

The background of the cover is a deep, dark purple. In the foreground, there are two large, light green Passiflora flowers with intricate blue and white patterns on their petals and centers. The flowers are shown in various stages of bloom, with some buds visible. The overall composition is artistic and focuses on the botanical details of the plant.

STERN'S  
**INTRODUCTORY**

# Plant Biology

Thirteenth Edition

James E. Bidlack

Shelley H. Jansky



edition thirteen

INTRODUCTORY

# Stern's Plant Biology

**James E. Bidlack**

University of Central Oklahoma

**Shelley H. Jansky**

University of Wisconsin–Madison





STERN'S INTRODUCTORY PLANT BIOLOGY, THIRTEENTH EDITION

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# Contents in Brief

## About the Authors ix

## Preface x

- 1** What Is Plant Biology? 1
- 2** The Nature of Life 13
- 3** Cells 29
- 4** Tissues 53
- 5** Roots and Soils 65
- 6** Stems 85
- 7** Leaves 104
- 8** Flowers, Fruits, and Seeds 124
- 9** Water in Plants 147
- 10** Plant Metabolism 164
- 11** Growth and Development 191
- 12** Meiosis and Alternation of Generations 216
- 13** Genetics and Molecular Biology 226
- 14** Plant Breeding, Propagation, and Biotechnology 249
- 15** Evolution 268
- 16** Plant Names and Classification 282
- 17** Domain (Kingdom) Bacteria, Domain (Kingdom) Archaea, and Viruses 298
- 18** Kingdom Protista 322
- 19** Kingdom Fungi 351
- 20** Introduction to the Plant Kingdom: Bryophytes 376
- 21** The Seedless Vascular Plants: Ferns and Their Relatives 391
- 22** Introduction to Seed Plants: Gymnosperms 416
- 23** Seed Plants: Angiosperms 435
- 24** Flowering Plants and Civilization 455
- 25** Ecology 481
- 26** Biomes 506

**Appendix 1** Scientific Names of Organisms Mentioned in the Text A1

**Appendix 2** Biological Controls A20

**Appendix 3** Useful and Poisonous Plants, Fungi, and Algae A27

**Appendix 4** House Plants and Home Gardening A52

**Appendix 5** Metric Equivalents and Conversion Tables A76

**Glossary G1**

**Photo Credits C1**

**Index I1**

# Contents

## About the Authors ix

## Preface x

### 1 What Is Plant Biology? 1

- Overview 2
- Learning Outcomes 2
- The Relationship of Humans to Their Environment 3
- KEY THEME: ecology** Who Needs Plants? 4
- Botany as a Science 7
- Diversification of Plant Study 7
- Plant Biology and the Internet 9
- SUMMARY 11
- REVIEW QUESTIONS 11
- DISCUSSION QUESTIONS 11
- ADDITIONAL READING 11
- LEARNING ONLINE 12

### 2 The Nature of Life 13

- Overview 14
- Learning Outcomes 14
- Attributes of Living Organisms 14
- Chemical and Physical Bases of Life 15
- KEY THEME: molecular** The Skinny on Fats 23
- SUMMARY 27
- REVIEW QUESTIONS 28
- DISCUSSION QUESTIONS 28
- ADDITIONAL READING 28
- LEARNING ONLINE 28

### 3 Cells 29

- Overview 30
- Learning Outcomes 30
- Cells 30
- Eukaryotic versus Prokaryotic Cells 33
- Cell Structure and Communication 33
- Cellular Components 36
- Cellular Reproduction 44
- Microscopes 48
- Higher Plant Cells versus Animal Cells 50
- SUMMARY 51
- REVIEW QUESTIONS 52
- DISCUSSION QUESTIONS 52
- ADDITIONAL READING 52
- LEARNING ONLINE 52

### 4 Tissues 53

- Overview 54
- Learning Outcomes 54
- Meristematic Tissues 54
- KEY THEME: molecular** Chimeras and Variegated Leaves 55
- Tissues Produced by Meristems 56
- KEY THEME: ecology** Plants and Environment 61
- SUMMARY 63
- REVIEW QUESTIONS 64
- DISCUSSION QUESTIONS 64
- ADDITIONAL READING 64
- LEARNING ONLINE 64

### 5 Roots and Soils 65

- Overview 66
- Learning Outcomes 66
- How Roots Develop 66
- Root Structure 67
- Specialized Roots 71
- KEY THEME: ecology** Plants Need Roots 75
- Mycorrhizae 76
- Root Nodules 77
- Human Relevance of Roots 77
- Soils 78
- KEY THEME: ecology** Metal-Munching Plants 81
- SUMMARY 82
- REVIEW QUESTIONS 83
- DISCUSSION QUESTIONS 83
- ADDITIONAL READING 84
- LEARNING ONLINE 84

### 6 Stems 85

- Overview 86
- Learning Outcomes 86
- External Form of a Woody Twig 86
- Origin and Development of Stems 87
- KEY THEME: ecology** Standing in Fields of Stone 88
- Tissue Patterns in Stems 90
- KEY THEME: ecology** Dendroclimatology 92

Specialized Stems 97  
Wood and Its Uses 99

SUMMARY 102  
REVIEW QUESTIONS 103  
DISCUSSION QUESTIONS 103  
ADDITIONAL READING 103  
LEARNING ONLINE 103

## 7 Leaves 104

Overview 105  
Learning Outcomes 105  
Leaf Arrangements and Types 106  
Internal Structure of Leaves 107  
Stomata 108  
Mesophyll and Veins 110  
Specialized Leaves 111  
**KEY THEME: ecology** More on Leaf  
Structure 112  
Autumnal Changes in Leaf Color 119  
Abscission 120  
Human and Ecological Relevance  
of Leaves 121

Glass Cuts from Grass? 122

SUMMARY 122  
REVIEW QUESTIONS 123  
DISCUSSION QUESTIONS 123  
ADDITIONAL READING 123  
LEARNING ONLINE 123

## 8 Flowers, Fruits, and Seeds 124

Overview 125  
Learning Outcomes 125  
Differences between Dicots and  
Monocots 128  
Structure of Flowers 128  
Fruits 129  
**KEY THEME: ecology** Goober Peas 131  
Fruit and Seed Dispersal 137  
Seeds 141  
The Seed That Slept for 1,200 Years 144

SUMMARY 145  
REVIEW QUESTIONS 146  
DISCUSSION QUESTIONS 146  
ADDITIONAL READING 146  
LEARNING ONLINE 146

## 9 Water in Plants 147

Overview 148  
Learning Outcomes 148  
Molecular Movement 149  
Measuring Water Potential and  
Psychrometry 151

Water and Its Movement through the Plant 153  
Regulation of Transpiration 156  
Transport of Food Substances (Organic  
Solute) in Solution 157

Mineral Requirements for Growth 159

SUMMARY 162  
REVIEW QUESTIONS 162  
DISCUSSION QUESTIONS 162  
ADDITIONAL READING 163  
LEARNING ONLINE 163

## 10 Plant Metabolism 164

Overview 165  
Learning Outcomes 165  
Enzymes and Energy Transfer 166  
Photosynthesis 166  
Photosynthesis and Pizza 176  
Respiration 180  
Additional Metabolic Pathways 186  
Assimilation and Digestion 187  
**KEY THEME: ecology** Photosynthesis, Global  
Warming, and Tropical Rain Forests 188

REVIEW QUESTIONS 190  
DISCUSSION QUESTIONS 190  
ADDITIONAL READING 190  
LEARNING ONLINE 190

## 11 Growth and Development 191

Overview 192  
Learning Outcomes 192  
Nutrients, Vitamins, and Hormones 192  
Plant Hormones beyond “The Classic Five” 200  
Hormonal Interactions 201  
Other Hormonal Interactions 201  
Plant Movements 202  
Photoperiodism 209  
Phytochromes and Cryptochromes 210  
A Flowering Hormone? 211  
Temperature and Growth 212  
Dormancy and Quiescence 213

SUMMARY 214  
REVIEW QUESTIONS 215  
DISCUSSION QUESTIONS 215  
ADDITIONAL READING 215  
LEARNING ONLINE 215

## 12 Meiosis and Alternation of Generations 216

Overview 217  
Learning Outcomes 217  
The Phases of Meiosis 218

**KEY THEME : ecology** Why Plants Have a Sex

Life 219

Alternation of Generations 222

**KEY THEME : molecular** FISH and GISH Molecular

Techniques 223

SUMMARY 224

REVIEW QUESTIONS 224

DISCUSSION QUESTIONS 224

ADDITIONAL READING 225

LEARNING ONLINE 225

## 13 Genetics and Molecular Biology 226

Overview 227

Learning Outcomes 227

Molecular Genetics 228

**KEY THEME : molecular** Massive DNA

Sequencing 230

**KEY THEME : molecular** The Polymerase

Chain Reaction (PCR) 232

Cytogenetics 237

Mendelian Genetics 238

Quantitative Traits 244

Extranuclear DNA 245

Linkage and Mapping 245

The Hardy-Weinberg Law 247

SUMMARY 247

REVIEW QUESTIONS 248

DISCUSSION QUESTIONS 248

ADDITIONAL READING 248

LEARNING ONLINE 248

## 14 Plant Breeding, Propagation, and Biotechnology 249

Overview 250

Learning Outcomes 250

Crop Plant Evolution 250

Plant Breeding 252

Plant Propagation 260

SUMMARY 266

REVIEW QUESTIONS 266

DISCUSSION QUESTIONS 267

ADDITIONAL READING 267

LEARNING ONLINE 267

## 15 Evolution 268

Overview 269

Learning Outcomes 269

An Introduction to Evolution 269

A Brief Overview of the Early Development of Evolutionary Concepts 271

Charles Darwin 273

Evidence for Evolution 274

Microevolution—Evolution within Species 275

Rates of Evolution 276

Macroevolution—How Species Evolve 276

The Role of Polyploidy in Evolution 278

Discussion 279

**KEY THEME : evolution** Our Daily Bread 280

SUMMARY 280

REVIEW QUESTIONS 281

DISCUSSION QUESTIONS 281

ADDITIONAL READING 281

LEARNING ONLINE 281

## 16 Plant Names and Classification 282

Overview 283

Learning Outcomes 283

Development of the Binomial System of Nomenclature 283

Development of the Kingdom Concept 286

Classification of Major Groups 287

Species Concepts 292

A Key to Major Groups of Organisms (Exclusive of Kingdom Animalia) 294

The Future of Plant Classification 296

SUMMARY 296

REVIEW QUESTIONS 297

DISCUSSION QUESTIONS 297

ADDITIONAL READING 297

LEARNING ONLINE 297

## 17 Domain (Kingdom) Bacteria, Domain (Kingdom) Archaea, and Viruses 298

Overview 299

Learning Outcomes 299

Features of Domains (Kingdoms) Bacteria and Archaea 300

Domain (Kingdom) Bacteria—the True Bacteria 303

Human Relevance of the Unpigmented, Purple, and Green Sulfur Bacteria 303

**KEY THEME : ecology** The Social Life of Prokaryotes 304

Class Cyanobacteriae—the Cyanobacteria (Blue-Green Bacteria) 310

Class Prochlorobacteriae—the Prochlorobacteria 313

Domain (Kingdom) Archaea—the Archaeobacteria 313

Viruses 315  
**KEY THEME : molecular** Plant Viruses 316  
 Viroids and Prions 320  
 SUMMARY 320  
 REVIEW QUESTIONS 321  
 DISCUSSION QUESTIONS 321  
 ADDITIONAL READING 321  
 LEARNING ONLINE 321

## 18 Kingdom Protista 322

Overview 323  
 Learning Outcomes 323  
 Features of Kingdom Protista 324  
 Algae 324  
 Phylum Chlorophyta—the Green Algae 324  
 Phylum Chromophyta—the Yellow-Green Algae, Golden-Brown Algae, Diatoms, and Brown Algae 331  
 Phylum Rhodophyta—the Red Algae 336  
 Phylum Euglenophyta—the Euglenoids 337  
 Phylum Dinophyta—the Dinoflagellates 338  
 Phylum Cryptophyta—the Cryptomonads 340  
 Phylum Prymnesiophyta (Haptophyta)—the Haptophytes 340  
 Phylum Charophyta—the Stoneworts 340  
 Human and Ecological Relevance of the Algae 341  
 Other Members of Kingdom Protista 344  
 Phylum Myxomycota—the Plasmodial Slime Molds 345  
 Phylum Dictyosteliomycota—the Cellular Slime Molds 346  
 Phylum Oomycota—the Water Molds 346  
 SUMMARY 348  
 REVIEW QUESTIONS 349  
 DISCUSSION QUESTIONS 350  
 ADDITIONAL READING 350  
 LEARNING ONLINE 350

## 19 Kingdom Fungi 351

Overview 352  
 Learning Outcomes 352  
 Distinctions Between Kingdoms Protista and Fungi 352  
 Kingdom Fungi 353  
 Lichens 371  
 SUMMARY 373  
 REVIEW QUESTIONS 374  
 DISCUSSION QUESTIONS 375  
 ADDITIONAL READING 375  
 LEARNING ONLINE 375

## 20 Introduction to the Plant Kingdom: Bryophytes 376

Overview 377  
 Learning Outcomes 377  
 Introduction to the Bryophytes 378  
 Phylum Hepaticophyta—Liverworts 379  
 Phylum Anthoceroophyta—Hornworts 383  
 Phylum Bryophyta—Mosses 383  
**KEY THEME : ecology** Hibernating Mosses 387  
 Human and Ecological Relevance of Bryophytes 388  
 SUMMARY 388  
 REVIEW QUESTIONS 389  
 DISCUSSION QUESTIONS 389  
 ADDITIONAL READING 390  
 LEARNING ONLINE 390

## 21 The Seedless Vascular Plants: Ferns and Their Relatives 391

Overview 392  
 Learning Outcomes 392  
 Phylum Psilotophyta—the Whisk Ferns 392  
 Phylum Lycophyta—the Ground Pines, Spike Mosses, and Quillworts 394  
 Phylum Equisetophyta—the Horsetails and Scouring Rushes 400  
 Phylum Polypodiophyta—the Ferns 404  
 Fossils 411  
**KEY THEME : ecology** Ferns and Fossil Fuels 412  
 SUMMARY 413  
 REVIEW QUESTIONS 414  
 DISCUSSION QUESTIONS 414  
 ADDITIONAL READING 414  
 LEARNING ONLINE 415

## 22 Introduction to Seed Plants: Gymnosperms 416

Overview 417  
 Learning Outcomes 417  
 Phylum Pinophyta—the Conifers 418  
**KEY THEME : ecology** Resilient and Useful Gymnosperms 419  
 Other Gymnosperms 422  
 Human Relevance of Gymnosperms 427  
**KEY THEME : evolution** A Living Fossil? 432  
 SUMMARY 433  
 REVIEW QUESTIONS 434  
 DISCUSSION QUESTIONS 434  
 ADDITIONAL READING 434  
 LEARNING ONLINE 434



## 23 Seed Plants: Angiosperms 435

Overview 436

Learning Outcomes 436

Phylum Magnoliophyta—the Flowering Plants 437

**KEY THEME : molecular** The Difference between “n” and “x” in Plant Life Cycles 444

Pollination Ecology 446

Herbaria and Plant Preservation 450

SUMMARY 453

REVIEW QUESTIONS 453

DISCUSSION QUESTIONS 454

ADDITIONAL READING 454

LEARNING ONLINE 454

## 24 Flowering Plants and Civilization 455

Overview 456

Learning Outcomes 456

Origin of Cultivated Plants 456

Selected Families of Flowering Plants 457

Dicots (Now Recognized in Two Groups) 459

Monocots 474

**KEY THEME : ecology** Wild Rice—More Than Just Food 476

**KEY THEME : ecology** Coffee and Caffeine 478

SUMMARY 479

REVIEW QUESTIONS 479

DISCUSSION QUESTIONS 480

ADDITIONAL READING 480

LEARNING ONLINE 480

## 25 Ecology 481

Overview 482

Learning Outcomes 482

Plants and the Environment 482

Life Histories 487

Natural Cycles 488

Succession 491

**KEY THEME : ecology** Plant Population Ecology 491

Impact of Humans on Plant Communities 496

Loss of Biodiversity 499

Restoration of the Land 501

**KEY THEME : ecology** John Muir, Father of America’s National Park System 502

SUMMARY 503

REVIEW QUESTIONS 504

DISCUSSION QUESTIONS 504

ADDITIONAL READING 504

LEARNING ONLINE 505

## 26 Biomes 506

Overview 507

Learning Outcome 507

Major Biomes of the World 507

**KEY THEME : ecology** Alpine Flora as an Indication of Climate Change: The Gloria Project 512

SUMMARY 516

REVIEW QUESTIONS 517

DISCUSSION QUESTIONS 517

ADDITIONAL READING 517

LEARNING ONLINE 517

**Appendix 1** Scientific Names of Organisms Mentioned in the Text A1

**Appendix 2** Biological Controls A20

General Controls A20

Specific Controls A22

Companion Planting A22

Additional Reading A26

**Appendix 3** Useful and Poisonous Plants, Fungi, and Algae A27

Wild Edible Plants, Fungi, and Algae A27

Poisonous Plants and Fungi A27

Medicinal Plants, Fungi, and Algae A27

Hallucinogenic Plants A45

Spice Plants A45

Dye Plants A45

Additional Reading A51

**Appendix 4** House Plants and Home Gardening A52

Growing House Plants A52

Common House Plants A53

Growing Vegetables A62

Common Vegetables and their Nutritional Values A63

Pruning A68

Major Types of Grafting A69

Additional Reading A75

**Appendix 5** Metric Equivalents and Conversion Tables A76

**Glossary G1**

**Photo Credits C1**

**Index I1**

# About the Authors



Jim Bidlack, Kingsley Stern, and Shelley Jansky at Kingsley's office residence in Paradise, California.

*Introductory Plant Biology* was originally written by Kingsley R. Stern (1927–2006), who spent over 40 years as a devoted botanist and teacher. It is estimated that Dr. Stern educated 15,000 students through classroom/laboratory teaching and inspired thousands of botanists as the author of this book, which has sold over 250,000 copies since the first edition was published in 1979. Kingsley's enthusiasm for the botanical world captivated those around him for many decades. He will long be remembered for his attention to detail and dedication to high standards, along with a refreshing sense of humor. It has always been Kingsley's aspiration that those who read *Stern's Introductory Plant Biology* will share his lifelong love of botany.

In late 1999/early 2000, Drs. Jim Bidlack and Shelley Jansky joined Kingsley Stern in editing and updating this textbook. They worked with Dr. Stern on several editions and have since carried his legacy forward to educate and inspire young botanists. This thirteenth edition reflects the same accuracy, content, and enthusiasm of the Stern writing style, along with revisions and updates to make it an up-to-date and enjoyable resource and textbook for plant biology.



## James E. Bidlack

Jim Bidlack received a B.S. Degree in Agronomy, with a Soil & Crop Option, from Purdue University in 1984 and continued his education with a Master's Degree in Crop Physiology at the University of Arkansas in 1986.

Upon completing a Ph.D. in Plant Physiology at Iowa State University in 1990, Jim joined the teaching faculty at the University of Central Oklahoma (UCO) where he is a Professor of Biology. His first paper was published from undergraduate research at Purdue University on the use of synthetic growth regulators to stimulate seed germination. Subsequent work at Arkansas, Iowa, and Oklahoma focused on soybean physiology, cell wall chemistry, and alternative crops, as well as teaching responsibilities in plant biology. Equipment and student salaries for Jim's research projects have been funded by grants from the National Science Foundation (NSF) and the United States Department of Agriculture (USDA). Nearly 20 refereed publications, as well as 50 abstracts and popular articles, have resulted from this work. Jim has been recognized with UCO's Presidential Partner's Excellence in Teaching Award; University Merit Awards in Service, Research, and Teaching; as well as the Biology Club and the Pre-Med Teaching Awards. Some of Jim's additional responsibilities have included participation on NSF and USDA Review Panels, Editor of the Biology Discipline for the Multimedia Educational Resource for Learning and Online Teaching (MERLOT), and President of Metabolism Foundation.



## Shelley H. Jansky

Shelley Jansky received a Bachelor's Degree in Biology from the University of Wisconsin–Stevens Point in 1982, and M.S. and Ph.D. degrees in Plant Breeding and Plant Genetics from the University of Wisconsin–Madison in

1984 and 1986, respectively. Her graduate work focused on developing methods to incorporate genes from wild relatives of potato into the cultivated potato. Then, she spent four years as an Assistant Professor at North Dakota State University, teaching courses in plant breeding and plant propagation, and performing research in the potato breeding program. She taught courses in botany, genetics, and horticulture, and continued to perform potato genetics research at the University of Wisconsin–Stevens Point from 1990 until 2004. She was the Chair of the Department of Biology and was promoted to Associate Professor in 1992 and Professor in 1995. In 2004, she accepted a position as a Research Geneticist with the U.S. Department of Agriculture and an Assistant Professor in the Department of Horticulture at the University of Wisconsin–Madison. Her potato research program focuses on the utilization of disease resistance and nutritional quality genes from wild potato relatives for the improvement of cultivated potato varieties. She received the University of Wisconsin–Stevens Point Excellence in Teaching Award in 1992 and the University Scholar Award in 2000. She has published 65 refereed research articles and five book chapters.

# Preface

Plants and algae are essential for life on earth as it exists today. They provide our world with oxygen and food, contribute an essential part of water and nutrient cycling in ecosystems, provide clothing and shelter, and add beauty to our environment. Some scientists believe that if photosynthetic organisms exist on planets beyond our solar system, it would be possible to sustain other forms of life that depend upon them to survive.

Botany today plays a special role in many interests of both major and nonmajor students. For example, in this text, topics such as global warming, ozone layer depletion, acid rain, genetic engineering, organic gardening, Native American and pioneer uses of plants, pollution and recycling, house plants, backyard vegetable gardening, natural dye plants, poisonous and hallucinogenic plants, nutritional values of edible plants, and many other topics are discussed. To intelligently pursue such topics, one needs to understand how plants are constructed, and how they function. To this end, the text assumes little prior knowledge of the sciences on the part of the student, but covers basic botany, without excessively resorting to technical terms. The coverage, however, includes sufficient depth to prepare students to go further in the field, should they choose to do so.

The text is arranged so that certain sections can be omitted in shorter courses. Such sections may include topics such as soils, molecular genetics, and phylum Bryophyta. Because botany instructors vary greatly in their opinions about the depth of coverage needed for photosynthesis and respiration in an introductory botany course open to both majors and nonmajors, these topics are presented at three different levels. Some instructors will find one or two levels sufficient, whereas others will want to include all three.

Both majors in botany and nonmajors who may initially be disinterested in the subject matter of a required course frequently become engrossed if the material is related repeatedly to their popular interests. This is reflected, as intimated above, in the considerable amount of ecology and ethnobotany included with traditional botany throughout the book.

## Organization of the Text

A relatively conventional sequence of botanical subjects is followed. Chapters 1 and 2 cover introductory and background information; Chapters 3 through 11 deal with structure and function; Chapters 12 and 13 introduce meiosis, genetics, and molecular biology. Chapter 14 discusses plant propagation and biotechnology; Chapter 15 introduces evolution; Chapter 16 deals with classification; Chapters 17 through 23 stress, in phylogenetic sequence, the diversity of organisms traditionally regarded as plants; and Chapter 24 deals with ethnobotanical

aspects and other information of general interest pertaining to 16 major plant families or groups of families. Chapters 25 and 26 present an overview of the vast topic of ecology, although ecological topics and applied botany are included in the preceding chapters as well. Some of these topics are broached in anecdotes that introduce the chapters, while others are mentioned in text boxes as well as the appendices.

## Learning Aids

A chapter outline, review questions, discussion questions, and additional reading lists are provided for each chapter. New terms are defined as they are introduced, and those that are boldfaced are included, with their pronunciation, in a glossary. A list of the scientific names of all organisms mentioned throughout the text is given in Appendix 1. Appendix 2 deals with biological controls and companion planting. Appendix 3 includes wild edible plants, poisonous plants, medicinal plants, hallucinogenic plants, spices, tropical fruits, and natural dye plants. Appendix 4 gives horticultural information on house plants, along with brief discussions on how to cultivate vegetables. Nutritional values of the vegetables are included. Appendix 5 covers metric equivalents and conversion tables.

## New to this Edition

The thirteenth edition has retained the hallmark style and pedagogy that have made it one of the most enduring and popular introductory plant biology books on the market. At the same time, this edition has undergone many changes to expand upon, revise, and update topics in plant biology. All chapters now incorporate measurable learning outcomes and updated additional readings. For those instructors using Connect Botany, all learning outcomes (LOs) are directly tied to assessment within the question and test banks. In addition, most of the chapters include revisions and updates as suggested by reviewers. Some of the major changes include an introduction to the new classification of plants and plant-related species, integration of biotechnology into several chapters, and inclusion of new featured text boxes addressing key themes of ecology, evolution, and molecular biology throughout the text. These new text boxes provide instructors and students with information that helps them to understand how modern botany affects our everyday lives. Many new photographs have replaced some of the older pictures or have been added within individual chapters. Some of the more interesting components that make this 13th Edition more accurate and up-to-date with our current understanding of plant biology include:

Chapter 1 (What is Plant Biology?): New information on climate change, population dynamics, and alternative energy has been added to many parts of the chapter to make it more engaging and up-to-date. Text boxes on “Who Needs Plants?” as well as “Biology and the Internet” have been extensively re-written and several photographs have been replaced.

Chapter 2 (The Nature of Life): Figures on energy conversion and enzyme action have been replaced to improve accuracy, and a new text box entitled “The Skinny on Fats” has been added.

Chapter 3 (Cells): Many of the figures have been revised; particularly the cell and its components to more accurately represent how these are seen under a microscope. New, modern photographs of microscopes have been added along with a better explanation of confocal electron microscopy. Updated text information now includes discussion of endosymbiotic theory as well as functions of vacuoles.

Chapter 4 (Tissues): The text box on “Chimeras and Variegated Leaves” has been modified to provide more detail. New information has been added on discussion of cell wall thickening in collenchyma cells and tracheary elements, and an improved depiction of lenticels is now shown in the section on periderm.

Chapter 5 (Roots and Soils): Improved photographs of sweet potatoes, cassava, and a soil profile have been incorporated into the chapter. The text has been modified to provide a more accurate description of Casparian strips, lateral root formation, and soil horizons. The sections on parasitic roots and mycorrhizae have been extensively re-written to incorporate new terminology for these topics.

Chapter 6 (Stems): Artwork showing heartwood and softwood has been replaced to show a better representation of the characteristics and location of these parts of woody stems. The section on wood and its uses has been extensively modified so that the figures are better organized and figure legends are easier to read.

Chapter 7 (Leaves): Photographs of thorns and prickles, as well as some modified leaves, have been replaced to show better depiction of these structures.

Chapter 8 (Flowers, Fruits, and Seeds): A photograph of a rare Australian orchid, as well as a more clearly-displayed specimen of *Rafflesia* have been added to the chapter. A new text box on “Goobar Peas” has been incorporated into text, along with a more accurate description of germination.

Chapter 9 (Water in Plants): A sharper opening photograph for the chapter has been added along with more refined artwork to show diffusion and the pressure-flow hypothesis. The section on water potential has been extensively rewritten and a new text box on “Measuring Water Potential and Psychrometry” has been added to the chapter.

Chapter 10 (Plant Metabolism): Artwork has been revised to show a better summary of photosynthesis and respiration, and more details in the Calvin cycle. A new text box has been added on “Photosynthesis, Global Warming, and Tropical Rain Forests” to show applications of metabolic concepts.

Chapter 11 (Growth and Development): New figures have been incorporated to show structures of plant hormones as well as signal transduction and a new text box entitled,

“Plant Hormones—Beyond the Classic Five,” has been added. Updated information has also been added about auxin-tryptophan interactions, the role of ethylene in fruit ripening, photoreceptor proteins, and the flowering locus T gene.

Chapter 12 (Meiosis and Alternation of Generations): Descriptions of meiotic phases have been revised to be more accurate, along with new discussions of chiasma and polyploidy. Two new text boxes on “Why Plants Have a Sex Life” and “FISH and GISH Molecular Techniques” have been added.

Chapter 13 (Genetics and Molecular Biology): A new textbox has been added on “Massive DNA Sequencing,” along with an improved image of Gregor Mendel.

Chapter 14 (Plant Breeding, Propagation, and Biotechnology): Updated images have been incorporated to provide better explanations of transgenics, plant propagation, and tissue culture. New text has been added to describe the development of golden rice.

Chapter 15 (Evolution): Several parts of this chapter have been revised and updated to include discussions on epigenesis and polyploidy. A new text box on “Our Daily Bread” has been added to describe the domestication of wheat.

Chapter 16 (Plant Names and Classification): This chapter has been extensively rewritten to describe modern classification techniques. Sections on the International Code of Nomenclature of Cultivated Plants and the Phylocode have been added, along with a newly-proposed classification key.

Chapter 17 (Domain (Kingdom) Bacteria, Domain (Kingdom) Archaea, and Viruses): New, three-dimensional depictions of bacteria have been incorporated into the chapter along with improved artistic representations of viruses. A discussion of *Clostridium difficile*, has been added, as well as a new text box entitled “The Social Life of Prokaryotes.”

Chapter 18 (Kingdom Protista): Improved images of red algae, *Euglena*, and dinoflagellates have been incorporated to show more accurate depictions of these specimens.

Chapter 19 (Kingdom Fungi): The use of DNA sequence data for classification of fungi is described. New information is also introduced, including use of fungi in cleaning oil spills and treatment of certain tree species to prevent the spread of disease.

Chapter 20 (Introduction to the Plant Kingdom: Bryophytes): New introductory information has been added on the evolutionary origin of plants, along with a summary of bryophyte classification. Artwork for hornworts has been improved and new pictures of hairy cap moss and peat moss have been added to the chapter.

Chapter 21 (The Seedless Vascular Plants: Ferns and Their Relatives): Improved photographs of ferns have been incorporated into the text, along with new evolutionary information about the origin of seedless vascular plants. In addition, a new text box on “Ferns and Fossil Fuels” has been added to the chapter.

Chapter 22 (Introduction to Seed Plants: Gymnosperms): A new photograph of the rare *Wollemi* pine, along with a more modern photograph of a newsprint factory have been added to the text. The introductory paragraph has been updated with new information about molecular analysis of gymnosperms as well as a summary of their current classification. A text box

on “Resilient and Useful Gymnosperms” has been added to show modern uses of pines and related species.

Chapter 23 (Seed Plants: Angiosperms): Improved photographs of snowplant flowers, as well as pollination of other flowers, have been included in the text. A more extensive explanation of angiosperm origin has also been added to the introduction.

Chapter 24 (Flowering Plants and Civilization): The photograph of a poppy capsule has been replaced and a new

text box on “Wild Rice—More than Just Food” has been added to the chapter.

Chapter 25 (Ecology): Topics that address the impact of humans on the biosphere have been reorganized to follow a more logical approach to headings and sub-headings.

Chapter 26 (Biomes): This chapter has been reorganized and rewritten to incorporate world biomes in addition to those found in North America.

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## Stern's Introductory Plant Biology Lab Manual, 13th Edition by James Bidlack

**(ISBN: 978-0-07-7508784**  
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The laboratory manual that accompanies *Stern's Introductory Plant Biology* has been revised and updated. It is written for the student who is entering the study of botany. The exercises utilize plants to introduce biological principles and the scientific method. They are written to allow for maximum flexibility in sequencing.

# What Is Plant Biology?

Overview  
Learning Outcomes  
The Relationship of Humans to Their Environment  
ECOLOGY: Who Needs Plants?  
Human and Animal Dependence on Plants  
Botany as a Science  
Hypotheses  
Diversification of Plant Study  
GENERAL: Plant Biology and the Internet  
SUMMARY  
REVIEW QUESTIONS  
DISCUSSION QUESTIONS  
ADDITIONAL READING  
LEARNING ONLINE

A mountain iris (*Iris missouriensis*) growing along a slope near the roadside in the Carson National Forest, New Mexico.

# OVERVIEW

This chapter introduces you to botany: what it is, how it developed, how it relates to our everyday lives, and what its potential is for the future. The discussion includes a brief introduction to some common questions about plants and their functions, an examination of the scientific method, and a brief look at botany after the invention of the microscope. It concludes with a brief survey of the major disciplines within the field of botany.

## Learning Outcomes

1. Explain how humans have impacted their environment, particularly during the past century.
2. Describe how hypotheses are formulated and used in the scientific method.
3. Explain how and why all life is dependent on green organisms.
4. List the aspects of botany with which each of the major botanical disciplines is concerned.

While in high school in southern Africa, I was once invited to a friend's farm during spring break. One day as I was returning to the farmhouse from a walk around the farm, I heard groaning coming from inside. I learned that my friend's father had been clearing cactus-like *Euphorbia* plants from some land. The plants produce a poisonous, milky latex, which the father had taken great care to wash thoroughly from his hands. Absentmindedly, however, he had splashed some of the water in his face, and traces of the poison had gotten into his eyes, causing great pain. Another family member immediately ran to the nearby barn and obtained some colostrum milk from a cow that had just given birth. The eyes were bathed in the milk, which contains an antidote for that poison, and the pain subsided. I was told that if the milk had not been quickly available, the man would have been blind within half an hour. In Venezuela and Brazil, however, cow trees (e.g., *Brosimum utile*; *Mimusops huberi*) produce a sweet, nutritive latex that is relished by the natives of the region. Still other plants such as opium poppies produce latex that contains narcotic and medicinal drugs (Fig. 1.1). Why do plants such as *Euphorbia* species produce poisons, while parts of so many other plants are perfectly edible, and some produce spices, medicines, and a myriad of products useful to humans?

In the popular story "Little Shop of Horrors," Audrey II is a plant that thrives on human blood. While this scenario makes for an interesting piece of dark comedy, there are plants that feed on insects and occasionally frogs, rodents, and birds (Fig. 1.2). What do these plants gain from their carnivorous diet?

Occasionally we hear or read of experiments—often associated with school science fairs—that suggest plants respond in some positive way to music or soothing talk; conversely, some plants are said to grow poorly when they are harshly yelled at. Do plants really respond to their surroundings, and, if so, how and to what extent?

California's huge coastal redwoods and Tasmania's giant gum trees can grow to heights of 90 or more meters (300 or more feet). When these giant trees are cut down, there is no



**Figure 1.1** Immature opium poppy capsules that were gashed with a razor blade. Note the opium-containing latex oozing from the gashes.

evidence of pumps of any kind within them. How, then, does water get from the roots below ground to the tops of these and other trees? Do they have to expend large amounts of energy to carry water such long distances (Fig. 1.3)?

Our tropical rain forests, which once covered 14% of the earth's land surface, now occupy only 6% of land area. They are disappearing at the rate of several acres a minute as the plant life is cleared for agriculture, wood supplies (primarily for fuel), cattle ranching, and other human activities such as mining for gold. Experts estimate that all rain forests may be destroyed within 40 years. Rain forests are home to



**Figure 1.2** Pitcher plants. Pitcher plants are carnivorous plants that grow in nutrient-poor environments. Small insects trapped in their pitchers are digested and used as a source of minerals.

50% of all the species of living organisms; it is estimated that 137 species are destroyed every day due to rain-forest deforestation. What will be the long-term impacts of these activities, and can they be reversed?

There is no doubt that our climate is changing. There is much debate, though, about the effects that global warming will have on life as we know it. Are those who proclaim that global warming will eventually have disastrous effects on modern civilization and living organisms simply exaggerating, or is there a scientific basis for the claims? Plant life constitutes more than 98% of the total *biomass* (collective dry weight of living organisms) of the earth. Plants and other green organisms have the exclusive capacity to produce oxygen while converting the sun's energy into forms vital to the existence of both plant and animal life. At the same time, plants remove the large amounts of carbon dioxide given off by all living organisms as they respire. In other words, virtually all living organisms are totally dependent on green organisms for their existence. If some major disease were to kill off all or most of the green organisms on land and in the oceans and lakes, all the animals on land, in the sea, and in the air would soon starve. Even if some alternative source of energy were available, animal life would suffocate within 11 years—the time estimated for all the earth's oxygen to be completely used up if it were not replaced. Just how do green plants capture the sun's energy, use carbon dioxide, and give off oxygen?

This book tries to answer these and other questions about living organisms—particularly those pertaining to plants, algae, fungi, and bacteria. Moreover, additional information about plant biology related to future societies, conservation, and human benefits is discussed.



**Figure 1.3** California coastal redwoods (*Sequoia sempervirens*). Coastal redwoods may grow for thousands of years and some reach heights of nearly 100 meters (330 feet).

## The Relationship of Humans to Their Environment

It has been estimated that the total human population of the world was less than 20 million in 6000 B.C. During the next 7,750 years, it rose to 500 million; by 1850, it had doubled to 1 billion; and 70 years later, it had doubled again to 2 billion. The 4.48-billion mark was reached in 1980, and within 5 years it had grown to 4.89 billion. In 2011, the human population size reached a milestone, exceeding 7 billion people. The earth remains constant in size, but the human population continues to grow.

In feeding, clothing, and housing ourselves, we have had a major impact on our environment. We have drained wetlands and cleared natural vegetation from vast areas of land. California, for example, now has less than 5% of the wetland it had 100 years ago. We have dumped wastes and other pollutants into our waters and added pollutants to the atmosphere. We have killed pests and plant disease organisms with poisons. These poisons have also killed natural

KEY THEME : **ecology**

### Who Needs Plants?

Human existence depends on plants. In fact, we need plants more than we need animals. In addition to providing oxygen essential to all aerobic organisms, plants act as the foundations of our civilizations, providing food, animal feed, shelter, clothing, industrial products, and medicines. Despite our dependence on plants, though, human activities threaten their survival. Given the fundamental need for plants by humans, it is surprising that conservation efforts in past decades have instead focused on so-called charismatic megafauna (large mammals such as tigers and whales). In recent years, though, there has been a refocusing of conservation strategies to be more inclusive of all members of the biotic world, including plants, fungi, bacteria, and algae. This new direction reflects the growing recognition that preservation of all biological diversity is important for the survival of the human race.

predators and other useful organisms and, in general, have disrupted the delicate balance of nature that existed before humans began degrading their natural surroundings.

If we are to survive on this planet beyond the 21st century, there is little question that humans have to stop increasing in numbers, and the many unwise agricultural and industrial practices that have accompanied the mushrooming of human populations must be replaced with practices more in tune with restoring some ecological balance. Agricultural practices of the future will have to include the return of organic material to the soil after each harvest, instead of adding only inorganic fertilizers. Harvesting of timber and other crops will have to be done in a manner that prevents topsoil erosion, and the practice of clearing brush with chemicals will have to be abolished. Industrial pollutants will have to be rendered harmless and recycled whenever possible.

Many products that now are still largely discarded (e.g., garbage, paper products, glass, metal cans) will also have to be recycled on a much larger scale. Biological pest controls (discussed in Appendix 2) will have to replace the use of poisonous controls whenever possible. Water and energy conservation will have to be universally practiced, and rare plant species, with their largely unknown gene potential for future crop plants, will need to be saved from extinction by preservation of their habitats and by other means. The general public will have to be made even more aware of the urgency for wise land management and conservation—which will be especially needed when pressures are exerted by influential forces promoting unwise measures in the name of “progress”—before additional

large segments of our natural resources are irreparably damaged or lost forever. Alternatives appear to be nothing less than death from starvation, respiratory diseases, poisoning of our food and drink, and other catastrophic events that could ensure the premature demise of large segments of the world’s population.

Scientists and, increasingly, the general public have become alarmed about the effects of human carelessness on our environment. Damage to forests and lakes caused by acid rain, contamination of ground water by nitrates and pesticides, reduction of the ozone shield, major global climatic changes, depletion of aquifers, and loss of biodiversity have gained widespread publicity.

## Human and Animal Dependence on Plants

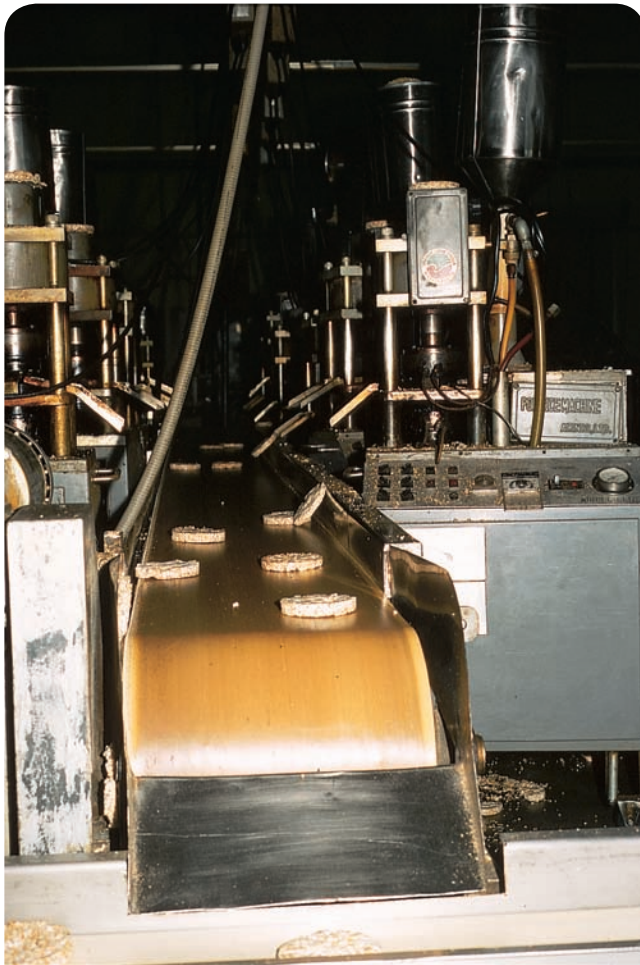
Our dependence on green organisms to produce the oxygen in the air we breathe and to remove the carbon dioxide we give off doesn’t stop there. Plants are also the sources of products that are so much a part of human society that we largely take them for granted. We know, of course, that wheat, rice, corn, potatoes, and other vegetables are plants (Fig. 1.4); but all foods, including meat, fish, poultry, eggs, cheese, and milk, to mention just a few, owe their existence to plants. Condiments such as spices (Fig. 1.5) and luxuries such as perfumes are produced by plants, as are some dyes, adhesives, digestible surgical stitching fiber, food stabilizers, beverages (Fig. 1.6), and emulsifiers.

Our houses are constructed with lumber from trees, which also furnish the cellulose for paper, cardboard, and synthetic fibers. Some of our clothing, camping equipment, bedding, draperies, and other textile goods are made from fibers of many different plant families (Fig. 1.7). Coal is fossilized plant material, and oil came from microscopic green organisms or animals that either directly or indirectly were plant consumers. All medicines and drugs at one time came from plants, fungi, or bacteria, and many important ones, including most of the antibiotics, still do (Fig. 1.8). Microscopic organisms play a vital role in recycling both plant and animal wastes and aid in the building of healthy soils. Others are responsible for human diseases and allergies.

Although shortages of oil and other fossil fuels may sometimes be politically or economically manipulated, there is no question that these fuels are finite and eventually will disappear. Accordingly, the development of alternative energy sources is receiving increased attention.

Methane gas, which can be used as a substitute for natural gas, has been produced from animal manures and decomposed plants in villages in India and elsewhere for many years, and after several years of trial on a small scale in the United States, the production of methane on a larger scale from human sewage is being investigated.

The United States is the largest producer of ethanol in the world. Corn, switchgrass, and other sources of carbohydrates are currently used in the manufacture of ethanol, which



(a)



(b)

**Figure 1.4** Rice cakes being manufactured. (a) Unprocessed rice is poured into small ovens, where the kernels are expanded. The kernels are then compressed into cakes, which are conveyed by belt to a packaging area. (b) Part of a produce section in a grocery store.



**Figure 1.5** Some of the spices derived from plants.

is blended with gasoline. Most cars in the United States can run on fuel containing up to 10% ethanol. Flexible fuel vehicles have been designed to use fuel blends containing up to 85% ethanol. In 2010, over 200 ethanol plants in the United States produced 13.2 billion gallons of ethanol, up from 1.6 billion gallons in 2000. The Energy Independence and Security Act of 2007 calls for 39 billion gallons of renewable fuel to be used annually in the United States. Currently, ethanol fuel in the United States is mainly produced from corn, but there are concerns about losing food crop land to produce fuel. In addition, the energy and pollution balance of ethanol production is under debate. Cellulosic ethanol, which is derived from inedible plant fiber such as wood chips or switchgrass may overcome some of these concerns.

What about plants and the future? As you read this, the population of the earth already has exceeded 7 billion persons, every one of whom needs food, clothing, and shelter in order to survive. To ensure survival, we may need to learn not only how to cultivate food plants but also how to use plants to remove pollutants from the water, air, and soil (Fig. 1.9), to make land productive again, and to renew urban areas. In addition, we need to minimize the destruction of plant habitats caused primarily by the huge increase in the number of earth's inhabitants. This subject and related matters are further discussed in Chapter 25.

At present the idea that humanity may not be able to save itself may seem radical, but there are a few who have suggested that it might become necessary in the future to emigrate to other planets. Regardless of humanity's future, it is essential that our understanding of plants be used to sustain life on this and maybe even other planets. Experiments with portable oxygen generators have been in progress for many years. Tanks of water teeming with tiny green algae are taken aboard a spacecraft and installed so that they are exposed to light for at least part of the time. The algae not only produce oxygen, which the spacecraft inhabitants can breathe, but also utilize the waste carbon dioxide produced by respiration. As the algae multiply, they can be fed to a special kind of shrimp, which in turn multiply and become food for the space



(a)

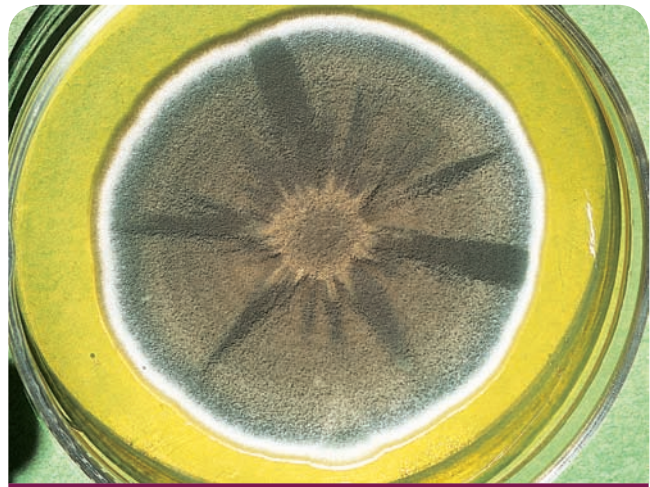


(b)

**Figure 1.6** Ripening coffee berries. (a) Berries are picked by hand when they are red. The seeds are extracted for roasting after the berries are fermented. (b) Coffee beans cooling after being roasted.



**Figure 1.7** Cotton plants. The white fibers, in which seeds are embedded, are the source of textiles and fabrics. The seeds are the source of vegetable oils used in margarine and shortening. After the oils have been extracted, the remaining “cotton cake” is used for cattle feed.



**Figure 1.8** A *Penicillium* colony. The tiny beads of fluid on the surface contain penicillin, widely used as an antibiotic.

travelers. Other wastes are recycled by different microscopic organisms. When this self-supporting arrangement, called a *closed system*, is perfected, the range of spacecraft should greatly increase because heavy oxygen tanks will not be necessary, and the amount of food reserves will be reduced.

Today, teams of botanists, anthropologists, and medical doctors are interviewing medical practitioners and herbal healers in remote tropical regions and taking notes on various uses of plants by the local inhabitants. These scientists are doing so in the hope of preserving at least some plants with potential for contributions to modern civilization before disruption of their habitats results in their extinction.



**Figure 1.9** A polluted waterway in an urban area.

## Botany as a Science

The study of plants, called **botany**—from three Greek words, *botanikos* (botanical), *botane* (plant or herb), and *boskein* (to feed), and the French word *botanique* (botanical)—appears to have had its origins with Stone Age peoples who tried to modify their surroundings and feed themselves. At first, their interest in plants was mostly practical and centered around how plants might provide food, fibers, fuel, and medicine. Eventually, however, an intellectual interest arose. Individuals became curious about how plants reproduced and how they were put together. This inquisitiveness led to plant study becoming a **science**, which, broadly defined, is simply “a search for knowledge of the natural world.” **Botanists** are scientists who study plants.

A science is distinguished from other fields of study by several features. It involves the observation, recording, organization, and classification of facts, and more important, it involves what is done with the facts. *Scientific procedure* involves the process of experimentation, observation, and the verifying or discarding of information, chiefly through inductive reasoning from known samples. There is no universal agreement on the precise details of the process. A few decades ago, scientific procedure was considered to involve a routine series of steps that involved first asking a *question*, then formulating a *hypothesis*, followed by conducting experiments, and finally developing a *theory*. This series of steps came to be known as the *scientific method*, and there are still instances where such a structured approach works well. In general, however, the scientific method now describes the procedures of developing and testing *hypotheses*.

## Hypotheses

A **hypothesis** is simply a tentative, unproven explanation for something that has been observed. It may not be the correct explanation—testing will determine whether it is correct

or incorrect. To be accepted by scientists, the results of any experiments designed to test the hypothesis must be repeatable and capable of being duplicated by others.

The nature of the testing will vary according to the circumstances and materials, but good experiments are run in two forms, the second form being called a *control*. In the first form, a specific aspect, or *variable*, is changed. The control is run in precisely the same way but *without* changing the specific aspect, or variable. The scientist then can be sure that any differences in the results of the parallel experiments are due to the change in the variable.

For example, we may *observe* that a ripe orange we have eaten tastes sweet. We may then make the hypothesis that all ripe citrus fruits taste sweet. We may test the hypothesis by tasting oranges and other citrus fruits such as tangerines and lemons. As a result of our testing (since lemons taste sour), we may *modify the hypothesis* to state that only some ripe citrus fruits are sweet. In such an experiment, the variable involves more than one kind of ripe citrus fruit; the control, on the other hand, involves only ripe oranges.

When a hypothesis is tested, *data* (bits of information) are accumulated and may lead to the formulation of a useful generalization called a *principle*. Several related principles may lend themselves to grouping into a *theory*, which is not simply a guess. A theory is a group of generalizations (principles) that help us understand something. We reject or modify theories only when new principles increase our understanding of a phenomenon.

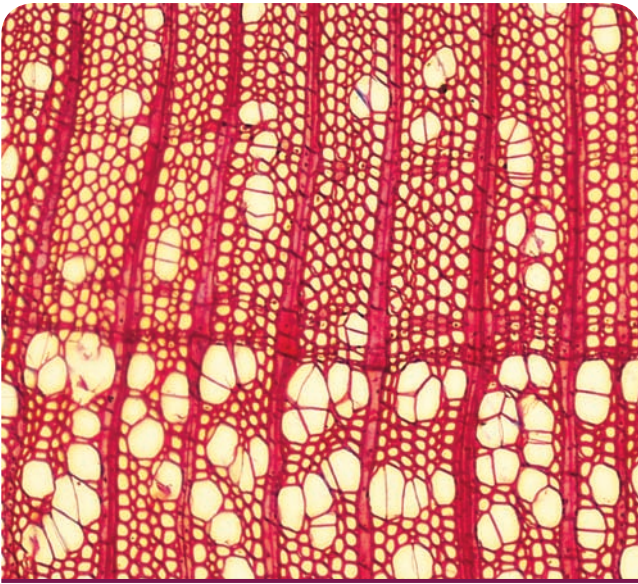
While the testing of hypotheses is a rigorous, well-defined process, the development of hypotheses is not. This aspect of science is creative because it involves finding new ways to look at our natural world. Often, the most successful scientists are those who can think “outside the box,” integrating observations across fields or organisms to create a hypothesis that explains a complex phenomenon.

## Diversification of Plant Study

**Plant anatomy**, which is concerned chiefly with the internal structure of plants, was established through the efforts of several scientific pioneers. Early plant anatomists of note included Marcello Malpighi (1628–1694) of Italy, who discovered various tissues in stems and roots, and Nehemiah Grew (1628–1711) of England, who described the structure of wood more precisely than any of his predecessors (Fig. 1.10).

Today, knowledge of plant anatomy is used to help us find clues to the past, as well as for many practical purposes. For example, the related discipline of *dendrochronology* deals with determining past climates by examining the width and other features of tree rings. We can also learn much from archaeological sites by matching tree rings found in the wood of ancient buildings to the rings of wood of known age. Plant anatomy is also used to solve crimes. Forensic laboratories may use fragments of plant tissues found on clothing or under fingernails to determine where a crime took place or if certain persons could have been present where the





**Figure 1.10** A thin section of *Magnolia* wood as seen through a light microscope.  $\times 40$ .

crime was committed. The anatomy of leaves, stems, and other plant parts is used to unravel and sort out relationships among plants. A form of plant anatomy, known as *paleobotany*, involves the study of plant fossils.

**Plant physiology**, which is concerned with plant function, was established by J. B. van Helmont (1577–1644), a Flemish physician and chemist, who was the first to demonstrate that plants do not have the same nutritional needs as animals. In a classic experiment, van Helmont planted a willow branch weighing 5 pounds in an earthenware tub filled with 90.7 kilograms (200 pounds) of dry soil. He covered the soil to prevent dust from settling on it from the air. The willow produced roots and grew, and after 5 years, he reweighed the willow and the soil. He found that the soil weighed only 56.7 grams (2 ounces), less than it had at the beginning of the experiment, but that the willow had gained 76.7 kilograms (169 pounds). He concluded that the tree had added to its bulk and size from the water it had absorbed. We know now that most of the weight came as a result of photosynthetic activity (discussed in Chapter 10), but van Helmont deserves credit for landmark experimentation in plant physiology.

Modern plant physiologists use cloned *genes* (units of heredity that are found mostly within the nuclei of cells) to learn in precise detail much more about plant functions, including how plants conduct materials internally; how temperature, light, and water are involved in growth; why plants flower; and how plant growth regulatory substances are produced, to mention just a few.

During past centuries, Europeans who explored other continents took large numbers of plants back home with them, and it soon became clear to those working with the plants that some sort of formalized system was necessary just to keep the collections straight. Several *plant taxonomists* (botanists who specialize in the identifying, naming,

and classifying of plants) proposed ways of accomplishing this, but we owe much of our present system of naming and classifying plants to the Swedish botanist Carolus Linnaeus (1707–1778) (see Fig. 16.2).

**Plant taxonomy** involves describing, naming, and classifying organisms. **Plant systematics** is a related field but is broader than taxonomy. It is the science of developing methods for grouping organisms. Plant taxonomy is the oldest branch of plant study, begun in antiquity, but Linnaeus did more for the field than any other person in history. Thousands of plant names in use today are those originally recorded in Linnaeus's book *Species Plantarum*, published in 1753. An expanded account of Linnaeus and his system of classification is given in Chapter 16.

There are still thousands of plants, fungi, and other organisms that have not yet been described or even discovered. Although it obviously is already too late to identify species that were not described before they became extinct, plant taxonomists around the world have united to try to identify and describe as many new organisms as possible—many with food, medicinal, and other useful potential—before much more of their natural habitat disappears. Other plant taxonomists, through the use of *cladistics* (analysis of shared features) and molecular techniques, are refining our knowledge of plant relationships. By the year 2000 we had acquired so much new information about natural relationships that some major reclassification took place (see Chapter 16). The molecular knowledge and techniques are also contributing to the improvement of many of our food crops, although some of the changes are controversial.

Many plant taxonomists specialize in certain groups of plants. For example, *pteridologists* specialize in the study of ferns; *bryologists* study mosses and plants with similar life cycles.

The discipline of **plant geography**, the study of how and why plants are distributed where they are, did not develop until the 19th century (Fig. 1.11). The allied field of **plant ecology**, which is the study of the interaction of plants with one another and with their environment, also developed in the 19th century.

After the publication in 1962 of a best-seller entitled *Silent Spring* (authored by Rachel Carson), public awareness of the field of ecology as a whole increased considerably. In this book, based on more than 4 years of literature research, Carson noted that more than 500 new toxic chemicals are put to use annually as pesticides in the United States alone, and she detailed how these chemicals and other pollutants are having a negative impact on all facets of human life and the environment.

The study of the form and structure of plants, **plant morphology**, was developed during the 19th century, and during the 20th century much of our basic knowledge about the form and life cycles of plants was incorporated into the plant sciences as we know them today. During this time, the number of scientists engaged in investigating plants also greatly increased.

**Genetics**, the science of heredity, was founded by the Austrian monk Gregor Mendel (1822–1884), who performed



**Figure 1.11** Plant ecologists, plant geographers, and other biologists recognize large communities of plants and animals that occur in areas with distinctive combinations of environmental features. These areas, called *biomes*, are represented here by the tropical rain forest, which, although occupying less than 5% of the earth's surface, is home to more than half of the world's species of organisms.

classic experiments with pea plants. Today, various branches of genetics include *plant breeding*, which has greatly improved the yields and quality of crop plants, and *genetic engineering*. Genetic engineering involves the transfer of genes from one organism to another and has already improved the pest, frost, and disease resistance of some crop plants. Genetic engineering is being used to develop better agricultural, medicinal, and other useful plants. It is also being used to control human, animal, and plant diseases. In recent years, the field of **genomics**, which focuses on genes and their function, has burst onto the genetics scene and now impacts nearly all genetics research.

**Cell biology** (previously called **cytology**), the science of cell structure and function, received a boost from the discovery of how cells multiply and how their various components perform and integrate a variety of functions, including that of sexual reproduction. The mid-20th-century development of *electron microscopes* (see Chapter 3) further spurred cell research and led to vast new insights into cells and new forms of cell research that continues to the present.

**Economic botany** and **ethnobotany**, which focus on practical uses of plants and plant products, had their origin in antiquity as humans discovered, used, and eventually cultivated plants for food, fiber, medicines, and other purposes. Today there is increased interest in herbal medicines (see Appendix 3) and many other uses of plants by the general public. Research is being conducted in collaboration with indigenous peoples with an eye to discovering new medicines and other useful plant products previously unknown in developed countries.

There is still a vast amount of botanical information to be discovered. Dozens of research journals publish thousands of botanical scientific papers every year. In recent years, open source journals have allowed free online access to research findings for scientists all over the world. While scientists have identified about 2 million species of organisms, the earth likely contains between 5 and 100 million species.

## Plant Biology and the Internet

It wasn't long ago when families, students, teachers, and the general public relied on personal interactions, phone conversations, and written documents as primary methods for exchanging information. In just the past two decades, however, these types of communications have been enhanced, and to some extent, replaced by the **Internet**. As of 2012, over 2 billion people (nearly one-third of the human population) use the Internet in some way to share intelligence. The Internet, which is a system of networks that connects computers around the world, has enriched our society by providing a fast and reliable way of communicating. The popularity of the Internet stems from its speed and ease-of-use, although users should keep in mind that this tool should be used as an accessory, not a complete replacement for traditional means of information exchange.

People use the Internet for direct communication, education, and recreation, among other things, and do so through the use of various devices. The recent inception of wireless connection has increased worldwide use of the Internet because it allows access to information virtually anywhere and by any device that can pick up a signal. Laptop computers with Internet access (Box Fig. 1.1), for instance, can be taken to the field to navigate through the wilderness, locate and identify specimens, and interact directly with scientists at other locations to exchange information. Even more popular are the numerous handheld devices such as *Android*, *BlackBerry*, *iPhone*, and *Smartphone*, which are smaller and less expensive than the bulkier systems. These handheld devices include mobile phone access, which makes them among the most popular Internet access tools on the planet.

(Continued)