying from the soft, spongy stalks of aquatic plants to the hard, towering trunks of giant forest trees hundreds of feet tall. Some stems even grow underground.

### *Stem Functions*

Regardless of their size, structure, and shape, all stems perform three basic functions: support of the plant and uplift of leaves and reproductive structures, transporting fluids between leaves and roots, and food storage.

**Support and Uplift** A stem is the vertical axis of a plant's shoot system. It produces and carries leaves and flowers and supports the plant's weight. Unlike animals which are supported at the organ/organ system level, plants are supported at the cellular level. The cell walls of each of billions to trillions of cells meshed together side-by-side, front-to-back, and top-to-bottom combined with the turgor pressure within each cell hold the plant firmly but flexibly upright.

In low-growing plants and those adapted for a horizontal life such as vines and creepers, vertical support by the stem is a nonissue. However, in the majority of plants, it means survival itself.

**Fluid Transport** Fluid flow in plant stems happens in two different directions simultaneously. Water and minerals absorbed into the roots move upward to the leaves where they are needed for photosynthesis. At the same time, food in the form of carbohydrates is moving downward from the leaves to supply the stem and roots with energy.

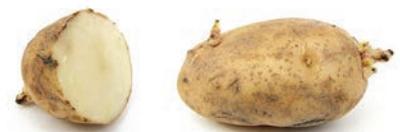
Fluids in plants move through the *vascular system*, a series of tubes, channels, and openings that form a continuum throughout the plant from roots to stem to leaves and back again. The vascular system is composed of two types of tissue: xylem (Gr. *xylon*, wood) that conduct water and minerals upward from the vascular cylinder of the roots to the leaves, and phloem (Gr. *phloos*, bark) that transports carbohydrates (food) downward from the leaves to the stem and roots. Fluid transport in plants will be more completely detailed in a later chapter.

**Food Storage** Most plants have stems that are adapted to store some food but in others, which are highly modified, such as the potato, onion, and tulip, food storage is a major function. In order to survive **dormancy**, plants often store food in their stems during their growth period. During dormancy a plant's growth and activity slows or stops. Dormancy occurs during cold winters or long dry periods that may last for months or even years. When conditions once again support activity, the dormant plant begins to grow, using food previously stored until new growth can begin to produce enough food. Several kinds of modified stems are used by plants for this purpose: rhizomes, tubers, bulbs, and corms.

- *Rhizomes* are thick, fleshy, creeping stems that usually grow horizontally along or just beneath the surface of the soil. Along the length of the rhizomes are buds from which leaves and stems can grow. When frost kills the above-ground portion of the plant, the rhizomes survive and slumber on until they burst forth with new growth in the spring. Garden plants such as irises, canna lilies, and many species of grasses are examples of angiosperms with rhizome stems (**Figure 9.23**).
- *Tubers* are modified underground stems that are swollen with stored food, usually in the form of starch. Tubers have one or more prominent "eyes," which are actually lateral (side) buds. New above-ground stem and leaves grow from these buds. The potato is an example of a well-known tuber (**Figure 9.24**).

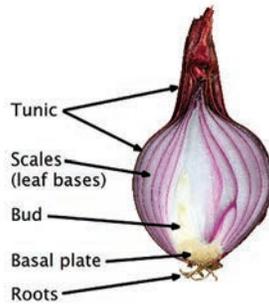


**Figure 9.23** The horizontal rhizome of an iris (Iridaceae).



**Figure 9.24** Potato tubers with sprouts growing from lateral buds called sets or "eyes" as they are commonly known.

- *Bulbs* are underground stems with the small stem at the center of the bulb. Most of the food stored in this type of stem is located in the layers of short, thick leaves that wrap around and protect the stem. The onion, tulips, and daffodils are examples of angiosperms with bulbous stems (**Figure 9.25**).



**Figure 9.25** Cutting through an onion reveals a bud wrapped in leaf scales. The leaf scales are food reserves to help the plant survive through the first stages of growth. Growth of the bud occurs from the basal plate.

- *Corms* have a swollen stem base that is modified into a mass of storage tissue. A corm does not have visible storage rings when cut in half. This distinguishes it from a true bulb. Unlike bulbs in which nutrients are stored in fleshy leaves, corm store food in the stem rather than the leaves. The corm contains a basal plate (bottom of the bulb from which roots develop), a thin tunic and a growing point. Examples of plants that develop from corms include gladiolus, crocus, and autumn crocus (**Figure 9.26**).



**Figure 9.26** The corm of a gladiolus. Roots coming off the corm can be seen as can bulblets around the edge of the corm. Developing from lateral buds, bulblets can grow into a new plant.

### ***Stem Structure***

Based on differences in morphology and anatomy, stems may be categorized as herbaceous monocots, herbaceous eudicots, or woody eudicots.

**Herbaceous Monocot Stems** Herbaceous stems are the standard form for most monocots and some eudicots. The stems of herbs are relatively smooth being covered by a thin epidermis, green (some photosynthesis occurs there), and pliable. Herbaceous stems contain no secondary (lateral) growth cells (**cambium**) and while herbaceous stems do contain coarse sclerenchyma fibers that aid in support, they lack the thick-walled

*secondary xylem* (wood) of woody stems. As a result, herbaceous stems usually do not grow very large in either height or width.

An herbaceous stem is normally divided into nodes and internodes; the *nodes* hold buds which grow into one or more leaves, inflorescence (flowers), and secondary branches. The *internodes* distance one node from another (Figure 25.10).

The anatomy of an herbaceous monocot stem is best exemplified by examining such a stem in cross-section (Figure 9.27). The outermost tissue is a single layer of *epidermis*. The epidermis may exude a thin waxy layer known as the *cuticle*. The cuticle may give the monocot stem a polished, glossy look and is thought to function as a mechanical barrier to soil, bacteria, viruses, and fungi and as a permeability barrier to water and other molecules. Beneath the epidermis are two or three layers of fibrous *sclerenchyma* cells for support. Large balloon-like *parenchyma* cells packed with stored food fill the interior of the stem in a region known as the *pith*. Scattered throughout the parenchyma are the vascular bundles. The vascular bundles are composed of both xylem and phloem tissue. The large tubes in the bundle are the xylem tissue while the smaller tubes are the phloem tissue. The first-formed xylem cells usually collapse as a result of lateral and vertical stresses during growth, leaving a large air space. The functioning xylem consists of two large vessels and several smaller vessels between them. The phloem consists only of sieve tubes and companion cells. The entire bundle is enclosed in a *bundle sheath* of *sclerenchyma* fibers.

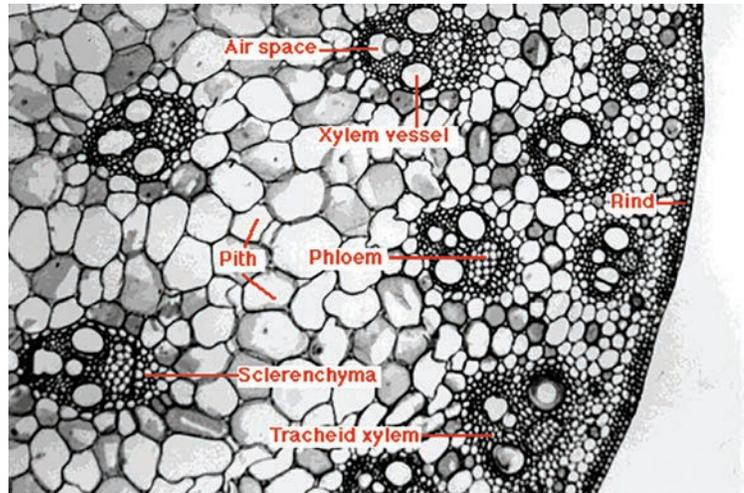
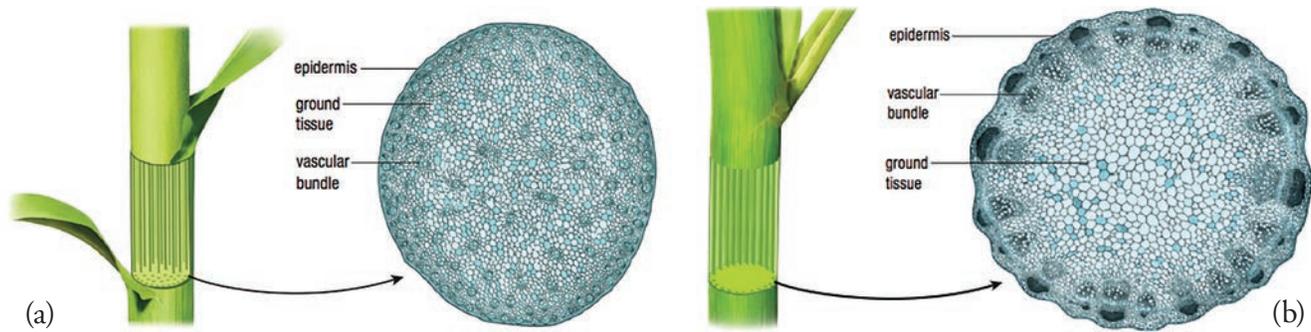


Figure 9.27 In herbaceous monocot stems the vascular bundles are scattered throughout the stem.

Three parts of the outer stem—the subepidermal band of *sclerenchyma* fibers, the thick-walled *parenchyma* cells, and the sheath around each of the vascular bundles—form an area known as the *rind*. It is the structural components within the rind which provide support and enable the mature corn stem to resist winds and the stresses produced by the weight of leaves and ears.

Three parts of the outer stem—the subepidermal band of *sclerenchyma* fibers, the thick-walled *parenchyma* cells, and the sheath around each of the vascular bundles—form an area known as the *rind*. It is the structural components within the rind which provide support and enable the mature corn stem to resist winds and the stresses produced by the weight of leaves and ears.

**Herbaceous Eudicot Stems** Some eudicots, such as alfalfa (*Medicago sativa*), the buttercups (*Ranunculus sp.*), and the sunflower (*Helianthus annuus*) have mature herbaceous stems that closely resemble those of young woody eudicots and conifers. The vascular tissues of herbaceous eudicots may be arranged in bundles, or they may appear as continuous layers. The vascular bundles of herbaceous eudicots are usually arranged in circular fashion to the outside of the stem (Figure 9.28). Each vascular bundle contains both xylem and phloem, with the xylem toward the center of the stem and the phloem towards the outside. This ring of vascular bundles surrounds a central area of pith (parenchyma cells). To the outside of the vascular bundles lies the cortex consisting mainly of *parenchyma* cells and often fibers. The outermost layer is the *epidermis*. In some herbaceous eudicots, supportive *sclerenchyma* or *collenchyma* cells and fibers may be found beneath the *epidermis*.



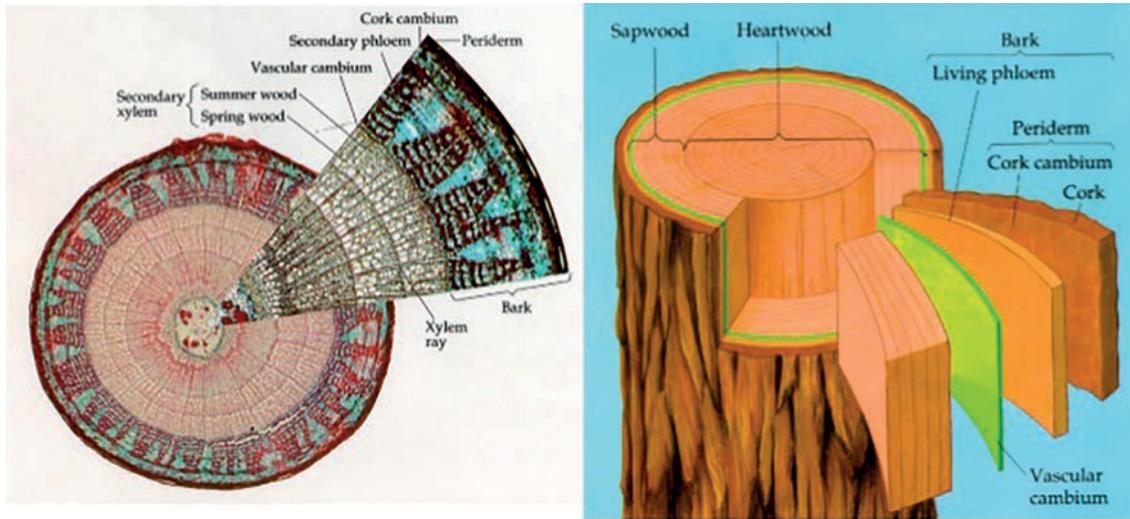
**Figure 9.28** Herbaceous Stems. (a) An herbaceous monocot stem and (b) An herbaceous dicot stem. The major difference between these two types of stems is the placement of the vascular bundles.

Unlike herbaceous monocot stems, vascular cambium is found in herbaceous eudicot stems where it exists as either a continuous layer or is confined to the vascular bundles. The most notable difference between woody and herbaceous eudicots is the amount of activity of the vascular cambium and the length of that activity. The vascular cambium of woody eudicots is quite active producing much secondary xylem tissue (wood) perennially. Many herbaceous eudicots, however, are annuals so their vascular cambium never lives long enough to reach its potential.

**Woody Eudicot Stems** Woody stems have evolved independently in various divisions of the plant kingdom in the past. Today, however, only three divisions of gymnosperms and eudicot members of phylum Anthophyta possess woody stems.

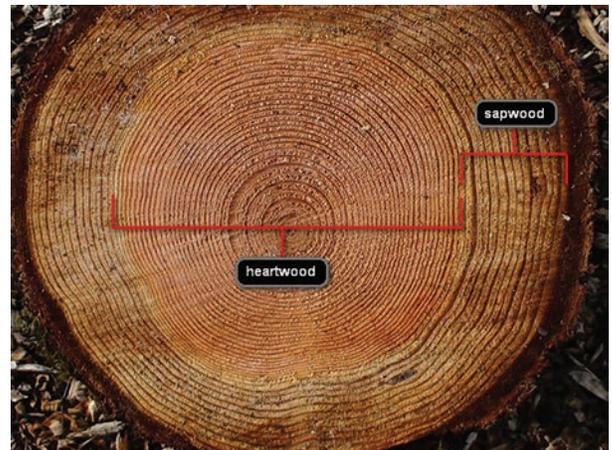
The anatomy of young woody stems resembles that of herbaceous eudicot stems initially. As the woody eudicot stem develops, however, significant differences between the two types of stems begin to appear. The main difference is that herbaceous eudicot stems are composed entirely of primary tissues—epidermis, ground tissue, and vascular tissue—that are formed each year from the primary (apical) meristems. Woody eudicot stems, however, have both primary and secondary tissue. Secondary tissues develop during subsequent years of growth from secondary (lateral) meristems, forming the vascular cambium and cork cambium. Secondary growth apically (height) and laterally (width) allows woody eudicot stems to live for many years and reach amazing heights and girths.

In temperate woody eudicots and conifers, secondary tissue growth is added annually to the original primary tissues (**Figure 9.29**). Secondary xylem produced by the vascular cambium is laid down outside the primary xylem; the secondary phloem is added to the inner side of the primary phloem. The vascular cambium continues to form secondary xylem (wood) and secondary phloem (bark) year after year and thus functions as a lateral meristem resulting in increased diameter of the stem.



**Figure 9.29** The anatomy of a woody eudicot stem seen in cross-section (left) and longitudinal view (right).

The amount of secondary phloem produced annually is far less than that of secondary xylem until secondary xylem (wood) forms the major interior mass of a woody stem. The wood of temperate trees is characterized by the presence of concentric layers known as **annual rings**. Each ring represents wood formed during a single growing season. Each growth ring consists of an inner layer, the *springwood* and an outer layer, the *summerwood* (**Figure 9.30**). The cells of springwood, formed early in the growing season, may differ from the cells of the summerwood in kind, arrangement and size, and in thickness of the cell walls. In the spring, when water is usually more abundant, the cells known as springwood are larger with relatively thin cell walls compared to those summerwood cells produced during the late summer or fall. These differences result in springwood being easily distinguished from summerwood by the unaided eye. Since each ring typically represents one growing season, in temperate regions the age of a tree can be determined by counting the annual rings. In those areas that have two rainy seasons per year, two growth rings form, but trees in some tropical regions lack clearly visible growth rings because growth continues evenly year-round. In reality, each ring is a cross section of a hollow cone that encloses all the previously formed wood of the entire tree, not only of the trunk and branches but of the roots as well. As the tree increases in height, it tapers from a considerable girth at the base to the diameter of twigs at the top. The age of a tree may be determined by counting the rings on the cut surface of the wood but to be reasonably accurate as this count must be made on the surface of stump as close as possible to the soil level, for counts made higher up the tree will only give the age at the level the counting is done.



**Figure 9.30** Sapwood is composed of living xylem that is actively transporting water and minerals (sap) up to the branches. Heartwood is composed of dead xylem (wood) that no longer conducts sap.

The width of individual rings varies greatly, and much effort has been spent in attempts to correlate these differences with variations in the environment. Among the environmental factors are light, temperature, rainfall, soil moisture, length of growing season, and competition. In general, when the environment is favorable, the rings are wide; when unfavorable the rings are narrow (**Figure 9.31**).



**Figure 9.31** The annual growth rings of a newly-logged tree. Note the very narrow ring between year 7 and year 8 as compared to years 1-5. What might account for this narrow ring?

### Box 9.2

#### *Life Within the Rings*

Have you ever looked down at a large stump or at the end of a large sawed limb? Perhaps you have examined sections of trees in a museum with the growth rings correlated to historical events, such as the signing of the Declaration of Independence. If so, you have seen tree growth rings. A surprising amount of information can be gleaned from studying these rings and a number of highly specialized fields of botany have developed around the study of tree growth rings:

*Dendrochronology* (*dendron*, tree + *chronos*, time + *logos*, to study) is the science of using growth rings to determine the age of a given stem.

*Dendroarchaeology* is the science of that uses tree rings to date when timber was felled, transported, processed, or used for the construction of wooden artifacts. Study of the growth rings of living trees and of beams from buildings of increasing age, the pueblos of Arizona and New Mexico have been dated back to around 1,200 years ago.

*Dendroclimatology* is the science that uses growth ring widths to reconstruct past climate events. Example: Analyzing the varying width of growth rings to how much rainfall fell per year long before weather records were kept. Serious droughts in 840, 1067, 1379, and 1632 are shown by very narrow rings in the beams of pueblos. A calamitous drought, starting in 1276 and lasting for 23 years, brought starvation to the area and the abandonment of most of the ancient villages.

*Dendroecology* is the science that uses tree rings to study factors that influence ecosystems and changes that occur in ecological processes over time such as defoliation by insect outbreaks; the effects of air, water, and soil pollution on tree growth and forest health; the age, maturity, and successional status of forest stands; and the effects of human disturbances and management on forest vitality.

*Dendrogeomorphology* is the science that uses tree rings to date earth surface processes that created or altered the landscape. Example: Analyzing changes in tree growth patterns via tree rings to date a series of landslides.

*Dendroglaciology* is the science that uses tree rings to date and study past and present changes in glaciers. Example: Dating the rings on trees growing on glacial moraines to establish the approximate date of glacial advance.

*Dendropyrochronology* is the science that uses tree rings to date and study past and present wildfires. Example: Dating the fire scars left in tree rings to determine how often wildfires occurred in the past.

A chronology (arrangement of events in time) can be made by comparing different sample. Using a boring tool, a long slender core is extracted (**Figure 9.32**). Suppose the sample was taken from a standing but long dead bristlecone pine tree. Its outer growth rings are compared with the inner rings of a living tree. If a pattern of individual ring widths in the two samples prove to be identical at some point, we can carry dating further into the past.

With this method of matching overlapping patterns found in different wood samples, bristlecone pine chronologies have been established almost 9,000 years into the past.



**Figure 9.32** Dendrochronologists use hollow drill bits to extract cores for analysis,

## LEAVES

*A leaf is the only wealth that can actually feed people.*

—Alan Savory

The plant clans adorn their stem scaffoldings with a finery of leaves that spreads like a green carpet over Mother Earth. Within this verdant blanket, every single leaf is busy devouring carbon dioxide and expelling oxygen. All together, at least 25 million square miles of leaf surface on just the land alone are engaged daily in the miraculous chemistry we call *photosynthesis*.

### ***Leaf Functions***

Leaves are produced by meristematic regions (buds) on the stem. Once leaves develop they have one primary function, and that is to produce nutrients (food) for the plant through the process of photosynthesis. Photosynthesis is arguably the most important biochemical process on Earth, and its extent challenges the imagination. The total production of sugar by the world's photosynthetic creatures—plants, algae, and cyanobacteria—both land and ocean combined produce not the hundreds of millions of tons of products like steel and concrete we humans churn out yearly but an estimated mind-boggling 200 *billion* tons of sugar (carbohydrates) annually. The total production of sugar by land plants is on the order of 40 billion tons a year. In doing so, Green World provides both air and food for human and beast.

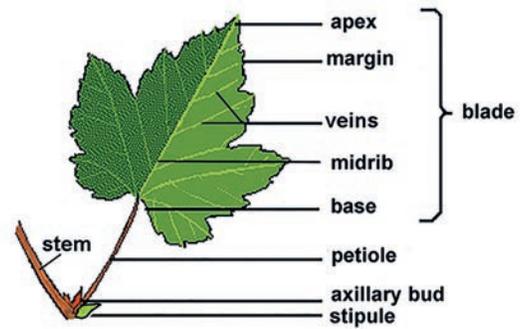
As plants have evolved, they have had to pick a lifestyle and marshal their resources accordingly: to grow woody or not, to live as annuals or perennials, or to adapt to wet climates or dry. Another forced choice has been even more fundamental: Do you live fast and die young, or take it slow and survive to a very old age? Over 30 biologists recently completed the most comprehensive global plant survey ever made. And one of their most surprising findings is that both live-fast and live-old plants coexist in every kind of climate.

Focusing only on leaves, the team found that some plants invest a lot in photosynthesis but little in defense. Their leaves have a large surface area compared with their dry mass, and they require a generous supply of enzymes (powerful chemicals used by all living things for various purposes) and nutrients. Such leaves are good at responding rapidly to growth opportunities. Their downside is that they dry out more readily and are vulnerable to disease, herbivores (plant-eating animals), pollution, or weather. The leaves of other species invest less in photosynthesis and more in defense: they're tougher and make various nasty chemicals that deter herbivores.

The key discovery was that all species of plants regardless of habitat or climate type take their primary cue from one central trade-off—maximizing photosynthesis (live-fast) versus ensuring survival (live-long).

## Leaf Morphology

Morphologically it is hard to generalize about the structure of the original solar collectors we call leaves for they come in an astonishing variety of sizes, shapes, and configurations. However, there are two basic parts to a leaf regardless of how complex it appears: the flat, expanded *blade* containing the *veins* (vascular tissue) and photosynthetic cells and the *petiole* (leaf stem), a stalk-like portion that connects the blade to the stem and contains the leaf traces (**Figure 9.33**). As is often the case in nature there are exceptions in that some plants form *sessile leaves* in which the blade attaches directly to the stem with no petiole present (**Figure 9.34**).



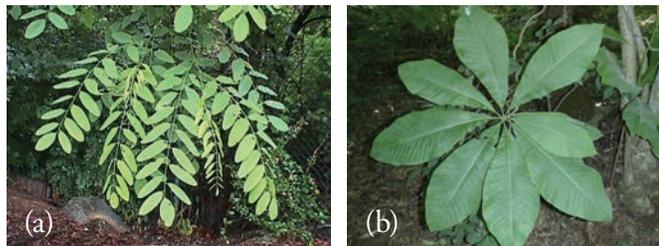
**Figure 9.33** At the base of the petiole are stipules, small, paired appendages and axillary buds that may develop into a branch or flower cluster.



**Figure 9.34** Sessile leaves of St. John's Wort (*Hypericum calycinum*) displaying axillary buds but no petioles.

Morphologically leaves vary greatly as to the arrangement of the leaves on the stem, the shape of each blade, the appearance of the leaf margin of each blade, and the venation of each blade.

Leaf arrangement or **phyllotaxy** is either *simple* (a one piece blade) or *compound* (blade subdivided into smaller *leaflets*). When the leaflets occur in a featherlike pattern, the leaf is said to be *pinnately compound* but *palmately compound* when the leaflets have a common attachment point and fan out in a palm-like arrangement (**Figure 9.35**). Leaves also vary greatly as to the shape of each leaf and the appearance of the leaf margin of each leaf (**Figure 9.36**).



**Figure 9.35** Compound Leaves. (a) Pinnately compound leaves of a black locust tree (*Robinia pseudoacacia*) and (b) Palmately compound leaves of the umbrella magnolia tree (*Magnolia tripetala*).

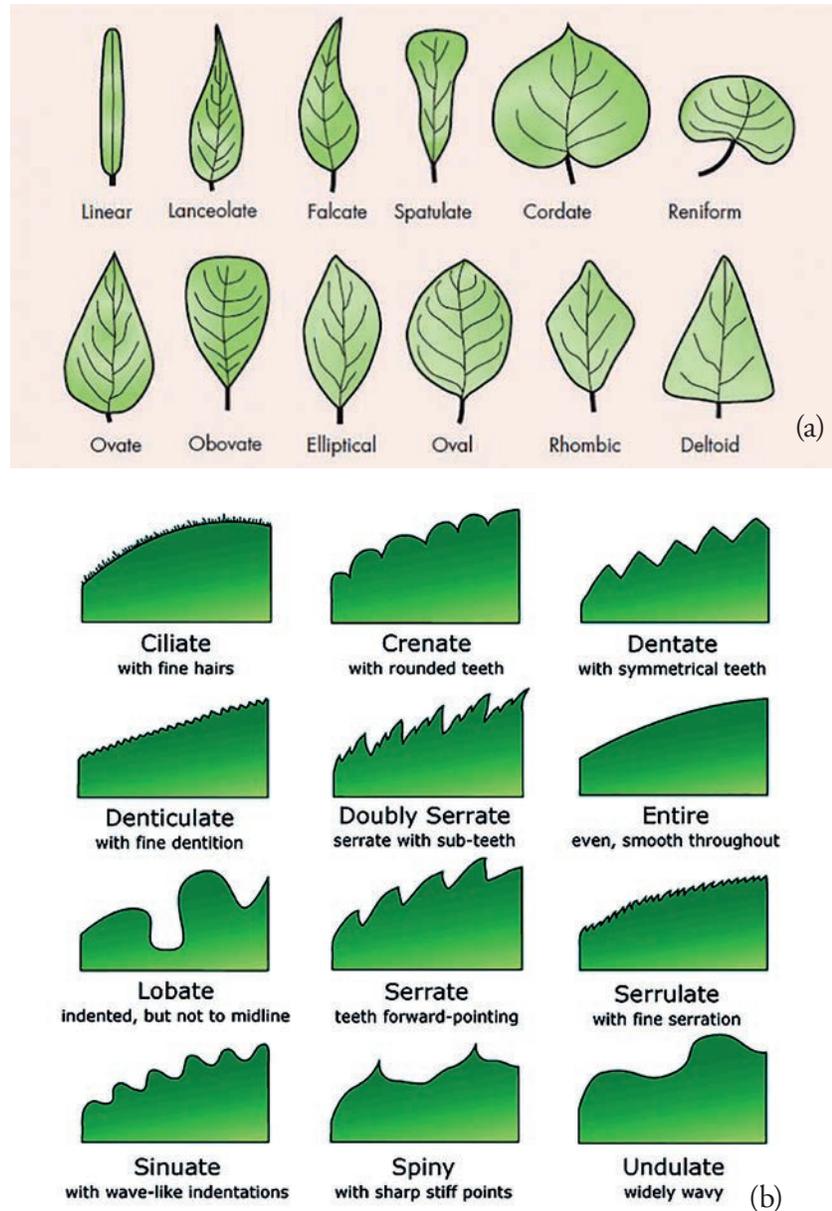
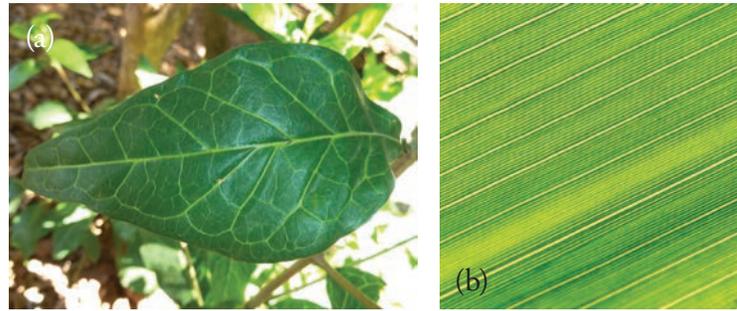


Figure 9.36 Leaves vary greatly as to shape (a) and the appearance of the leaf margin (b).

Some variation between leaves can also be seen in the venation pattern of each leaf. There are two general patterns of leaf venation: netted venation and parallel venation. Most ferns and eudicots possess *netted venation* or *reticulate venation* in which the veins form a branching network. By comparison, most gymnosperms and monocots form *parallel venation* or *striate venation* in which the veins run parallel with each other (Figure 9.37).



**Figure 9.37** Leaf Venation Patterns. (a) Netted venation of common rothmannia (*Rothmannia capensis*) and (b) Parallel venation of giant cane (*Arundo donax*).

### ***Modified Leaves***

Plants may have leaves that have been adapted to perform a number of functions besides photosynthesis.

**Trap Leaves** About 630 species arrayed into a dozen genera of plants have developed what might be considered a strange even bizarre adaptation to living in acidic bogs and rock outcroppings where the soil is poor nutrients, especially nitrogen. These plants, known collectively as insectivorous or carnivorous plants, have evolved a variety of different leaf adaptations for trapping small invertebrates and digesting them for their nutrient (not energy) content. The common misconception about these plants is that they trap insects and other arthropods for food (energy). This is not the case. These plants are green and produce food (sugar) through photosynthesis like all other plants. They have just evolved a rather strange way of supplementing their soil nutrient requirements. Insectivorous plants attract and trap prey, produce digestive enzymes, and absorb the resulting available nutrients.

Three basic trap mechanisms are found in carnivorous plants.

1. *Pitfall traps* trap prey in a rolled leaf that contains a pool of digestive enzymes or bacteria at the bottom. Foraging insects are attracted to the top of the tubular leaf by visual lures (colored pigments) and nectar bribes. The lip and sides of the pitcher are very slick and may be grooved in such a way so as to ensure that the insects cannot crawl out once they fall in (**Figure 9.38**). The liquid in the bottom of the trap drowns the insect, and its body is gradually dissolved. This may occur by bacterial action or by enzymes secreted by the plant itself.
2. *Flypaper traps* use a sticky mucilage or glue to immobilize prey. The leaf of flypaper traps is studded with mucilage-secreting glands, which may be short and nondescript (like those of the butterworts), or long and mobile (like those of many sundews). Sundews (*Drosera capensis*) have long tentacles with a sticky drop of goo at the tip of each tentacle. When triggered, the tentacles rapidly fold over the prey gluing it down (**Figure 9.39**).
3. *Snap traps* utilize rapid leaf movements. Only two plants use a snap trap—the Venus flytrap (*Dionaea muscipula*) which traps a variety of small arthropods and the aquatic waterwheel plant



**Figure 9.38**

(*Aldrovanda vesiculosa*) which traps a variety of small invertebrates. Trigger hairs inside the trap lobes are sensitive to touch. In the Venus flytrap, when two trigger hairs are bent (stimulated) 0.5 to 30 seconds apart, rapid hydraulic changes in the shape of cells in the midrib of the trap leaf occur allowing the lobes, held under tension, to snap shut (**Figure 9.40**).



**Figure 9.39** The tentacles of some sundews can bend 180° in less than a minute, impressively fast by plant standards.



**Figure 9.40** When the trigger hairs inside a trap leaf are tripped, the Venus flytrap can close and intercept its prey in less than a minute.

**Xenophytic Leaves** Plants that live in dry, desert environments are known as *xenophytes* (Gr. *xeros*, dry + *phyton*, plant). Some desert plants only produce leaves following brief rainy seasons. Other species form thick, succulent leaves that store water during the dry season. Leaves of desert plants frequently have sunken stomata and thick cuticles. These sunken stomata minimize water loss. Some plants have dense layers of trichomes (hairs) that give the leaf a white or ever woolly appearance. These trichomes reduce water loss and also keep the leaf from overheating. The ultimate water-saving adaptation, however, may lie with the cacti of family Cactaceae whose leaves have modified into nothing more than hard, sharp spines (**Figure 9.41**)



**Figure 9.42** Tendrils of summer squash (*Cucurbita pepo*) grasping rusty wires for support.



**Figure 9.41** In cacti, the leaves are so reduced and modified that they can no longer conduct photosynthesis. That function has been assumed by the stem.

**Tendrils** are leaves modified into slender coiling structures. Tendrils provide a supporting structure to certain climbing plants by growing around nearby objects (**Figure 9.42**).

### **Leaf Anatomy**

As we discovered, morphologically (externally) leaves vary greatly in a number of aspects based on species. Anatomically (internally), however, leaves of all species are nearly identical in their arrangement of tissues.

The tissues of a leaf may be classified as *epidermis*, *mesophyll*, and *vascular bundles* (**Figure 9.43**).

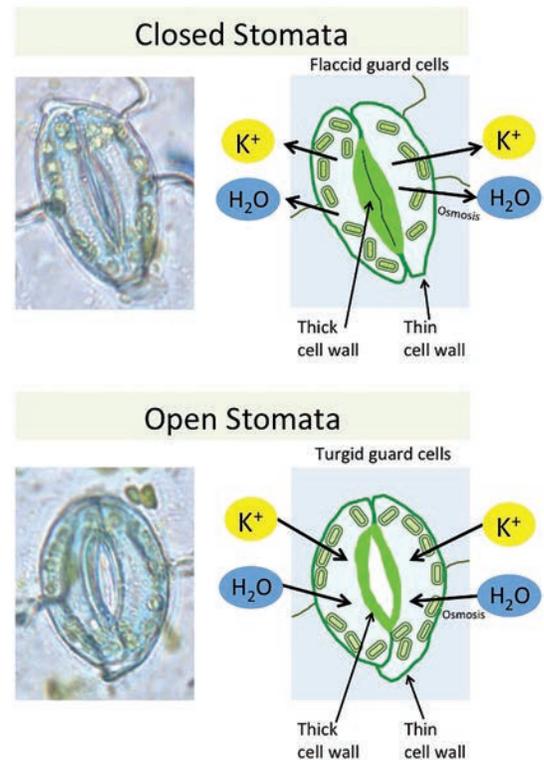


Figure 9.43

**Epidermis** The epidermis is composed of a single layer of interlocking cells that usually contain no chloroplasts. Although distinguished into upper and lower epidermis, the epidermis is actually a continuous layer wrapped around the mesophyll. The epidermis produces and is covered by a thin, waxy layer known as the *cuticle*. The cuticle functions as a permeability barrier keeping water in, but at the micro and nano-structure level, the cuticle also confers specialized surface properties that prevent contamination of the leaf with external water, dirt, and microorganisms.

The major water loss from a leaf is normally through **stomata** (Gr. *stoma*, mouth). The stomate is an intercellular space formed by the splitting of the cell wall between two specialized epidermal cells known as *guard cells*. (This label is a misnomer as these cells do not “guard” the stomate but rather they regulate the size of the opening between the guard cells.) Guard cells, unlike other epidermal cells, contain chloroplasts. In surface view, the guard cells appear bean-shaped and the inner walls of the guard cells are shown to be much thickened (**Figure 9.44**).

The stomate is opened or closed as turgor pressure within the guard cells changes. When guard cells take up water (increasing turgor pressure), the thick inner walls swell and curve so that the stomate grows larger (opens). When guard cells lose water (decreasing turgor pressure), the stomate grows smaller (closes). Environmental factors and internal conditions play a major role in the status of the stomates. In high wind and/or high-temperature conditions, the stomates close to conserve



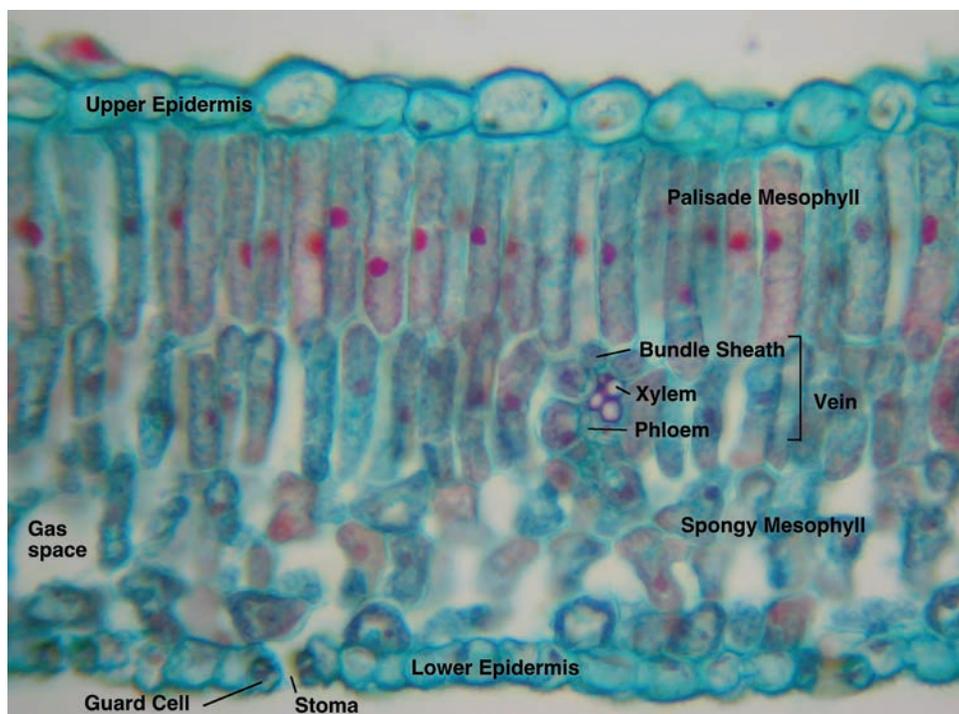
**Figure 9.44** The influx of potassium ions ( $K^+$ ) results in an influx of water and the stomata closes. An outflow of potassium ions results in an outflow of water and the stomata opens.

water. High concentrations of  $\text{CO}_2$  inside the leaf will also trigger the stomates to close because this signals that sufficient levels of  $\text{CO}_2$  are available for photosynthesis.

When the stomates are open, they are the chief path through which gases, such as water vapor, carbon dioxide, and oxygen, move from the leaf into the air and from the air into the leaf. Stomates may be present in both the upper and lower epidermis, but the number in the lower epidermis is usually greater than in the upper epidermis. Most woody plants have no stomates in the upper epidermis at all.

**Mesophyll** Within the leaf, photosynthesis is localized in the mesophyll. This tissue, with the exception the vascular bundles, includes all the cells between the upper and lower epidermis. The cells of the mesophyll are thin walled and retain a nucleus even when mature.

The mesophyll is usually divided into two parts. The cells toward the upper side of the leaf are elongated at right angles to the surface and form one to three compact layers. These cells make up the *palisade parenchyma*. Below the palisade cells and extending to the lower epidermis is a zone of irregularly shaped cells with large intercellular spaces. These cells form the *spongy parenchyma*. The intercellular spaces of this tissue, together with similar but smaller spaces between the palisade cells, form a system of air passages extending throughout the leaf (**Figure 9.45**).



**Figure 9.45** A microscopic view of the internal structure of a leaf.

All the mesophyll cells contain chloroplasts embedded in the cytoplasm surrounding a large central vacuole. The chloroplasts in the palisade cells outnumber those in the spongy tissue two or three to one. In a sunflower leaf, for example, the cells of the palisade layer averaged 77 chloroplasts per cell, those of the spongy mesophyll only 27 per cell. Estimating about 400,000 chloroplasts to each square millimeter of elm

leaf—a conservative appraisal—it has been calculated that the total surface area of the chloroplasts in the leaves of a mature elm tree may amount to as much as 140 square miles.

**Vascular Bundles** As we learned earlier vascular bundles are specialized strands of tissue that function both in support and in transport. The larger bundles within the leaf can be seen externally on the surface as the main veins. Internally, the vascular bundles of a leaf are the terminus of the leaf traces that enter the base of the leaf through the petiole.

In eudicot leaves, the vascular bundles (veins) divide and subdivide to form smaller and smaller strands that extend to all parts of the leaf. These smaller bundles are connected at frequent intervals to form a netlike system. In monocot leaves the vascular bundles (veins) run parallel to each other with no cross connections. The vascular bundle system of the leaf is very extensive; it has been calculated, for example, that if the vascular bundles, large and small, in a single elm leaf were placed end to end they would be more than 213 m (700 feet) or  $2\frac{1}{3}$  football fields long.

The vascular bundles are usually located about halfway between the upper and lower epidermis. Vascular bundles are composed of two kinds of tissue of fundamental importance, xylem and phloem. Together these constitute the vascular tissues.

The smaller vascular bundles are so numerous that most cells of the mesophyll are only a few cells removed from the conducting tissue. Water and mineral salts from the soil reach the mesophyll cells of the leaf through the xylem; food manufactured in the mesophyll moves in the opposite direction through the phloem.

### Box 9.3

#### *Colors of Fall*

The bright, crisp days of fall bring with them one of the most beautiful color transformations in all of Green World. Almost overnight, trees that have worn a cloak of green all spring and summer are suddenly veiled in brilliant reds, yellows, oranges, brown, and even purple (**Figure 9.46**).

The color of a leaf results from an interaction of different chemicals (pigments) produced by the plant. The main pigment classes responsible for leaf color are porphyrins, carotenoids, and flavonoids.



Figure 9.46

Pigment Class	Compound Type	Colors
Porphyrin	chlorophyll	green
Carotenoid	carotene, lycopene xanthophyll	yellow, orange, red yellow
Flavonoid	flavone flavonol anthocyanin	yellow yellow red, blue, purple, magenta

Chemical interactions within the plant, particularly in response to acidity (pH) also affect the leaf color. When leaves appear green, it is because they contain an abundance of chlorophyll. The chlorophyll masks other pigment colors. Anthocyanins, in turn, mask carotenoids. Visualize painting piece of paper first with yellow then covering the yellow with a layer of red. Finally, add a layer of green over the red. You will see only the green layer (chlorophyll), but the red (anthocyanin), and yellow (carotenoids) are still there just masked (hidden).

As summer turns to autumn, decreasing light levels cause chlorophyll production to slow and the decomposition rate of chlorophyll to increase. As a result, the green color will fade from the leaves. At the same time, anthocyanin production in leaves increases, in response to surging sugar concentrations. Leaves containing primarily anthocyanins will appear red. Leaves with good amounts of both anthocyanins and carotenoids will appear orange. Leaves with carotenoids but little or no anthocyanins will appear yellow. In the absence of these pigments, other plant chemicals also can affect leaf color. An example includes tannins, which are responsible for the brownish color of some oak leaves.

## In Summary

- Roots, stems, and leaves form the vegetative organs of a plant.
- The main types of differentiated cells that commonly occur in plants are: parenchyma cells, collenchyma cells, and sclerenchyma.
- Three types of tissues are found in vascular plants: the dermal tissue system, the vascular tissue system, and the ground tissue system.
- Angiosperms may be divided into two groups: monocotyledons (monocots) and eudicotyledons (eudicots) (formerly monocotyledons [monocots]).
- The main functions of roots are absorption, anchorage, food and water storage, and hormone production.
- Root systems are either a taproot system found in eudicots and gymnosperms or a fibrous roots system found in monocots and some eudicots.
- Specialized roots include storage roots, aerial roots, prop roots and buttress roots, and haustorial roots.
- Roots have three major zones: the meristematic zone, the elongation zone, and the maturation zone.

- The tissues of mature roots can be divided into three types: epidermis, cortex, and vascular cylinder.
- Stems perform three basic functions: support of the plant and uplift of leaves and reproductive structures, transporting fluids between leaves and roots, and food storage.
- Roots that have been modified for food storage include rhizomes, tubers, bulbs, and corms.
- Based on differences in morphology and anatomy, stems may be categorized as herbaceous monocots, herbaceous eudicots, or woody eudicots.
- The primary function of leaves is to produce food for the plant through the process of photosynthesis.
- There are two basic parts to a leaf regardless of how complex it appears: the flat, expanded blade containing the veins (vascular tissue) and photosynthetic cells and the petiole (leaf stem).
- Leaf arrangement may be simple, pinnately compound or palmately compound.
- There are two general patterns of leaf venation: netted venation and parallel venation.
- Modified leaves include trap leaves, xenophytic leaves, and tendrils.
- The tissues of a leaf may be classified as epidermis, mesophyll, and vascular bundles.

## Roots—Review and Reflect

1. **Plants Have Organs?** You happen to mention to your roommate that your biology teacher was discussing plant organs in class. “Wait a minute,” says your roommate. “Animals have organs but plants do not. That’s ridiculous.” How would you respond?
2. **Plant Cell Types** As part of a lab practical exam you have been given three unmarked microscope slides. Each slide contains a different type of plant cell— parenchyma cells, collenchyma cells, and sclerenchyma cells. Explain what characteristics you would look for to identify which type of cell is on each slide.
3. **Human-Plant Analogs** Human skin is analogous to what plant tissue? The human circulatory system (except the heart) is analogous to what plant tissue? Ground tissue in plants is analogous to what tissue(s) in humans? Explain your selection of each analog.
4. **Define It** Imagine you have been asked to write a botanical dictionary. In your dictionary how would you define a *root*?
5. **Stop It** The biological world exists because water and mineral solutes flow into roots. Do you really understand the process by which that happens? Let’s test your understanding by challenging you to list and explain as many ways as you can think of to prevent water from flowing into roots.
6. **Drill Down** Imagine you are the captain of a one-person drilling submarine. You and your ship have been shrunk down to microscopic size and placed on the epidermis of an actively growing root about two inches from the root tip. Your mission is to drill through the root and investigate and describe the various tissues that comprise the root— *epidermis*, *cortex*, and *vascular cylinder*. Discuss the size, type, and number of cells in each tissue you encounter.

## Roots—Create and Connect

1. **Root Vampire** Found in the desert climates of Western Australia, the Australian Christmas tree (*Nuytsia floribunda*) has an unusual root system. Write a short report on the strange root system of this plant.

### Guidelines

- A. Format your report in the following manner:
    - *Title page* (including your name and lab section)
    - *Body of the Report* (include pictures, charts, tables, etc. here as appropriate). The body of the report should be a minimum of two pages long—double-spaced, 1 inch margins all around with 12 pt font.
    - *Literature Cited* A minimum of two references required. Only one reference may be from an online site. The *Literature Cited* page should be a separate page from the body of the report, and it should be the last page of the report. Do NOT use your textbook as a reference.
  - B. The instructor may provide additional details and further instructions.
2. **Space Potatoes** Imagine you work for BotGen, a plant bioengineering company. BotGen has been awarded a contract from NASA to bioengineer plants to be grown in hydroponic conditions as food for astronauts during extremely long space missions. You are in charge of engineering a storage root system for the new plants NASA seeks. (Other sections of the company will bioengineer the stem and leaves of the new plants). Diagram, label, and explain the storage root system you would develop to satisfy the design parameters of the mission.

## Stems—Review and Reflect

1. **Are Stems Necessary?** Your study buddy turns to you and says, “I don’t get it. Why do plants need stems? Why don’t the leaves just grow out of the roots?” What would you say?
2. **Herbaceous vs. Woody—External** You have a herbaceous monocot stem in one hand and a woody eudicot stem in the other. How could you tell which was which?
3. **Herbaceous vs. Woody—Internal** Your instructor has forewarned you that on the lab practical exam you will be required to distinguish between a microscopic cross section view of both an herbaceous monocot stem and a woody eudicot stem. What clues will you look for to decide which is which?
4. **A Worm’s View** Imagine you are a tree-boring insect resting on the bark of a mature oak tree. Your goal is to bore into the center of the tree you are on. Describe each layer you bore through on your way to the center.
5. **Count Don’t Cut** You have been charged with the task of determining the age of a very large and obviously very old tree, but you can’t cut it down to count the rings. How would you meet the challenge?

## Stems—Create and Connect

1. ***A Knotty Problem*** What is the structure shown in **Figure 9.47**? Explain how these structures form.
2. ***Blowing in the Wind*** Withstanding the wind is a constant challenge for plants. Imagine you are the noted botanist Pat Phloem. Your hypothesis is that tomato seedlings will develop hardier stems when exposed to the wind than tomato seedlings grown where the air is calm. Design an experiment to test your hypothesis.



Figure 9.47

### Guidelines

- A. Following the tenets of a well-constructed experiment, your design should include the following components in order:
  - ***The Problem Question.*** State exactly what problem you will be attempting to solve.
  - ***Your Hypothesis.*** While this is a fictitious experiment, word your hypothesis as realistically as possible.
  - ***Methods and Materials.*** Explain exactly what you will do in your experiment including the materials necessary to accomplish the task. Be specific, take nothing for granted, and do not expect people to read your mind as they read your work.
  - ***Collecting and Analyzing Data.*** Explain what type(s) of data will be collected, and what statistical tests might be performed on that data. It is not necessary to concoct fictitious data or imaginary observations.
- B. Your instructor may provide additional details or further instructions.

## Leaves—Review and Reflect

1. ***What's in a Quote?*** It has been said that the inner workings of a leaf make life on this planet possible. Explain this statement by relating it to the primary function of leaves.
2. ***Eudicot or Monocot?*** As part of a lab practical exam over leaves your instructor has handed you two leaves—one eudicot and one monocot—and asked you to identify which is which based solely on the morphology of each leaf. How would you meet the challenge?
3. ***Adapting Morphology to Counter Environment*** Leaves have proven to be quite pliable from an evolutionary standpoint and have adapted to meet the challenges presented to them by ever-changing environmental conditions. Name and describe three such leaf adaptations.
4. ***One Leaf or Many?*** Observe the leaf pictured in **Figure 9.48**. Is this one leaf or many leaves? Explain
5. ***Pinpointing Photosynthesis*** Does photosynthesis occur in all the internal tissues of a leaf? Explain



Figure 9.48

## Leaves—Create and Connect

1. **Upside Down Stomates?** A researcher compared the average number of stomata on the topside and the underside of several different plants. His data are summarized in the table. Analyze the data and answer the questions that follow the table.

**Table 9.2**  
*Average Number of Stomata Per Square Meter*

<i>Type of Plant</i>	<i>Top Surface of Leaves Area</i>	<i>Bottom Surface of Leaves</i>
Tomato	12	122
Pumpkin	29	275
Bean	40	288

### Questions

- A. What generalization can be made based on the data?
  - B. Is this true for most/many plants? Investigate and if it is true, what would be the advantage for plants to have the majority of their stomates on the underside of their leaves?
2. **Light vs. Transpiration Rate** Several environmental factors can influence the rate of transpiration. As temperature increases, for example, so does the rate of transpiration (up to a point). Another environmental factor that could influence the rate of transpiration is the intensity of light. Design an experiment to determine whether the intensity of light influences the rate of transpiration.

### Guidelines

- A. Following the tenets of a well-constructed experiment, your design should include the following components in order:
  - *The Problem Question.* State exactly what problem you will be attempting to solve.
  - *Your Hypothesis.* While this is a fictitious experiment, word your hypothesis as realistically as possible.
  - *Methods and Materials.* Explain exactly what you will do in your experiment including the materials necessary to accomplish the task. Be specific, take nothing for granted, and do not expect people to read your mind as they read your work.
  - *Collecting and Analyzing Data.* Explain what type(s) of data will be collected, and what statistical tests might be performed on that data. It is not necessary to concoct fictitious data or imaginary observations.
- B. Your instructor may provide additional details or further instructions.