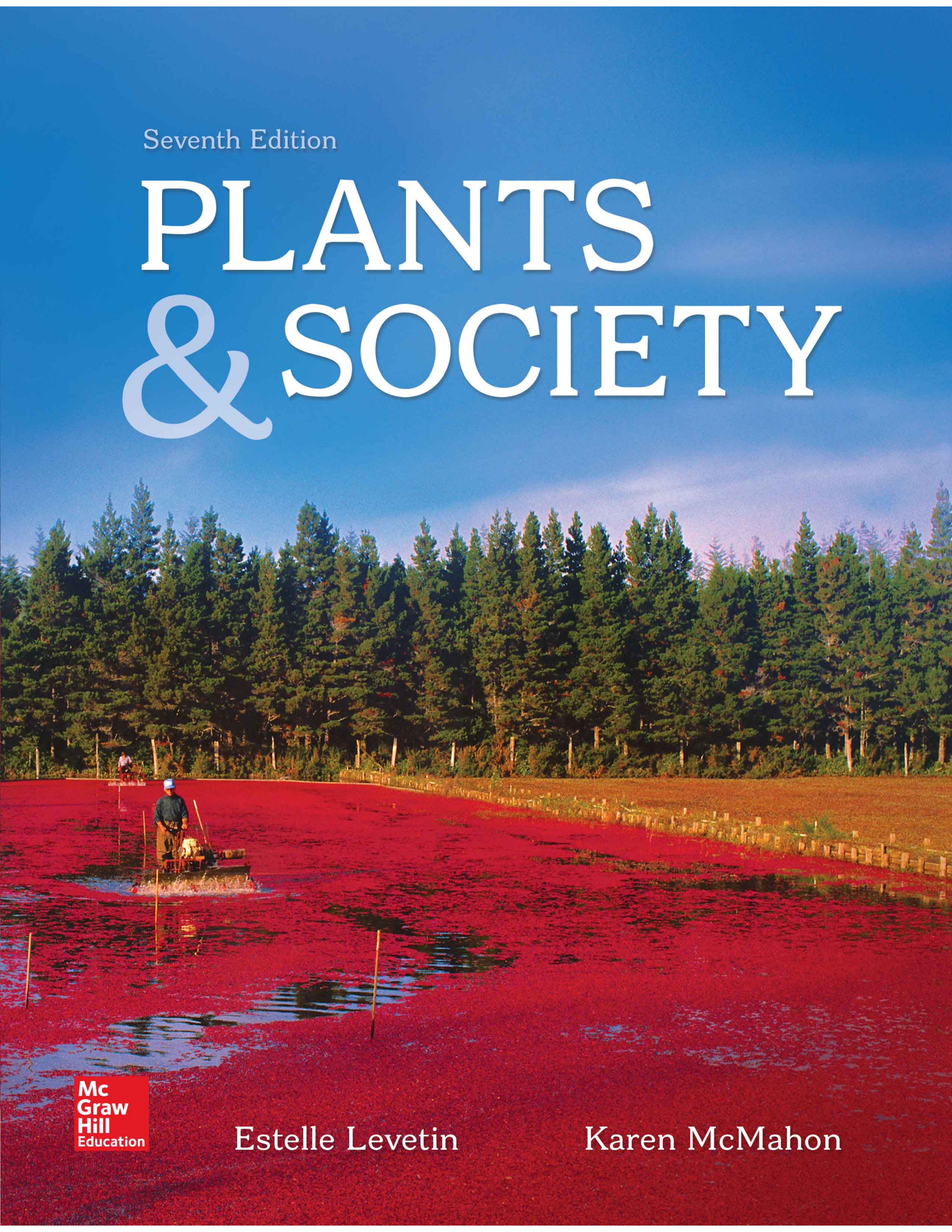
Seventh Edition

PLANTS & SOCIETY



McGraw Hill Education

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In loving memory of our mothers

Pauline Levetin

& *Dorothy Sink McMahon*

Contents in Brief

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Preface

In the twenty-first century, plant science is once again assuming a prominent role in research. Renewed emphasis on developing medicinal products from native plants has encouraged ethnobotanical endeavors. The destruction of the rain forests has made the timing for this research imperative and has spurred efforts to catalog the plant biodiversity in these environments. Efforts to feed the growing populations in developing nations have also positioned plant scientists at the cutting edge of genetic engineering with the creation of transgenic crops. However, in recent decades botany courses have seen a decline in enrollment, and some courses have even disappeared from the curriculum in many universities. We have written *Plants and Society* in an effort to offset this trend. By taking a multidisciplinary approach to studying the relationship between plants and people, we hope to stimulate interest in plant science and encourage students to further study. Also, by exposing students to society's historical connection to plants, we hope to instill a greater appreciation for the botanical world.

AUDIENCE

Recently, general botany courses have emphasized the impact of plants on society. In addition, many institutions have developed plants and society courses devoted exclusively to this topic. This emphasis has transformed the traditional economic botany from a dry statistical treatment of "bushels per acre" to an exciting discussion of "botanical marvels" that have influenced our past and will change our future. *Plants and Society* is intended for use in this type of course, which is usually one semester or one quarter in length. There are no prerequisites, because it is an introductory course. The course covers basic principles of botany and places a strong emphasis on the economic aspects and social implications of plants and fungi.

Students usually take a course of this nature in their freshman or sophomore year to satisfy a science requirement in the general education curriculum. Typically, they are not biology majors. Although most students enroll to satisfy the science requirement, many become enthusiastic about the subject matter. Students, even those with a limited science background, should not encounter any problems with the level of scientific detail in this text.

As indicated, the primary market for this text is a plants and society course; however, it would certainly be suitable for an introductory general botany course as well.

ORGANIZATION

We feel that *Plants and Society* is a textbook with a great deal of flexibility for course design. It offers a unique balanced approach between basic botany and the applied or economic aspects of plant science. Other texts emphasize either the basic or applied material, making it difficult for instructors who wish to provide better balance in an introductory course. Another distinctive feature is the unit on algae and fungi. While other texts cover certain aspects of this topic, we have an expanded coverage of algae and fungi and their impact on society.

Plants and Society is organized into 26 chapters that are grouped into seven units. The first nine chapters cover the basic botany found in an introductory course. However, even in these chapters we have included many applied topics, some in the boxed essays but others directly in the chapter text.

UNIT I Plants and Society: The Botanical Connections to Our Lives. Chapter 1 stresses the overall importance of plants in everyday life. The properties of life, molecules of life, flowering and non-flowering plants, algae, and fungi are introduced. The scientific method is explained as the process used by scientists to study and expand our knowledge of the natural world. The diversity and applications of phytochemicals are also presented.

UNIT II Introduction to Plant Life: Botanical Principles. This unit addresses basic botany. Chapters cover plant structure from the cellular level through the mature plant. Reproduction, including mitosis and meiosis and the life cycle of flowering plants, is discussed in two chapters. Other chapters cover genetics, evolution, plant physiology, plant systematics, and plant diversity. Some of the economic aspects of plants discussed in this unit are the importance of vegetables and fruits, the connection between sugar and slavery, plant essential oils and perfumes, phytoremediation, the applications of palynology, and species conservation.

UNIT III Plants as a Source of Food. This unit describes the major food crops. It begins with a chapter on the requirements for human nutrition and continues with a chapter on the origins of agriculture. Other chapters cover the grasses, the legumes, and starchy staples. The unit ends with a chapter on the Green Revolution, the loss of genetic diversity, the search for alternative crops, and the controversial development of transgenic crops.

UNIT IV Commercial Products Derived from Plants. This unit covers other crops that provide us with consumable products, such as beverages, herbs and spices, and materials such as cloth, wood, and paper. The historical origin and societal impact of these crops are explored.

UNIT V Plants and Human Health. This unit introduces students to the historical foundations of Western medicine, the practice of herbal medicine, and the chemistry of secondary plant products. Descriptions of the plants that provide us with medicinal products and psychoactive drugs are discussed. The unit also covers the common poisonous and allergy plants that are found in the environment.

UNIT VI Algae and Fungi: The Impact of Algae and Fungi on Human Affairs. This unit describes the economic importance of the algae and fungi, including their biology and crucial roles in the environment. The algae are recognized as key producers in aquatic environments and as sources of human food, devastating blooms, and industrial products. Fermented beverages and foods from fungi are discussed, as is the medical importance of fungi as sources of antibiotics, toxins, and diseases affecting crops and people.

UNIT VII Plants and the Environment. Chapter 26 is an introduction to the principles of ecology: the ecosystem, niches, food chains, biogeochemical cycles, and ecological succession. The major biomes of the world are discussed, with an emphasis on the economic value of certain desert plants and the strategy of extractive reserves in the rain forest. The problems associated with rising levels of the greenhouse gas CO_2 and the environmental consequences of global warming are addressed.

APPROACH

This textbook is written at the introductory level suitable for students with little or no background in biology. Like any introductory book, this book uses a broad-brush treatment. The nature of the course dictates an applied approach, with the impact of plants on society as the integrating theme, but the theoretical aspects of basic botany are thoroughly covered.

LEARNING AIDS

In addition to the textual material, each chapter begins with a chapter outline and key concepts. Important terms are in boldface type throughout the text, and each chapter ends with a summary and review questions. Thinking Critically questions are inserted in the text to draw the attention of the students as they read the chapter. The questions begin with either a summary of the preceding text or an introduction to new information that is complementary to the chapter. The questions that follow are designed not only to test comprehension but also, in many instances, to promote critical thinking by asking students to apply their knowledge to real-life situations. Thinking Critically questions may also be assigned by instructors or used to initiate in-class discussions. An appendix titled Atoms, Molecules, and Chemical Bonds and a glossary conclude the text. The classification of plants and other organisms discussed in the text and a review of metric units are located for quick access on the inside front and back covers respectively.

NEW TO THE SEVENTH EDITION

The seventh edition of *Plants and Society* been updated to spotlight exciting discoveries and update major advancements in the science of plants, algae, and fungi, with special emphasis on how these organisms impact humanity. These include:

- Discovery of the tannosome, an organelle recently identified in plant cells (Chapter 2).
- SLIPS, an innovative nonstick surface, inspired by the slippery surface found in carnivorous pitcher plants, which cause prey to fall into the traps (Chapter 3).
- Commercially useful enzymes obtained from plants and fungi (Chapter 4).
- Colony collapse disorder and its impact on the honey bee, the all-important pollinator for many crops (Chapter 5).
- Insight into the domestication of the tomato from its wild relatives revealed by the sequencing of the genome and the threat and control of citrus greening disease (Chapter 6).
- The topic of epigenetics has been added to explain how chemical changes in chromatin result in patterns of inheritance (Chapter 7).
- Classification is updated to reflect current phylogenetic research, and the section about gnetophytes has been expanded (Chapter 9).
- Minerals essential for human health have been updated with the recent addition of bromine; MyPlate as the USDA's latest approach to illustrate the *Dietary Guidelines to Americans* is added; and controversial research disputing the health benefits of HDL and antioxidants is presented (Chapter 10).
- The latest findings on the domestication of dogs has been updated; the domestication syndrome in the cat is presented; and a theory is proposed on how the shape of continents determined where agriculture originated and which crops would become domesticated (Chapter 11).
- Updates about world crop production; new information on how bread wheat evolved; new developments in wheat varieties resistant to wheat rust are presented; advances in the production of grasses for biofuel are described; and information gleaned from the sequencing of the wheat and millet genomes is presented (Chapter 12).
- The tepary bean has been highlighted; information concerning the nitrogen cycle and havesting oil has been updated(chapter 13).
- Data from the sequencing of the potato, cassava and banana genomes have been added; recent outbreaks of the late blight of potato are detailed; new facts about the origin and domestication of the sweet potato are presented; and the emerging threat from the cassava mosaic virus is introduced (Chapter 14).

- The development of herbicide- and disease-resistant crops is presented, and gene silencing as a technique to develop new crops has been added (Chapter 15).
- The health benefits of caffeine and tea have been expanded; the emerging threat of coffee rust to plantations in Central and South America is reviewed; and new information about the cacao trade and slavery has been added (Chapter 16).
- Two herbal sources of sweeteners, miracle fruit and stevia, are featured in the new *A Closer Look: Sweet Talk* (Chapter 17).
- Fungal pigments developed for commercial usage have been introduced (Chapter 18).
- Sublingual immunotherapy has been spotlighted as a new treatment for allergies (Chapter 21).
- A major reorganization reflects the current phylogenetic knowledge about algae, and the latest information about algal toxins has been added (Chapter 22).
- A major reorganization presents the current research on fungal phylogeny (Chapter 23).
- A new section on the impact of climate change on the wine growing industry has been added (Chapter 24)
- Updates on climate change and its impact are discussed (Chapter 26).
- Nearly 100 new photographs and several new or revised figures and tables have been added to the seventh edition.

ACKNOWLEDGMENTS

From our first introduction to botany as college students, we became irrevocably fixated on the lives of plants. We can remember the fascination we felt when we read about the plant explorers who discovered *extinct* ginkgo trees alive in China and how a trichome of the stinging nettle was the inspiration for the invention of the hypodermic needle. It is our hope that *Plants and Society* will present the world of plants and how they sustain humanity in a way that will inspire students to have a lifelong appreciation of plants.

We wish to thank the editorial staff at McGraw-Hill Higher Education for their editorial expertise and their endless patience during the publication of the seventh edition of *Plants and Society*. We especially want to acknowledge our Publisher, Michael Hackett; Executive Brand Manager, Michelle Vogler; Freelance Product Developer, Lori Bradshaw; and Content Project Manager, Mary Jane Lampe.

REVIEWERS

We are indebted to our colleagues who have taken time from demanding schedules to meticulously review *Plants and Society* for errors, inconsistencies, or omissions and to offer constructive feedback and suggestions. We thank you for making the seventh edition of *Plants and Society* the best edition.

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Lawrence Alice
Western Kentucky University
Robert Corbett
Lamar University
Larry Lake
Messiah College
Peter Brown
Mesa Community College
William Sanders
Florida Gulf Coast University

List of Boxed Readings

Supplements

PLANTS AND SOCIETY COMPANION WEBSITE

The companion website to accompany *Plants and Society* offers a variety of additional resources for instructors and students. Instructors will appreciate full-color PowerPoint image slides that contain illustrations and photos from the text, along with suggested activities. A comprehensive bank of test questions, aligned with each chapter of the text, is also available along with access to EZ Test Online. EZ Test Online allows instructors to create paper and online tests or quizzes in one easy-to-use program. Students will find multiple-choice quizzes, short-answer concepts and further resources to aid in their study. Also included is a listing of useful and poisonous plants, as well as tips for growing houseplants and home gardening.

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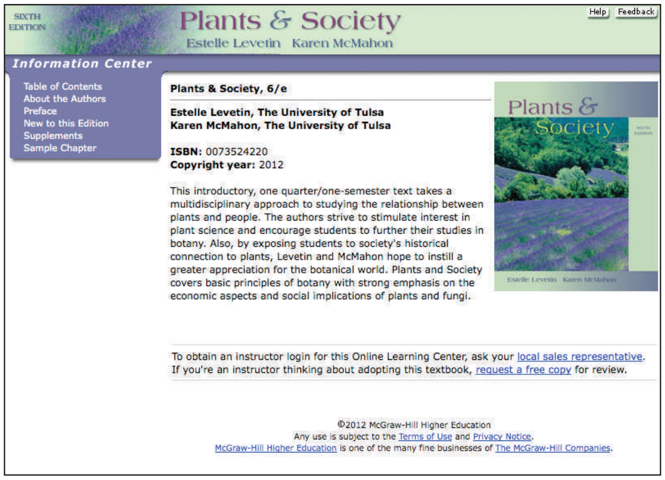

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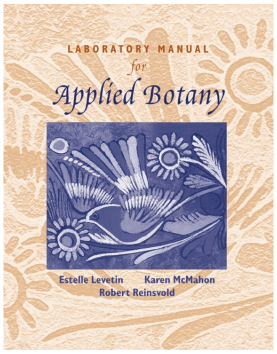
THE *LABORATORY MANUAL FOR APPLIED BOTANY* BY LEVETIN, MCMAHON, AND REINSVOLD



The lab manual features 18 exercises that focus on examining plants and plant products that have sustained or affected human society. Although the manual includes standard information on plant cells and tissues, there is a practical approach to the investigations. Students extract plant dyes, make paper from plant fibers, and study starch grains used in archeology. Several laboratory topics are devoted exclusively to economically important crops—grasses, legumes, starchy staples, and spices. Four additional appendixes—titled Science as a Process, A Field Trip to a Health Food Store, A Taster's Sampler of Caffeine Beverages and Foods, and Notes for Instructors—provide additional information for each of the labs.

UNIT I

CHAPTER

1

Plants in Our Lives

The botanical connections to our lives are many: food, medicines, materials, and beverages are just a few of the ways plants serve humanity.

KEY CONCEPTS

1. Green plants, especially flowering plants, are more than just landscaping for the planet, since they supply humanity with all the essentials of life: food and oxygen as well as other products that have shaped modern society.
2. The algae are an extremely diverse group of photosynthetic organisms that are key producers in aquatic food chains, a valuable source of human food, and the base for a number of commercial and industrial products.
3. Fungi are also an economically important group of organisms that affect society in numerous ways, from fermentation in the brewing process to the use of antibiotics in medicine to their role as decomposers in the environment and as the cause of many plant and animal diseases.
4. All living organisms share certain characteristics: growth and reproduction, ability to respond, ability to evolve and adapt, metabolism, organized structure, and organic composition.
5. The processes of life are based on the chemical nature and interactions of carbohydrates, lipids, proteins, and nucleic acids.

CHAPTER OUTLINE

Much of modern society is estranged from the natural world; people living in large cities often spend over 90% of their time indoors and have little contact with nature. Urbanized society is far removed from the source of many of the products that make civilization possible: most food is purchased in large supermarkets, most medicines are purchased at pharmacies, and most building supplies are purchased at lumber yards. Society's dependence on nature, especially plants, is forgotten (table 1.1).

In less urbanized environments, lifestyles are more attuned to nature. The farmer's existence is dependent on crop survival, and the farmer's work cycle is timed to the growing season of the crops. The few hunter-gatherer cultures that remain in isolated areas of the world are even more dependent on nature as they forage for wild plants and hunt wild animals. These foragers know that without grains there would be no flour or bread; without plant fibers there would be no cloth, baskets, or rope; without medicinal herbs there would be no relief from pain; without wood there would be no shelter; without firewood there would be no fuel for cooking or heat; and without vegetation there would be no wild game.

PLANTS AND HUMAN SOCIETY

Whether forager, farmer, or city dweller, humans have four great necessities in life: food, clothing, shelter, and fuel. Of the four, an adequate food supply is the most pressing need, and, directly or indirectly, plants and algae are the source of virtually all food through the process of **photosynthesis.** Through photosynthesis, plants and algae use solar energy to convert carbon dioxide and water into sugars and, as such, are the **producers** in the **food chain.** They are the base of most food chains, whether eaten by humans directly as **primary consumers** or indirectly as **secondary consumers** when eating beef (which comes from grain-fed or pasture-fed cattle). In addition to the food produced by photosynthesis, the oxygen given off as a by-product is Earth's only continuous supply of oxygen. As sources of food, oxygen, lumber, fuel, paper, rope, fabrics, beverages, medicines, and spices, plants support and enhance life on the planet.

Thinking Critically

Plants are crucial to the existence of many organisms, including human beings.

Could life on Earth exist without plants? Explain.

The Flowering Plants

The word *plant* means different things to different people: to an ecologist, a plant is a producer; to a forester, it is a tree; to a home gardener, a vegetable; and to an apartment dweller, a houseplant. Although there are many different types of plants, the most abundant and diverse plants in the environment are the flowering plants, or **angiosperms.** These are also the most economically important members of the Plant Kingdom and are the primary focus of this book. From the more than 350,000 known **species*** of angiosperms, an overwhelming diversity of products has been obtained and utilized by society. The food staples of civilization—wheat, rice, and corn—are all angiosperms; in fact, with minor exceptions, all food crops are angiosperms. The list of other products from angiosperms is considerable and includes cloth, hardwood, herbs and spices, beverages, many drugs, perfumes, vegetable oils, gums, and rubber.

All angiosperms are characterized by flowers and fruits. A typical angiosperm flower consists of four whorls of parts: **sepals, petals, stamens,** and one or more **carpels** (fig. 1.1). The stamens and carpels are the sexual reproductive structures. It is from the carpels that the fruit and its seeds will develop. The angiosperms traditionally have been divided into two groups, the **monocots** and the **dicots,** on the basis of structural and anatomical differences. Among the most familiar monocots are lilies, grasses, palms, and orchids. A few common dicots are geraniums, roses, tomatoes, dandelions, and most broad-leaved trees. The structure and reproduction of the angiosperms will be described in detail in later chapters.

The Non-Flowering Plants

In the Plant Kingdom, several distinct groups of non flowering plants can be found; these range from green algae (fig. 1.2a) to mosses and ferns to giant redwood trees, which are the largest organisms on Earth. Redwoods belong to a group of plants called gymnosperms. Like angiosperms, gymnosperms

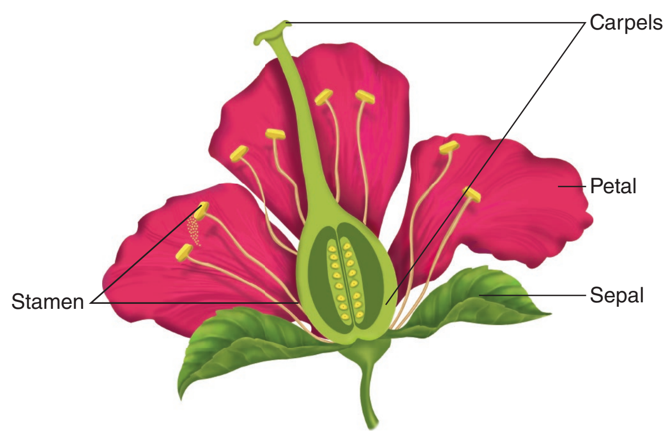


Figure 1.1 A flower, one of the defining characteristics of angiosperms.

*Each kind of organism, or species, has a two-part scientific name consisting of a genus name and a specific epithet; for example, white oak is known scientifically as *Quercus alba.* After the first mention of a scientific name, the genus name can be abbreviated, *Q. alba.* When referring to oaks in general, it is acceptable to use the genus name, *Quercus,* alone. Sometimes an abbreviation for species, "sp." or plural "spp.," stands in for the specific epithet—e.g., *Quercus* sp. or *Quercus* spp. Both common and scientific names are used throughout this book; details on this topic are found in Chapter 8.

are seed-bearing plants, but the seeds are not formed in fruits. Gymnosperm seeds are generally produced in cones. One group of gymnosperms consists of conifers, such as pines, cedars, and redwoods. Among the non-flowering plants, the conifers have the greatest impact on society as a source of wood for construction, fuel, and paper. Non-flowering land plants are presented in Chapter 9, and additional material on conifer wood is presented in Chapter 18.

The Algae

Algae are a diverse group of photosynthetic organisms that are found in marine and freshwater habitats where they serve as the base of food chains. They range from microscopic organisms to large seaweeds and kelp that form extensive underwater forests. All algae were once considered the most primitive members of the Plant Kingdom, but today most types of algae are classified in separate kingdoms along with other simple organisms. Only the green algae (fig. 1.2a) are considered part of the Plant Kingdom. Many species of algae are recognized as important and nutritious food for people throughout the world; however, the widespread uses of algal extracts for industrial applications and as food additives generally go unrecognized.

A negative aspect of the algae is related to environmental damage caused by algal blooms, which are sudden population explosions of certain algal species. In recent years, the occurrence of algal blooms has increased throughout the world. Although these blooms sometimes occur naturally, the increase is believed to be related to nutrient pollution, especially from agricultural runoff, human sewage, and animal wastes. Blooms are particularly dangerous when the algae are capable of producing toxins that can cause massive fish kills or human poisoning. The algae and their connections to society will be examined in Chapter 22.

(a)

(b)

Figure 1.2 (a) Boulder covered in a green alga known as sea lettuce, *Ulva* sp., on a beach in Cornwall, England. (b) Cluster of deer mushrooms, *Pluteus cervinus,* growing on mulch in an Oklahoma garden.

Table 1.1
How Much Do Plants Affect Society?

__________	1.	True or False—Plants provide most of the calories and protein for the human diet.
__________	2.	True or False—Today plant extracts are widely used in herbal remedies and alternative medicine, but they are no longer important in prescription drugs.
__________	3.	True or False—The search for cinnamon led to the discovery of North America.
__________	4.	True or False—New varieties of plants are being created through genetic engineering; these provide enormous profits for large agrotechnology companies but have no practical value.
__________	5.	True or False—The introduction of the potato to Europe in the sixteenth century initiated events that led to a devastating famine in Ireland.
__________	6.	True or False—Trees are the only source of pulp for papermaking.
__________	7.	True or False—The estimated number of genes in *Arabidopsis thaliana,* the first plant genome sequenced, has about one-fourth the number of genes estimated for the human genome.
__________	8.	True or False—The Salem Witchcraft Trials in the 1690s might have resulted from a case of fungal poisoning.
__________	9.	True or False—Tomatoes were once considered to be an aphrodisiac.
__________	10.	True or False—A poisonous plant is one of the most important dietary staples in the tropics.

(*continued*)

Table 1.1
Continued

Answers	
1. True	In nations such as the United States and those in Western Europe, approximately 65% of the total caloric intake and 35% of the protein are obtained directly from plants, while in developing nations close to 90% of the calories and over 80% of the protein are from plants (Chapters 10, 15).
2. False	Approximately 25% of all prescription drugs in Western society contain ingredients derived from plants; however, 80% of the world's population does not use prescription drugs but relies exclusively on herbal medicine (Chapter 19).
3. True	Columbus was one of many explorers trying to find a sea route to the rich spicelands of the Orient. Cinnamon and other spices were so valued in the fifteenth century that a new, faster route to the East would bring untold wealth to the explorer and his country (Chapter 17).
4. False	Transgenic crops, containing one or more genes from another organism, are being planted throughout the world. Some of these crops have been engineered to be more nutritious, disease resistant, or insect resistant and have been found to be beneficial to people and the environment (Chapter 15).
5. True	The potato, native to South America, became a staple food for the poor in many European countries, especially Ireland. The widespread dependence on a single crop led to massive starvation when a fungal disease, late blight of potato, destroyed potato fields in the 1840s. Over 1 million Irish died from starvation or subsequent diseases; another 1.5 million emigrated (Chapter 14).
6. False	While trees provide a sizeable percentage of pulp for the world's paper, many types of plant material can be used. Historically, cotton, hemp, linen, rice straw, and bamboo have been used as sources of pulp. Also, recycling paper helps decrease our dependence on trees for pulp. Recycling a 1.2-meter (4-foot) stack of newspapers would save a 12-meter (40-foot) tree (Chapter 18).
7. False	*Arabidopsis* is estimated to have over 27,000 genes, more than that of the fruit fly and even more than the estimate of 20,500 genes for the human genome (Chapter 7).
8. True	Searching for the cause of the hysteria that led to the accusations of witchcraft in Salem, Massachusetts, some historians have suggested ergot poisoning. Caused by a fungal disease of rye plants, an ergot forms in place of a normal grain and produces hallucinogenic toxins. Consumption of contaminated rye flour can lead to hallucinations, neurological symptoms, or even death (Chapter 25).
9. True	When tomato plants were first introduced to Europe, they were viewed with suspicion by many people, since poisonous relatives of the tomato were known. It took centuries for the tomato, neither poisonous nor an aphrodisiac, to fully overcome its undeserved reputation (Chapters 6, 20).
10. True	Bitter varieties of cassava (*Manihot esculenta*) contain deadly quantities of hydrocyanic acid (HCN), which can cause death by cyanide poisoning. Cultures in South America, Africa, and Indonesia have developed various processing methods to remove HCN and render the cassava edible (Chapter 14).

The Fungi

One other group of organisms that has had a significant impact on society is the fungi, including the molds, mildews, yeast, and mushrooms (fig. 1.2b). Although biologists once considered the fungi a type of simple plant, today they classify them as neither plants nor animals but put them in other kingdoms. Second only to the angiosperms in economic importance, the fungi provide many beneficial items, such as penicillin, edible mushrooms, and, through the process of fermentation, beer, wine, cheese, and leavened bread. A negative aspect of their economic importance is the impact of fungal disease and spoilage. The most serious diseases of our crop plants are caused by fungi, resulting in billions of dollars in crop losses each year.

Fungi generally have a threadlike body, the **mycelium,** and propagate by reproductive structures called **spores.** Fungi are nonphotosynthetic organisms, obtaining their nourishment from decaying organic matter as **saprobes** or as **parasites** of living hosts. Ecologically, the fungi play an essential role as **decomposers,** recycling nutrients in the environment. Many fungi are also involved in symbiotic relationships with other organisms. The best known of these relationships are lichens, which are composite organisms formed by a fungus and an alga living together. Because of their traditional ties to botany (the study of plants), the fungi and their impact on humanity will be considered in this book and are presented in Chapters 23–25.

Plant Sciences

When humans began investigating the uses of plants for food, bedding, medicines, and fuel, the beginnings of plant science were evident. Early peoples were skilled regional botanists and passed on their knowledge to succeeding generations. This folk botany gradually amassed a great body of

Table 1.2
Subdisciplines of Botany

Bryology	Study of mosses and liverworts
Economic botany	Study of the utilization of plants by humans
Ethnobotany	Study of the use of plants by indigenous peoples
Forestry	Study of forest management and utilization of forest products
Horticulture	Study of ornamental plants, vegetables, and fruit trees
Mycology	Study of fungi
Paleobotany	Study of fossil plants
Palynology	Study of pollen and spores
Phycology	Study of algae
Plant anatomy	Study of plant cells and tissues
Plant ecology	Study of the role of plants in the environment
Plant biotechnology	Study and manipulation of genes between and within species
Plant genetics	Study of inheritance in plants
Plant morphology	Study of plant form and life cycles
Plant pathology	Study of plant disease
Plant physiology	Study of plant function and development
Plant systematics	Study of the classification and naming of plants

knowledge, laying the foundation for scientific botany, which began in ancient Greece. As the body of knowledge expanded over the centuries, areas of specialization developed within botany, and today many of them are recognized as disciplines in their own right (table 1.2).

Scientific Method

Like other biologists, botanists make advances through a process called the scientific method. This process is the tool that scientists use to study nature and develop an understanding of the natural world. Although the exact steps vary depending on the scientific discipline, generally the scientific method includes careful observation of some natural phenomenon, the development of a hypothesis (tentative explanation for the observation), the use of the hypothesis to make predictions, and experimentation to test the hypothesis. It is often necessary to modify the hypothesis based on the results of the experiments. This, too, is part of the scientific method.

Observation

Scientific study often begins with an observation. It may be something seen repeatedly, such as the blooming of tulips only in the spring. Another type of observation might be the realization that you and others in your family have allergy problems only in September and early October. Observations lead to speculations and questions. You might wonder what causes your September hay fever. With some research on the subject, you might learn that ragweed pollen in the air is the leading cause of fall hay fever. A visit to an allergist confirms the fact that you are allergic to ragweed pollen; however, you cannot find any ragweed plants in your neighborhood. This may lead you to ask the following questions: "Is there ragweed pollen in the air even though there are no plants near my home? Could this be causing my hay fever symptoms?"

Hypothesis

A hypothesis is a possible explanation or working assumption for the original observations. It comes directly from your observations and questions. In the example given here, you might form the following hypothesis: "Airborne ragweed pollen causes my hay fever symptoms every September and October." You may even make some predictions that your symptoms will increase when the airborne pollen level is high.

Hypothesis Testing

Once you have stated your hypothesis, you can find ways to test the hypothesis through experimentation. First, you must decide what type of evidence you will need. You find out information about air sampling and pollen identification and decide you will conduct air sampling from July to October during the coming year and determine the types of pollen in the air. You also decide to keep a daily diary of hay fever symptoms during this time and to search for ragweed plants in other locations. Your field work shows that ragweed plants are abundant in an abandoned field about 1 mile south of your neighborhood and along the banks of the river running through your town. Your air sampling data show that ragweed pollen first appeared in the air in late August and increased during the first 2 weeks of September, with the peak on September 12. The pollen levels then began decreasing and were gone from the air by late October. Your symptom chart showed a similar pattern, and, with the help of a friend who is studying statistics, you find a significant correlation between the pollen level and symptoms. The occurrence of ragweed pollen in the air, your symptom diary, and the presence of ragweed plants in town allow you to accept the hypothesis as correct.

Through the use of the scientific method, the body of knowledge increases, allowing scientists to expand their understanding of the workings of the natural world and leading to the development of scientific theories. In science, a theory is an accepted explanation for natural phenomena that is supported by extensive and varied experimental evidence. This definition is very different from the common usage of the word *theory*, which often means a guess. The scientific meaning of theory will always be used in

A CLOSER LOOK 1.1

Biological Mimics

The architecture of nature far surpasses any design developed by modern technology. In fact, engineers and inventors often appropriate their best ideas directly from the natural world. Both Velcro™ and barbed wire duplicate the designs found in certain plants.

Today, Velcro™ has hundreds of uses in diapers, running shoes, and space suits, even in sealing the chambers of artificial hearts. But it started from observations during the tedious task of removing cockleburs from clothing. In 1948, a Swiss hiker, George de Mestral, observed the manner in which cockleburs clung to clothing and thought that a fastener could be designed using the pattern. Cockleburs (box fig. 1.1a) have up to several hundred curved prickles that function in seed dispersal. These tiny prickles tenaciously hook onto clothing or the fur of animals and are thus transported to new areas. De Mestral envisioned a fastener with thousands of tiny hooks, mimicking the cocklebur prickles on one side and, on the other side, thousands of tiny eyes for the hooks to lock onto (box fig. 1.1b). It took 10 years to perfect the original concept of the "locking tape" that has become Velcro™, so common in modern life.

Osage orange (*Maclura pomifera*) is a tree in the mulberry family native to the south-central region of the United States in the area common to Oklahoma, Missouri, Texas, and Arkansas. It has several notable features. Female trees bear large, yellow-green fruits, nicknamed hedge apples (see fig. 8.5a). Hedge apples apparently contain chemicals that repel many insects, and they have been collected for that purpose. The bark is brown with a definite orange tint and becomes more furrowed and shaggier with age. The wood, which is bright orange, very dense, and resistant to rot and termites, was used by several Native American tribes to make war clubs and bows. This usage prompted the French to call the tree *bois d'arc,* meaning wood of the bow. But this story concentrates on the thorns. They are quite formidable. About an inch (2.54 centimeters) long, they alternate in spiral fashion along the length of the branch (box fig. 1.1c). It is these thorny branches that made the osage orange so valuable in the settling of the western plains in North America.

Osage orange was in great demand for its use as a living fence in the vast, treeless plains of the West. The trees were planted close and pruned aggressively to promote a bushy and thorny hedge. Because osage orange is a quick-growing tree, a fence of osage orange took only 4 or 5 years to fill out and could survive for more than a hundred years. Cuttings and seeds of osage orange were collected and sent to farmers throughout America to establish a thorny hedgerow to corral livestock and protect crops. In 1850, a single bushel of osage orange seed cost $50—a fantastic sum in those days. In 1860 alone, 10,000 bushels of seeds were sold, enough to produce 60,000 miles of hedge. In abandoned fields, you can still come across some of these old osage orange hedges or their descendants.

The osage orange hedge did have some drawbacks. A living fence could house insects and other vermin, rob the soil of nutrients and water, and produce shade that could interfere with crop growth. Also, they were not readily movable. What was needed was a new and improved hedgerow, and Michael Kelly was the first, in 1868, to patent a thorny fence made of wire that mimicked the branches of osage orange. It consisted of a single strand of wire with fitted, diamond-shaped sheet metal "barbs" at 6-inch intervals. Kelly established the Thorn Wire Hedge

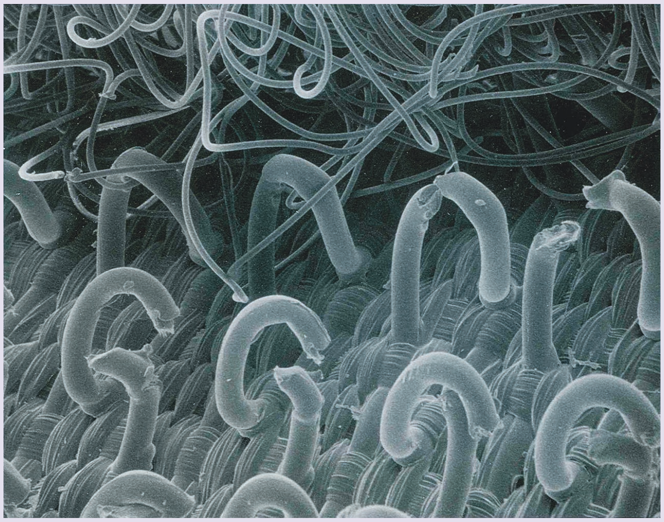
this book. The Cell Theory and Darwin's theory of evolution through natural selection are two of the theories that will be described.

FUNDAMENTAL PROPERTIES OF LIFE

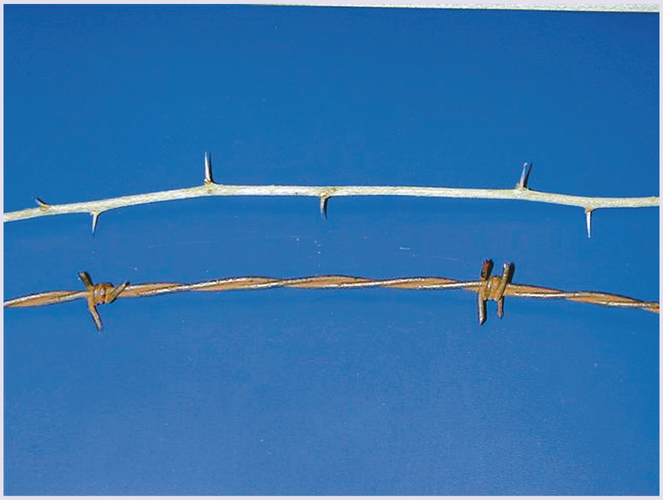
Although living organisms can be as different as oak trees, elephants, and bacteria, they share certain fundamental properties. These properties include the following:

1. **Growth and Reproduction** Living organisms have the capacity to grow and reproduce. Growth is defined as an irreversible increase in size and should not be confused with simple expansion. Although balloons and crystals can enlarge, this enlargement is not true growth. The ability to reproduce, or produce new individuals, is common to all life. Reproduction can be **sexual,** involving the fusion of **sperm** and **egg** to form a **zygote,** or **asexual,** in which the offspring are genetic clones of a single parent.
2. **Ability to Respond** The environment is never static; it is always changing, and living organisms have the capabilities to respond to these changes. These responses can be obvious, such as a stem turning toward the light (fig. 1.3) or an animal hibernating for the winter. Sometimes, however, the responses are subtle, such as changes in the chemical composition of leaves in trees

(a)



(b)



(c)

Box Figure 1.1 Biological mimicry. (a) The prickles on cocklebur. (b) Hooks on Velcro™. (c) Barbed wire is a design based on the thorny branches of osage orange.

Company in 1876 to manufacture his invention. Ultimately, he was bested by his competitors, who had similar ideas and a more successful design. Soon, the vast, open plains of the West were crisscrossed with fences of barbed wire (box fig. 1.1c). In a real sense, the Wild West was tamed by the thorny branches of osage orange.

Figure 1.3 A field of sunflowers with their heads all facing the sun.

under attack by insects. The chemical composition of intact leaves is altered, making the leaves unpalatable to the insects.

3. **Ability to Evolve and Adapt** All life constantly changes, or evolves. This process has been going on for billions of years, as evidenced by the fossil record. Sometimes changes promote survival because the altered species is better adapted to its environment. Many desert plants have evolved water-storing tissue, an adaptation that helps them survive in their arid environment.
4. **Metabolism** Metabolism is the sum total of all chemical reactions occurring in living organisms. Two of the most important metabolic reactions are **cellular respiration**

and photosynthesis. Respiration is a metabolic process in which food is chemically broken down to release energy. All life requires energy to run chemical reactions, and respiration occurs in all living organisms. Photosynthesis occurs in green plants, algae, and some bacteria. It is the process that links the energy of the sun with life on Earth. In this process, photosynthetic organisms utilize solar energy to manufacture sugars.

5. **Organized Structure** All living organisms are composed of one or more cells; the cell is the basic structure of life. The unique structures encountered in living organisms are often the inspiration for manufactured items, as seen in A Closer Look 1.1: Biological Mimics. From the smallest unicellular organism to the largest multicellular organism, all show a high degree of organization and coordination. The simplest level of organization is seen in bacteria, which are **prokaryotic cells** (fig. 1.4a). These are the most primitive types of cells known. All other organisms are composed of **eukaryotic cells.** In a eukaryotic cell, the **nucleus,** containing the hereditary material, is clearly visible (fig. 1.4b), and different metabolic activities are compartmentalized into specialized membrane-bound structures called **organelles.** Prokaryotic cells lack a discernible internal organization. Prokaryotes have no organized nucleus or other obvious membrane-bound structures, but they have hereditary material and carry out all the activities of life.
6. **Organic Composition** All living organisms are composed mainly of four types of compounds: **carbohydrates, proteins, lipids,** and **nucleic acids.** These are the molecules of life.

MOLECULES OF LIFE

The chemical composition of life is based on the element carbon and the classes of carbon compounds known as carbohydrates, lipids, proteins, and nucleic acids. Carbon is covalently bonded to other carbon atoms to create carbon chains that form the skeletons of these molecules. These four classes of compounds are the most important molecules in living organisms and often exist as large, complex **macromolecules;** however, other compounds also occur (see A Closer Look 1.2: Perfumes to Poisons). Carbohydrates, lipids, and proteins also constitute the major nutrients in the human diet and are discussed in detail in Chapter 10.

Carbohydrates

Carbohydrates, which include **sugars** and **starches** as well as **cellulose,** are composed of carbon, hydrogen, and oxygen (fig. 1.5). Many carbohydrates, especially **glucose,** are sources of energy for cells, while other carbohydrates, such as cellulose, are structural materials. The smallest carbohydrates are the **monosaccharides,** or the simple sugars. These contain only one sugar molecule; the most familiar examples of monosaccharides are glucose and **fructose.** The general formula for monosaccharides is $C_nH_{2n}O_n$, with *n* equal to 3, 4, 5, 6, or 7. Glucose and fructose have the same general formula, $C_6H_{12}O_6$, but they have different arrangements of the atoms and react differently.

Two sugar molecules chemically bonded together are known as a **disaccharide.** Common table sugar, **sucrose,** is a disaccharide composed of one glucose molecule and one

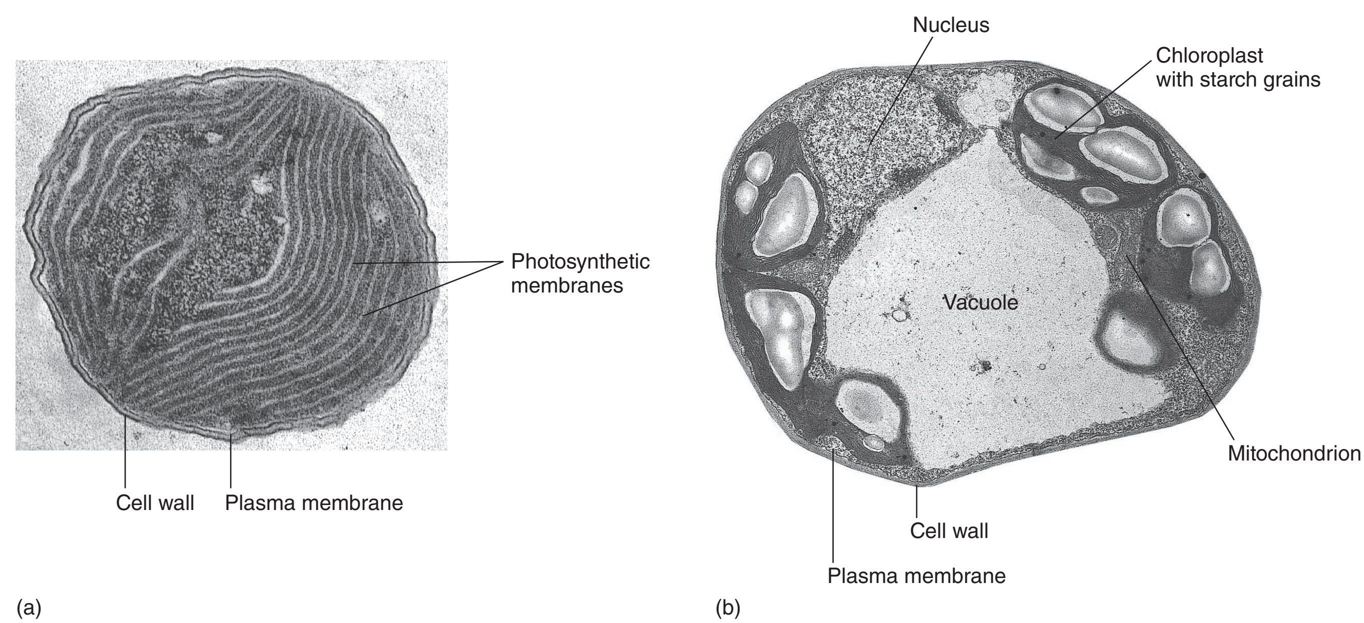


Figure 1.4 Cellular organization. (a) Prokaryotic cell. Although this cyanobacterial cell does contain internal photosynthetic membranes, there are no membrane-bound organelles or nucleus. (b) Eukaryotic cell. This *Elodea* leaf cell shows a nucleus and such membrane-bound organelles as chloroplasts, mitochondria, and a vacuole.

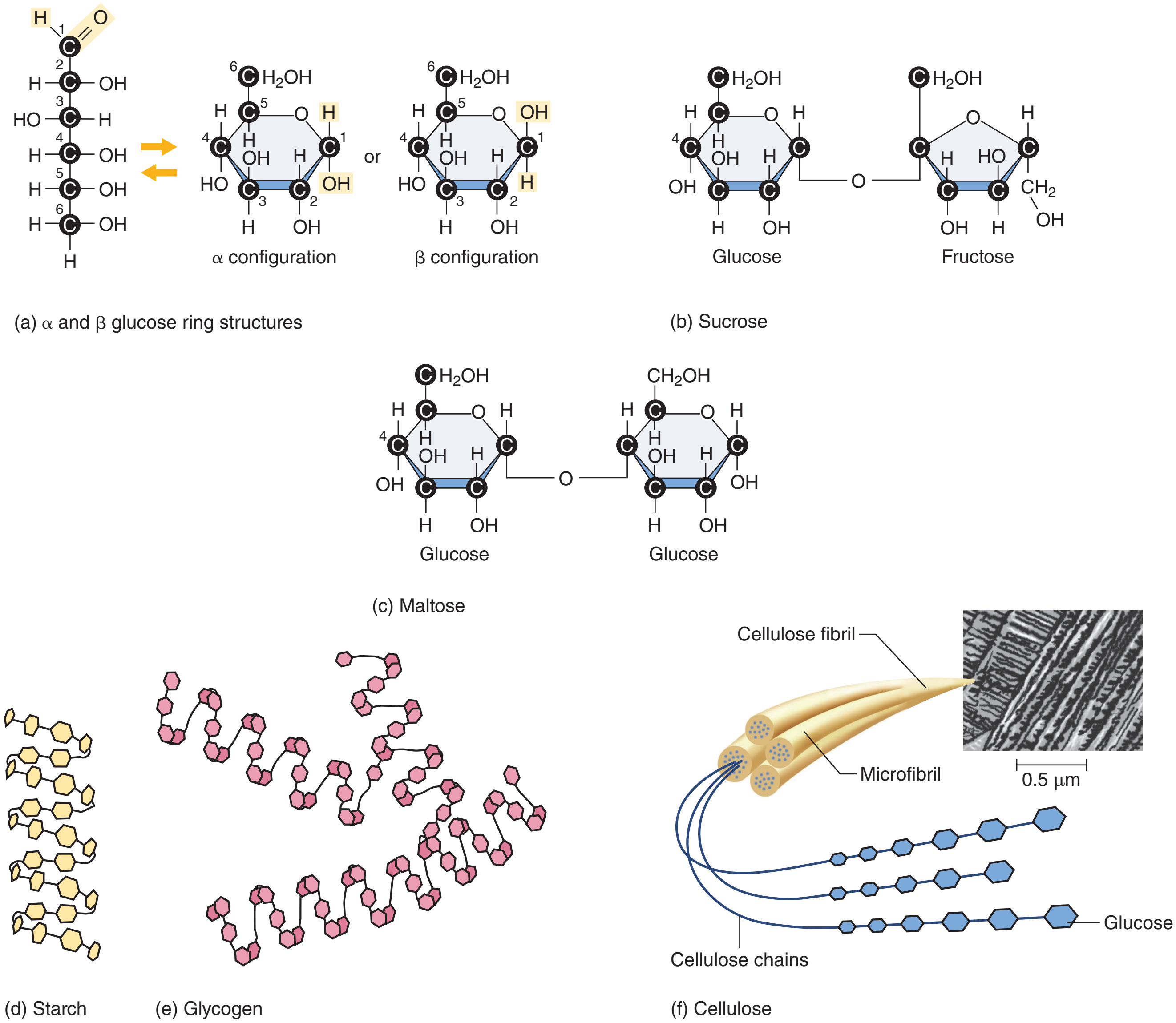


Figure 1.5 Carbohydrates. (a) Monosaccharides are known as simple sugars. Glucose, the most abundant monosaccharide, can exist in a straight chain or ring configuration. (b) Sucrose, a disaccharide, is composed of a molecule of glucose and a molecule of fructose bonded together. (c) Maltose, another disaccharide, forms from two glucose molecules. (d)–(f) Polysaccharides. All three molecules are made from thousands of glucose molecules, but they have different bonding arrangements. (d) Starch found as a storage molecule in green plants. (e) Glycogen found as a storage molecule in animals, bacteria, and fungi. (f) Cellulose, a structural component of plant cell walls, scanning electron micrograph.

fructose molecule. Although most plants transport carbohydrates from one part of the plant to another in the form of sucrose, only a few plants actually store this molecule (see A Closer Look 4.2: Sugar and Slavery). Most sucrose for table use comes from either sugarcane or sugar beet (fig. 1.5). Maltose, another disaccharide, contains two glucose molecules. This sugar is seldom found free in plants but is a breakdown product of starch and an important ingredient in the brewing of beer.

Polysaccharides consist of many thousands of sugar molecules bonded together. The three most common polysaccharides are starch, glycogen, and cellulose. These three are all composed of repeating glucose molecules, but they have different chemical bonding and arrangements (fig. 1.5). Both starch and glycogen are storage molecules; starch occurs in green plants, while glycogen is found in fungi, bacteria, and animals. Starch stored in plant stems, roots, seeds, and fruit is a major source of food for the human population (Chapters 6, 12, and 14). Cellulose is a structural component of plant cell walls, while chitin, a more complex molecule, is the major structural component in fungal cell walls.

Proteins

Proteins are large, complex macromolecules composed of smaller molecules known as **amino acids.** Carbon, hydrogen, oxygen, nitrogen, and sulfur are the elements found in

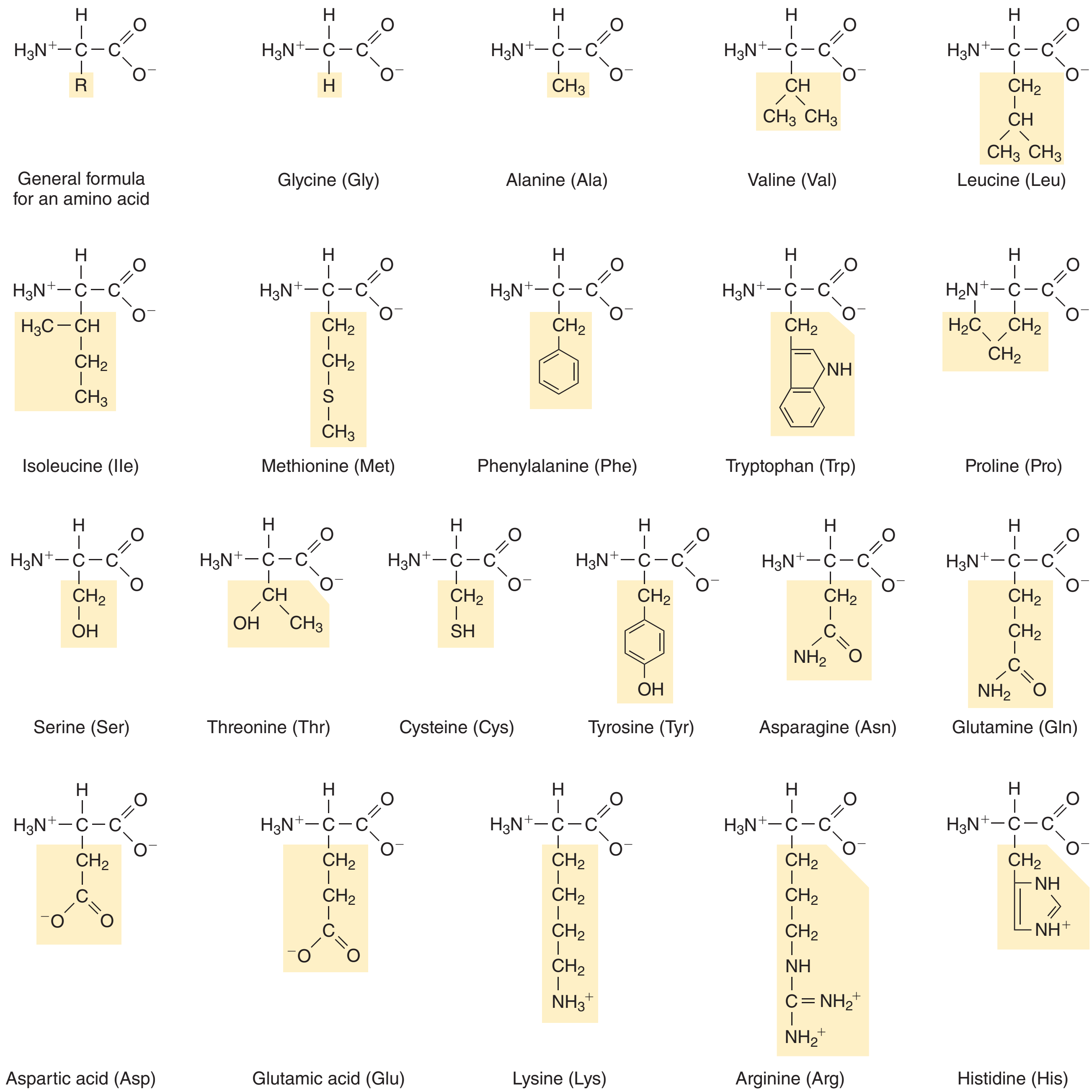


Figure 1.6 Amino acids. General formula for an amino acid and the 20 naturally occurring amino acids. All have the same backbone (N-C-C) and differ only in the side group (R-group) attached to the center carbon.

proteins. There are 20 different amino acids that are common to all life forms. All amino acids have a common backbone with a nitrogen atom and two carbon atoms (N-C-C) and differ only in the side group, called an R-group, attached to the central carbon atom (fig. 1.6). The number and arrangement of these 20 amino acids result in an infinite variety of proteins. Amino acids are attached to each other by a special covalent bond called a peptide bond, and long chains of amino acids are called **polypeptide** chains. In the complete protein structure, the polypeptide chain is twisted and folded into a specific, three-dimensional shape (fig. 1.7). Proteins have many functions; they can serve as enzymes (biological catalysts), structural materials, regulatory molecules, or transport molecules, to name a few of their many roles. Proteins produced by plants, especially legumes, are an important source of nutrients for the human diet (Chapter 13).

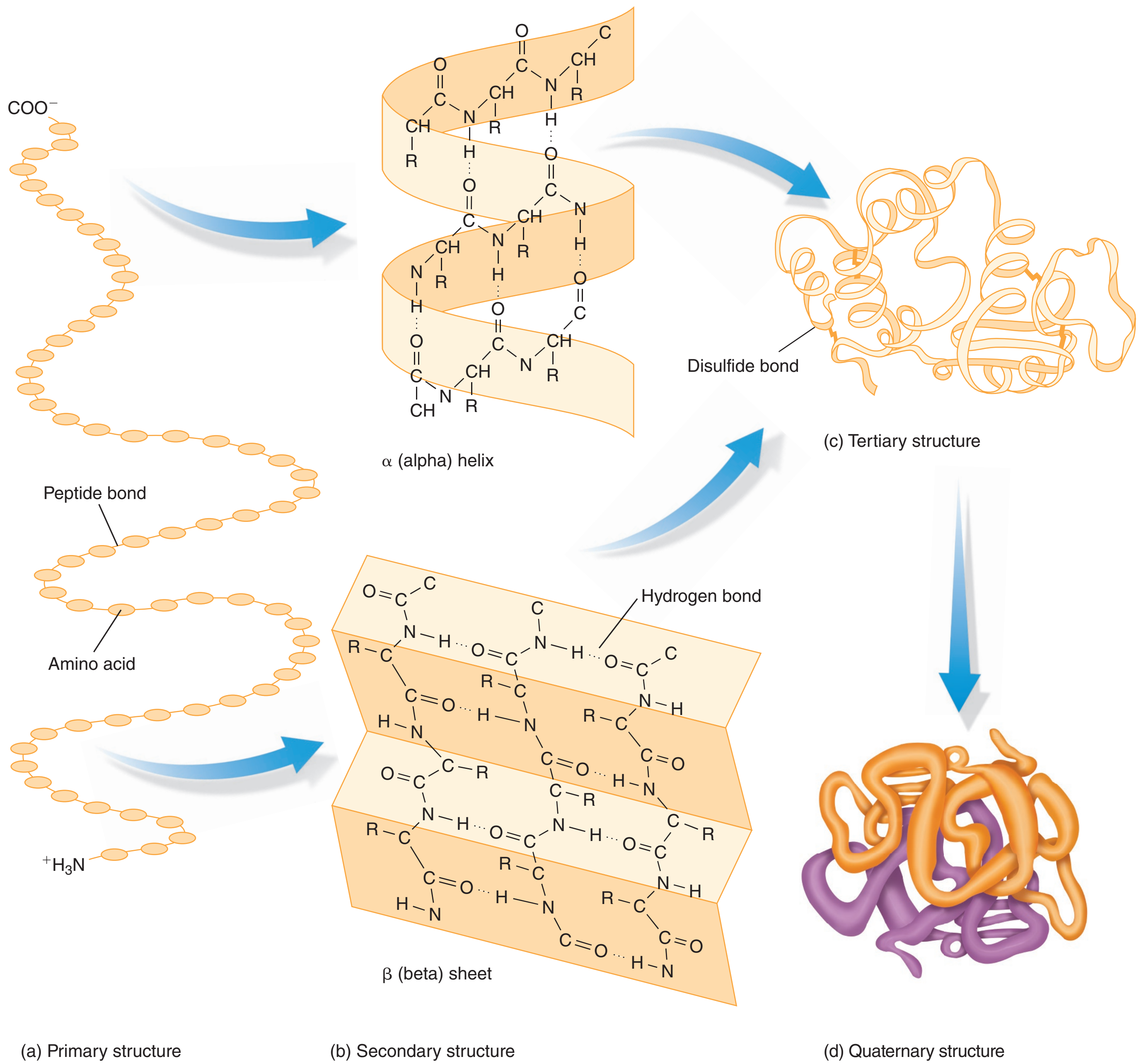


Figure 1.7 Protein structure. (a) Primary protein structure consists of the sequence of amino acids bonded together by peptide bonds to make a polypeptide chain. (b) Secondary protein structure consists of a helix, or pleated sheet, that spirals or folds the polypeptide chain. This is stabilized by hydrogen bonds. (c) Tertiary structure is a twisting and folding of the molecule. (d) Quaternary structure contains more than one polypeptide chain, each with its own tertiary structure.

Thinking Critically

The four major groups of macromolecules in living organisms are carbohydrates, proteins, lipids, and nucleic acids.

What are the primary roles of each of the molecules?

Lipids

Lipids are a diverse group of substances largely composed of only carbon and hydrogen. Small amounts of oxygen may occur in some lipids. There are many different types of lipids; what they have in common is that they are insoluble in water. Lipids include such compounds as **triglcerides, phospholipids, steroids** (fig. 1.8), and waxes. Different types of lipids have different functions. They can be important as

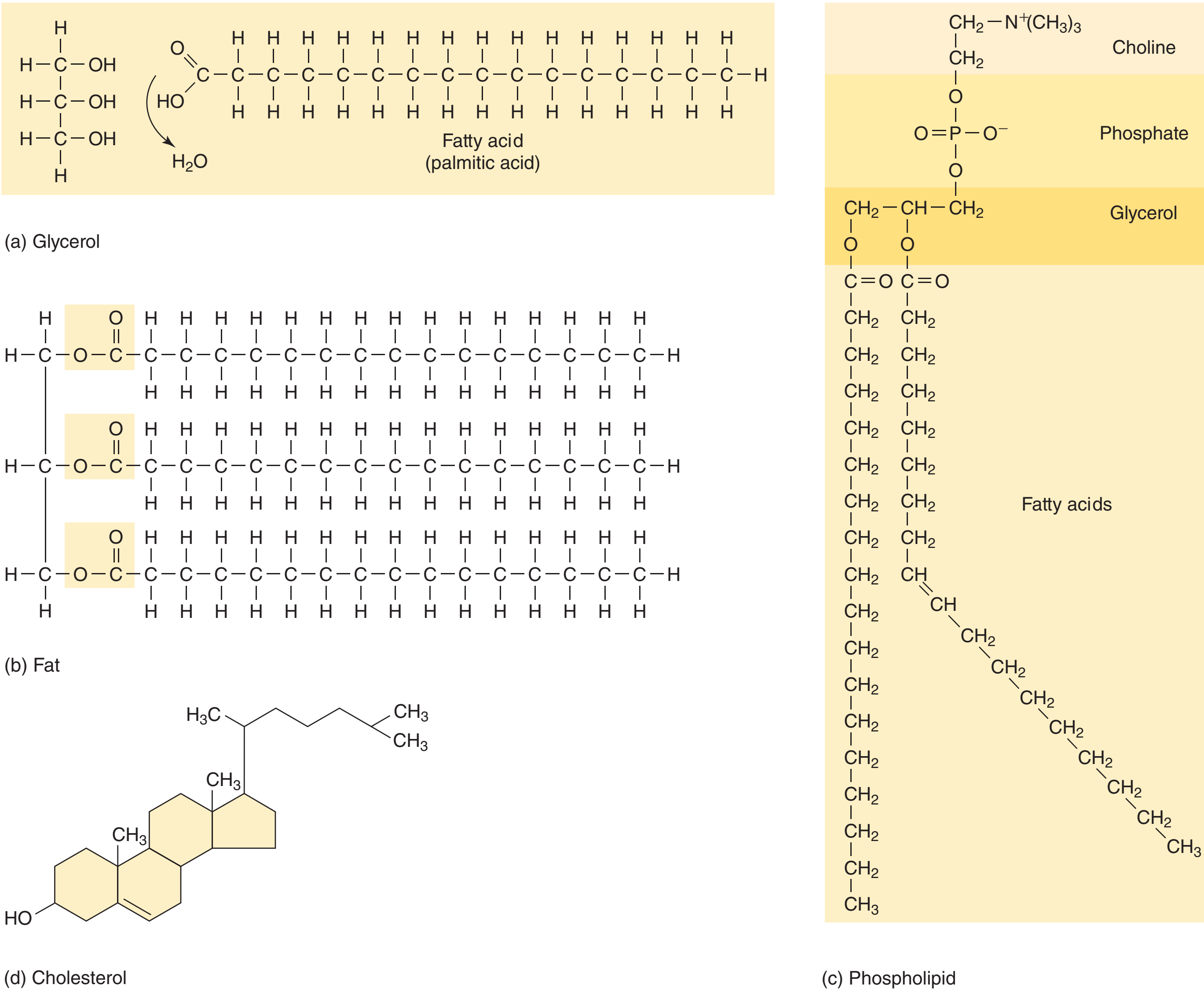


Figure 1.8 Lipids. (a) The building blocks of fats and oils consist of glycerol and fatty acids. (b) A fat, or triglyceride, formed from glycerol and three fatty acids. (c) A phospholipid is formed from glycerol, two fatty acids, a phosphate group, and choline. (d) Cholesterol, one of many steroids, is a more complex lipid. The four-ring steroid backbone is shaded.

sources of energy (triglycerides), as structural components of cell membranes (phospholipids and cholesterol), or as hormones (steroids). Triglycerides, better known as fats and oils, function as food reserves in many organisms. Fats are the usual energy reserves in animals, while seeds and fruits of certain plants store appreciable amounts of oil, which has been used by humans for thousands of years (Chapter 13).

Nucleic Acids

Nucleic acids contain carbon, hydrogen, oxygen, nitrogen, and phosphorus. Nucleic acids are composed of repeating units called **nucleotides,** which consist of a sugar (either **ribose** or **deoxyribose**), a phosphate group $(PO_4)^{-3}$, and a nitrogenous base (either a **purine** or a **pyrimidine base**) (fig. 1.9). Five different types of nucleotides occur, depending on the type of base. There are two purine bases, **adenine** and **guanine,** and three pyrimidine bases, **thymine, cytosine,** and **uracil. Deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)** are the two types of nucleic acids. Nucleotides containing adenine, guanine, and cytosine occur in both DNA and RNA. Thymine nucleotides occur only in DNA; uracil replaces thymine in RNA. Thus, both DNA and RNA contain four types of nucleotides, two purines and two pyrimidines.

It is the sequence of these nucleotide bases in the DNA molecule that is the essence of the genetic code. DNA is the hereditary material of life, unique in its ability to replicate itself and thus pass on the genetic code from one generation to the next. DNA, often called the **double helix** (fig. 1.9), exists

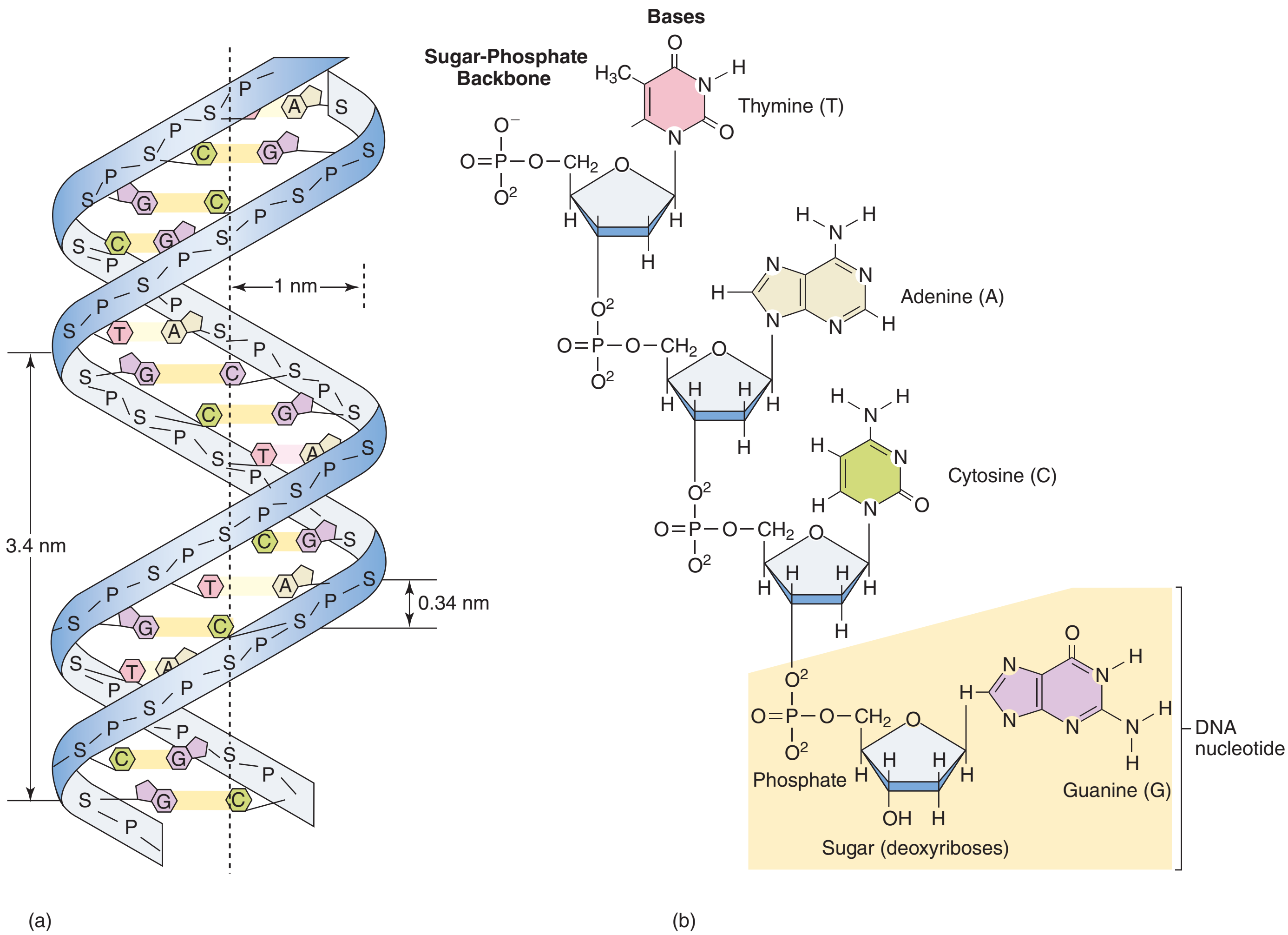


Figure 1.9 DNA molecule. (a) The double helix with the sugar-phosphate backbone making up the sides and the paired nitrogenous bases the interior. (b) Structures of the nucleotides (sugar, phosphate, and base) that make up the DNA molecule.

as a double-stranded molecule that is twisted into a helix. The sides of the helix are made of alternating sugar (deoxyribose) and phosphate groups, and the nitrogenous bases are found as purine-pyrimidine pairs (adenine always pairs with thymine and guanine with cytosine) in the interior of the helix.

Unlike DNA, RNA usually consists of a single strand, with ribose as part of the sugar-phosphate backbone. RNA is involved in the manufacture of proteins, using the instructions coded on the DNA molecule. The sequence of bases in DNA makes up a **gene,** and each gene codes for the formation of a specific product (see Chapter 7).

CHAPTER SUMMARY

1. Angiosperms, also called flowering plants, supply humanity with the essentials of life. The food staples of civilization—wheat, rice, and corn—are all angiosperms, as are almost all other food crops. Other angiosperm products that have shaped modern society include cloth, hardwood, herbs and spices, beverages, drugs, perfumes, vegetable oils, gums, and rubber.

2. The algae are aquatic, photosynthetic organisms that show a great diversity of form, ranging in size from the microscopic unicellular algae to gigantic seaweeds. They are important as components of aquatic food chains, contributors to the global photosynthetic rate, and sources of a number of economically important products. However, in the case of algal blooms, they can be detrimental to both the environment and the economy.

3. Fungi are also an economically important group of organisms. They include molds, mildews, yeast, and mushrooms. Fungi provide many beneficial items, such as penicillin, beer, wine, edible mushrooms, and leavened bread. A negative aspect of their economic importance is the impact of fungal disease and spoilage.