

CONTENTS IN BRIEF

1 THE SCIENCE OF BIOLOGY 1

PART ONE: THE CELL

- 2 SMALL MOLECULES 23
- 3 LARGE MOLECULES 45
- 4 ORGANIZATION OF THE CELL 70
- 5 MEMBRANES 110
- 6 ENERGY, ENZYMES, AND CATALYSIS 131
- 7 CELLULAR RESPIRATION AND FERMENTATION 156
- 8 PHOTOSYNTHESIS 184

PART TWO: INFORMATION AND HEREDITY

- 9 CHROMOSOMES AND CELL DIVISION 217
- 10 MENDELIAN GENETICS 242
- 11 NUCLEIC ACIDS AS THE GENETIC MATERIAL 271
- 12 MICROBIAL GENETICS 304
- 13 GENE EXPRESSION AND CELL DIFFERENTIATION 327
- 14 IMMUNE SYSTEMS AND DISEASE 355

PART THREE: MULTICELLULAR LIFE

- 15 THE MULTICELLULAR WAY OF LIFE 381
- 16 PLANT DEVELOPMENT 400
- 17 REPRODUCTION IN FUNGI AND PLANTS 424
- 18 NUTRITION OF PLANTS AND FUNGI 448
- 19 PLANTS AND THEIR TERRESTRIAL ENVIRONMENT 465
- 20 REPRODUCTION IN ANIMALS 487
- 21 ANIMAL DEVELOPMENT 517
- 22 ANIMAL NUTRITION 543
- 23 GAS EXCHANGE AND TRANSPORT IN ANIMALS 571
- 24 EXCRETION AND OSMOREGULATION 601

PART FOUR: INTEGRATION AND BEHAVIOR

- 25 ANIMAL HORMONES 625
- 26 NEURONS AND NERVOUS SYSTEMS 649
- 27 SENSORY SYSTEMS 678
- 28 EFFECTORS 698
- 29 BEHAVIOR 720
- 30 SOCIAL BEHAVIOR 744

PART FIVE: THE DIVERSITY OF LIFE

- 31 ORIGINS 773
- 32 TAXONOMY AND PHYLOGENY 794
- 33 MONERA AND PROTISTS 811
- 34 FUNGI AND PLANTS 842
- 35 ANIMALS 881

PART SIX: THE STRATEGY OF EVOLUTION

- 36 THE PROCESSES OF EVOLUTION 931
- 37 THE MULTIPLICATION OF SPECIES 953
- 38 MACROEVOLUTION 969
- 39 ECOSYSTEMS 994
- 40 GROWTH AND DYNAMICS OF POPULATIONS 1020
- 41 INTERACTIONS AMONG POPULATIONS 1043
- 42 ECOLOGICAL COMMUNITIES 1066
- 43 BIOGEOGRAPHY 1097

GLOSSARY 1121

CREDITS 1155

INDEX 1159

CONTENTS

CHAPTER ONE

THE SCIENCE OF BIOLOGY 1

- A brief history of Earth 1
- Science as a form of human behavior 3
- Facts and laws 4
- Biology: the science of life 5
- The characteristics of life 7

PART ONE: THE CELL

CHAPTER TWO

SMALL MOLECULES 23

- Atoms, elements, particles, and isotopes 24
- Box A Charge and mass on the subatomic scale 24
- Radioisotopes in biological research 26
- Energy and stability 28
- Box B Radioactive isotopes as clocks 28
- The behavior of electrons 29
- Chemical bonds 31
- Molecules and reactions 32
- Some quantities 33
- Water 35
- Ions, ionization, and ionic bonds 36
- Acidity and pH 37
- Polarity and the hydrogen bond 38
- Some simple organic compounds 40
- Box C D-Amino acid formation as a calendar 42

CHAPTER THREE

LARGE MOLECULES 45

- Carbohydrates: monosaccharides and disaccharides 46
- Carbohydrates: polysaccharides 48
- Box A Carbohydrates and cell surfaces 51
- Lipids 52
- Box B Lipids and vision 56
- Amino acids and proteins 57
- Levels of protein structure 60
- Nucleic acids 64

CHAPTER FOUR

ORGANIZATION OF THE CELL 70

- A comment on size 71
- The prokaryotic cell 72
- Box A The Gram stain and bacterial cell walls 74
- Probing the subcellular world: microscopy 76
- Box B The best-known prokaryote: *Escherichia coli* 77

Major organizing concepts 9

- Early speculation about evolution 11
- Charles Darwin and evolution 12
- Objections to Darwin's theory 14
- The importance of the world view 16
- Levels of organization in biology 17
- Questions beyond science 18

Box C Types of light microscopy 79

- The eukaryotic cell 80
- Membranes in eukaryotic cells 81
- Nucleus and cytoplasm 83
- Structures of the nucleus 85
- The mitochondria 87
- Plastids 89
- Origin of the eukaryotes 91
- Endoplasmic reticulum 94
- The Golgi apparatus 95
- Endocytosis and exocytosis 96
- Lysosomes 97
- Microbodies 98
- Vacuoles 99
- Microtubules and microfilaments, cilia and flagella 100
- Fine structure of the cytosol 102
- The cell wall 103
- Eukaryotes, prokaryotes, and viruses 104
- Fractionating the eukaryotic cell: isolating organelles 105
- Box D Are viruses alive? 107

CHAPTER FIVE

MEMBRANES 110

- Membrane structure and composition 111
- Membrane lipids 111
- Membrane proteins 112
- Membrane carbohydrates 116
- Microscopic views of biological membranes 116
- Movement of materials in the microscopic world 118
- Crossing the membrane barrier 118
- Box A Einstein's diffusion equations 119
- An explanation of simple diffusion 121
- Facilitated diffusion and active transport 121
- Osmosis 122
- Membranes and energy transformations 125
- Receptors on the membrane surface 126
- Other activities of membranes 128
- Membrane formation and continuity 128

CONTENTS

CHAPTER SIX

ENERGY, ENZYMES, AND CATALYSIS 131

Energy and the laws of thermodynamics 132

Chemical equilibria 133

The equilibrium constant 134

Free energy and equilibria 135

Free energy, heat, and entropy 136

Reaction rates 137

Rate constants 139

Box A Equilibrium constants and rate constants 139

Enzymes and selective catalysis 140

Molecular structure of enzymes 141

Box B The beginnings of enzyme anatomy 142

Structures and actions of proteolytic enzymes 143

Prosthetic groups 145

Substrate concentration and reaction rate 146

Enzyme inhibition 146

Coupling of reactions 148

Subunits, allosteric effects, and control 149

Control of metabolism through allosteric effects 151

Sensitivity of enzymes to the environment 152

CHAPTER SEVEN

CELLULAR RESPIRATION AND FERMENTATION 156

Anaerobic and aerobic energy metabolism 156

Adenosine triphosphate, the cell's energy currency 159

The flow of energy through the living world 160

An overview of the release of energy from glucose 161

The transfer of hydrogen atoms and electrons 162

ATP revisited 164

Glycolysis 165

Overview of the citric acid cycle 168

Reactions of the citric acid cycle 170

The respiratory chain 171

Oxidative phosphorylation and mitochondrial structure 173

Fermentation 176

Comparative energy yields 177

Connections with other pathways 178

Feedback regulation 178

CHAPTER EIGHT

PHOTOSYNTHESIS 184

Early studies of photosynthesis 185

Basic physics of light 186

Pigments 187

Absorption spectra and action spectra 188

The photosynthetic pigments 190

An electron carrier for photosynthesis 191

The subpathways of photosynthesis 192

Working out the Calvin-Benson cycle 193

The first stable product of carbon dioxide fixation 196

What is the carbon dioxide acceptor? 197

The photosynthetic carbon reduction cycle 199

Alternate modes of carbon dioxide fixation 200

Photorespiration 203

The activation of chlorophyll: a "light reaction" 204

Cyclic photophosphorylation 205

Noncyclic photophosphorylation 206

ATP formation in the chloroplast 208

Limiting factors and compensation points 209

Box A Photosynthesis in the halobacteria 209

Photosynthesis and cellular respiration 210

PART TWO: INFORMATION AND HEREDITY

CHAPTER NINE

CHROMOSOMES AND CELL DIVISION 217

Mitosis 219

Chromosomal structure 223

The mechanism of chromosomal movement 224

Cytokinesis 225

The cell cycle 226

Box A Dissecting the interphase 227

Asexual and sexual reproduction 228

Ploidy and the karyotype 230

Meiosis 232

Box B Events in prophase I of meiosis 236

Mitosis, meiosis, and ploidy reviewed 237

Cell division in prokaryotes 238

CHAPTER TEN

MENDELIAN GENETICS 242

Mendel's strategy 244

Box A Physical scientists in biology 244

"Experiment 1" 245

Segregation of genes 246

Box B Elements of probability 247

The test cross 248

Box C Mendel's law 248

Incomplete dominance 250

The source of differing alleles 250

Assortment of genes 251

Linkage 252

Box D Probabilities in the dihybrid cross 252

Sex determination 253

Sex linkage 255

The ratios are averages, not absolutes 257

Fruit flies and bread molds 258

Box E Mating type versus sex 259

Recombination in eukaryotes 260

Box F Gene mapping in eukaryotes 262

Cytogenetics 263

From genotype to phenotype 264

Quantitative inheritance 265

Non-Mendelian inheritance 267

CHAPTER ELEVEN

NUCLEIC ACIDS AS THE GENETIC MATERIAL 271

What does the gene control? 272

Box A Complementary surfaces and the template theory 272

What is the gene? 275

The structure of the DNA molecule 279

Structure of ribonucleic acid 280

Box B Complementary base pairing 281

Implications of the double-helical structure of DNA 282

Replication of the DNA molecule 282

Enzymes in DNA synthesis 285

From DNA to protein 287

Transcription 288

Transfer RNA 289

The ribosome 290

Translation 292

Box C Making the most of your DNA 293

RNA viruses and the central dogma 294

The genetic code 294

Mutations 297

Point mutations 298

Large-scale mutations 300

Box D The origin of new genes 300

A new twist in the study of DNA 301

CHAPTER TWELVE

MICROBIAL GENETICS 304

Mutations in bacteria and bacteriophage 305

Box A Counting a population of bacteria 306

A sexual process in bacteria 308

Box B Counting bacteriophage 308

Isolating specific bacterial mutants 311

The bacterial fertility factor 313

Transfer of male genetic elements 314

Sexduction 317

Recombination in viruses 317

Lysogeny and the disappearing viruses 318

Transduction 320

Episomes and plasmids 321

Recombinant DNA technology 321

Box C A feeble bacterium and a nasty plasmid 324

PART THREE: MULTICELLULAR LIFE

CHAPTER FIFTEEN

THE MULTICELLULAR WAY OF LIFE 381

Advantages of multicellularity 382

Effects of scale 385

Problems associated with multicellularity 386

CHAPTER THIRTEEN

GENE EXPRESSION AND CELL DIFFERENTIATION 327

The control of gene expression 329

Control of transcription in prokaryotes 329

Operons 331

Repressible systems 333

Catabolite repression 334

Eukaryotes and positive control 334

Control by degradation 335

Control of translation 336

Box A Turnover of proteins 336

Repeated genes and gene amplification 338

Chromosome inactivation 340

Self-assembling molecules 341

Self-assembly of a bacteriophage 343

Assembly of an organelle 344

Cell development 346

The role of RNA 347

Control of RNA synthesis and translation 348

Box B Controlled transcription of a single gene 349

Is differentiation reversible? 350

CHAPTER FOURTEEN

IMMUNE SYSTEMS AND DISEASE 355

Specific defenses against nonself invaders 356

Cells of the immune system 356

The immune response 358

Clonal selection and its consequences 360

Box A Antigens do not tell the organism how to make antibodies 360

Box B A lymphocyte produces one immunoglobulin specificity 361

Self, nonself, and tolerance 362

Disorders of the immune system 363

The immunoglobulins 364

Effectors of the immune system 365

Box C Monoclonal antibodies 366

The generation of diversity 367

Box D Generating diversity 367

Transplants 368

Transfusions and ABO blood groups 369

Rh incompatibility 370

Cancer 371

Nonspecific defense mechanisms against pathogens 373

Box E Interferon 373

Multicellular fungi 386

Multicellular plants 388

Animals 390

Animal structure 393

A comparison of animal skeletal systems 395

The origin of multicellularity 397

CONTENTS

CHAPTER SIXTEEN

PLANT DEVELOPMENT 400

- Embryo formation in flowering plants 401
- Seed germination 402
- Gibberellins 403
- Seed dormancy 406
- Phytochrome 407
- Early seedling growth 408
- Box A Escaping from the seed coat 408
- Auxin 410
- Auxin and cell walls 413
- The growing regions of the plant 416
- Differentiation and organ formation 417
- Cytokinins 418
- Bud dormancy and abscisic acid 418
- Box B Discovery of the cytokinins 418
- Senescence 420
- Growth substances and senescence 420
- Box C Keeping the latex flowing 421

CHAPTER SEVENTEEN

REPRODUCTION IN FUNGI AND PLANTS 424

- Asexual and sexual reproduction in fungi
and plants 425
- Alternation of generations 426
- Heterokaryon formation in the fungi 428
- Multiple hosts in the fungal life cycle 430
- Mosses and ferns 431
- The seed plants 434
- The flower 435
- Pollination 436
- Fruit 437
- Photoperiodic control of flowering 439
- Importance of night length 440
- Circadian rhythms and the biological
clock 441
- A flowering hormone? 444
- Vernalization and flowering 445

CHAPTER EIGHTEEN

NUTRITION OF PLANTS AND FUNGI 448

- Mineral nutrients 449
- Soils 451
- The scope of photosynthesis 453
- Nitrogen-fixing organisms 453
- Nitrogen fixation 455
- Symbiotic nitrogen fixation 456
- Denitrification 457
- Industrial applications of nitrogen fixation 457
- Nitrification 458
- Nitrate reduction 458
- Sulfur metabolism 459
- Heterotrophic seed plants 459
- Nutrition of fungi 460

CHAPTER NINETEEN

PLANTS AND THEIR TERRESTRIAL ENVIRONMENT 465

- The plumbing of a vascular plant 467
- The root 469
- Box A Fungal partners of plants 472
- The stem 473
- Growth in diameter of stems and roots 474
- Box B Wood 476
- The leaf 477
- Stomata: a compromise 478
- Reversed stomatal cycle in the Crassulaceae 479
- Special adaptations of leaves 480
- Transport in the xylem 481
- Transport in the phloem 482
- Strengthening tissues in the shoot 484

CHAPTER TWENTY

REPRODUCTION IN ANIMALS 487

- An overview of asexual reproduction 487
- Asexual reproduction in animals 488
- An overview of sexual reproduction 489
- Sexual reproductive systems of animals 490
- Vertebrate reproductive systems 491
- Gamete production (gametogenesis) 493
- Spermatogenesis 493
- Oogenesis 495
- Juxtaposing egg and sperm 496
- Fertilization events 498
- Location of mates and courtship among invertebrates 500
- Box A When mating is avoided 500
- Vertebrate mate location and courtship 501
- Protection of the embryo 503
- Nurture of the young 505
- Dispersal of the young 507
- Reproductive system of the human male 507
- Reproductive system of the human female 509
- Sexual responses in humans 510
- Pregnancy 511
- Box B Birth control 512
- Childbirth 514
- Menopause 515

CHAPTER TWENTY-ONE

ANIMAL DEVELOPMENT 517

- Embryos and animal affinities 519
- Preformation versus epigenesis 520
- Establishing multicellularity 522
- Formation of the blastula 523
- The formation of embryonic germ layers 524
- Gastrulation in chordate embryos 526
- Sheet to tube to brain: forming the nervous system 529
- Box A Tracking migrating cells: fate maps 529
- Prospective fate and prospective potency 530
- Induction and the organizer 531

Instructive versus permissive induction	533
Asymmetry in the egg and zygote	533
Box B Asymmetry in the sea urchin egg	535
Aggregation behavior in embryonic cells	536
Postembryonic development	537
Larval development and metamorphosis	538
Regeneration	539
Senescence and death	540

CHAPTER TWENTY-TWO

ANIMAL NUTRITION 543

Nutrient requirements	544
Sources of organic nutrients	545
Mineral nutrients	546
Vitamins	548
Box A Beriberi and the vitamin concept	548
Box B Scurvy and vitamin C	549
Other nutritional deficiency diseases in humans	550
Nutrient procurement: the act of predation	551
Food processing	553
Digestion in tubular guts	555
The vertebrate gut	557
Principles of digestion	558
Box C Early experiments on digestion	559
Mammalian chewing and swallowing	560
The stomach	562
Intestines	563
Enzymatic activity in the small intestine	564
Hormonal controls	566
Herbivores	566
"Sharp teeth and short guts": the carnivores	567

CHAPTER TWENTY-THREE

GAS EXCHANGE AND TRANSPORT IN ANIMALS 571

Rate of oxygen consumption	572
Oxygen availability	572
Box A Underwater survival	573

PART FOUR: INTEGRATION AND BEHAVIOR

CHAPTER TWENTY-FIVE

ANIMAL HORMONES 625

General properties of hormones	626
Glands and hormones	626
Developmental hormones in a bloodsucking bug	630
The anterior pituitary	631
Box A The paper factor	631
Pituitary and hypothalamus	633
Growth hormone	634
Human reproductive hormones	635
Hormones and the menstrual cycle	635

Size 574

Special respiratory mechanisms 575

Lungs 577

Box B Countercurrent distribution systems 577

Insect tracheae 580

Transport in animal bodies 582

Open and closed systems 582

The heart 584

The human circulatory system 586

The human heart 586

Blood movement and pressure 588

The capillary system 590

Box C William Harvey and the study of circulation 590

Blood 593

Box D Cardiovascular diseases 593

Blood pigments 595

Carbon dioxide transport 597

The lymphatic system 597

CHAPTER TWENTY-FOUR

EXCRETION AND OSMOREGULATION 601

The excretion of nitrogenous wastes 602

Water, salts, and the environment 604

Isotonic organisms and osmoregulating fishes 605

Water balance in terrestrial organisms 607

Types of excretory systems 608

Simple protonephridia 608

Malpighian tubules 609

Ultrafiltration in the crustaceans 609

Metanephridia 610

The vertebrate excretory system 611

The mammalian nephron 614

Urine formation 614

Final processing of urine 617

The cortex, the medulla, and water retention 618

What the kidney can and cannot do 619

Hormones and embryonic sexual differentiation 636

The adrenal medulla 636

The adrenal cortex 636

Some other glands and their hormones 638

Peptide hormones and the second messenger 639

Steroid hormone action 641

Controlling hormone levels 642

Prostaglandins 643

Discovery of "natural opiates" 644

Endorphins and hormones—and a common precursor 644

Activities of endorphins 645

Evolution of regulatory systems 646

CONTENTS

CHAPTER TWENTY-SIX

NEURONS AND NERVOUS SYSTEMS 649

- Major divisions of the nervous system 650
- Cells of the nervous system 650
- Reflex arcs 652
- The resting potential 654
- Electrotonic potentials 655
- Box A The Nernst equation 655
- Action potentials 657
- Mechanism of the action potential 658
- The refractory period 659
- Propagation of the action potential 659
- Synaptic transmission 660
- Neurotransmitters 662
- Clearing the synapse of neurotransmitter 662
- Events in the postsynaptic neuron 663
- Summation 663
- The neuromuscular junction 664
- Nervous integration 665
- The autonomic nervous system 666
- Cephalization 668
- Structures of vertebrate brains 669
- The cerebrum 669
- The hypothalamus 671
- The cerebellum 672
- The limbic system and the emotions 672
- The reticular formation 673
- Sleeping and dreaming 674
- Memory 675

CHAPTER TWENTY-SEVEN

SENSORY SYSTEMS 678

- Information filtering in sensory systems 679
- Types of sensory receptors 679
- Receptor cells 680
- Visual systems 680
- Vertebrate and cephalopod eyes 681
- Photoreceptors of the vertebrate eye 683
- Box A The blind spot of the vertebrate eye 683
- Events in the photoreceptors 684
- Color vision 685
- Information processing in an invertebrate eye 685
- Information processing in the vertebrate retina 686
- Visual information processing in the vertebrate brain 687
- Auditory systems 688
- Chemoreception 690
- Olfaction 691
- Chemoreception in arthropods 692
- Mechanoreception 693
- Proprioception 694
- Other receptors 695

CHAPTER TWENTY-EIGHT

EFFECTORS 698

- Ciliated cells 699
- Microtubules in cilia and flagella 700
- Amoeboid cells 701

- The skeleton 702
- The vertebrate skeleton 703
- Types of bone 703
- Other aspects of the vertebrate skeleton 705
- Box A The dynamics of bone 705
- Muscle 706
- Muscle function 707
- The sliding filament model 708
- Controlling the actin-myosin interaction 711
- Fast and slow muscles 713
- Cardiac muscle 713
- Smooth muscle 714
- Other effectors 714
- Trichocysts and nematocysts 714
- Chromatophores 714
- Glands 716
- Bioluminescence 717
- Electric organs 717

CHAPTER TWENTY-NINE

BEHAVIOR 720

- Costs and benefits 721
- Sign stimuli 722
- Behavioral genetics 723
- Box A Genes and hygienic behavior in honeybees 724
- Learning 726
- Mechanisms of learning 728
- Song learning 729
- Finding and choosing food 731
- Human food choices 733
- Avoiding being eaten 734
- Orientation 738
- Navigation 739
- The evolution of behavior 741

CHAPTER THIRTY

SOCIAL BEHAVIOR 744

- Costs and benefits of group living 744
- Individual adjustments to group living 747
- Roles of the sexes 748
- Communication: maintenance of social groups 750
- Chemical communication 750
- Visual and auditory communication 752
- Tactile and electrical communication 753
- Origins of communication signals 755
- Evolution of communication signals 756
- Interspecific communication 758
- Choosing associates 759
- The evolution of animal societies 761
- Box A Calculation of the coefficient of relatedness 761
- Spiders 762
- Insects 763
- Birds 764
- Mammals 765

PART FIVE: THE DIVERSITY OF LIFE

CHAPTER THIRTY-ONE
ORIGINS 773

- Spontaneous generation: old ideas 773
- Spontaneous generation revisited 775
- A common metabolic heritage 776
- Box A A humbug meteorite 776
- What the common heritage tells us 778
- The fossil record 778
- Precambrian rocks 781
- Ancient prokaryotes 781
- Eukaryotic and multicellular organisms 784
- Meteorites and extraterrestrial life 786
- Primitive Earth: atmosphere and energy sources 787
- Laboratory simulation 787
- From monomers to polymers 790
- Microspheres 790
- Coacervates 791
- Late stages of chemical evolution 792

CHAPTER THIRTY-TWO
TAXONOMY AND PHYLOGENY 794

- The goals of classification 795
- Cladistic, phenetic, and evolutionary systematics 795
- Taxonomic hierarchies 797
- Taxonomic characters 800
- Selection of taxonomic characters 803
- Homology and analogy 805
- Taxonomic keys 806
- Phylogenetic trees of life 807

CHAPTER THIRTY-THREE
MONERA AND PROTISTS 811

- Viruses 811
- Reproduction of viruses 813
- Classification of viruses 814
- The kingdom Monera (prokaryotes) 814
- Prokaryotes versus eukaryotes 817
- Metabolic diversity in the kingdom Monera 819
- Structural characteristics of bacteria 821
- Kingdom Monera, phylum Bacteria: gliding bacteria 821
- Kingdom Monera, phylum Bacteria: spirochetes 822
- Kingdom Monera, phylum Bacteria: curved and spiral bacteria 822
- Kingdom Monera, phylum Bacteria: gram-negative rods 822
- Kingdom Monera, phylum Bacteria: gram-positive rods 823
- Kingdom Monera, phylum Bacteria: actinomycetes 824
- Kingdom Monera, phylum Bacteria: rickettsias and mycoplasmas 824
- Kingdom Monera, phylum Bacteria: methanogens 825
- Kingdom Monera, phylum Bacteria: gram-negative and gram-positive cocci 826
- Bacteria and disease 827
- Kingdom Monera, phylum Cyanobacteria 827
- The kingdom Protista 829

- Kingdom Protista, phylum Mastigophora 830
- Kingdom Protista, phylum Sarcodina 833
- Kingdom Protista, phylum Sporozoa 835
- Kingdom Protista, phylum Ciliophora 836
- Cytoplasmic organization in the ciliates 839

CHAPTER THIRTY-FOUR
FUNGI AND PLANTS 842

- The kingdom Fungi 842
- Phylum Myxomycota 844
- Phylum Myxomycota, class Myxomycetes 844
- Phylum Myxomycota, class Acrasiomycetes 845
- Phylum Mastigomycota 846
- Phylum Eumycota, class Zygomycetes 847
- Phylum Eumycota, class Ascomycetes 847
- Subgroups of the ascomycetes 848
- Phylum Eumycota, class Basidiomycetes 849
- Phylum Eumycota, class Deuteromycetes (fungi imperfecti) 850
- Lichens 851
- The kingdom Plantae 852
- Algae 853
- Phylum Pyrrophyta 854
- Phylum Chrysophyta 855
- Phylum Phaeophyta 856
- Phylum Rhodophyta 857
- Phylum Chlorophyta 858
- The terrestrial plants 860
- Phylum Bryophyta 860
- Phylum Bryophyta, class Musci 861
- Phylum Bryophyta, class Hepaticae 862
- Phylum Bryophyta, class Anthocerotae 863
- Phylum Tracheophyta 863
- Phylum Tracheophyta, subphylum Psilopsida 864
- Leaves of tracheophytes 865
- Phylum Tracheophyta, subphylum Lycopsidea and Sphenopsida 867
- Phylum Tracheophyta, subphylum Pteropsida, class Filicinae 867
- Phylum Tracheophyta, subphylum Pteropsida, class Gymnospermae 869
- Fossil gymnosperms 871
- Phylum Tracheophyta, subphylum Pteropsida, class Angiospermae 873
- Angiosperm gametophytes 873
- Double fertilization 874
- Types of flowers 874
- Subclasses of the class Angiospermae 876

CHAPTER THIRTY-FIVE
ANIMALS 881

- Criteria for classifying animals: symmetry 883
- Criteria for classifying animals: embryology 884
- Criteria for classifying animals: body cavities 885
- Phylum Porifera 886
- Phylum Cnidaria 888

CONTENTS

Alternation of generations in cnidarians 889

Corals 890

Phylum Ctenophora 891

Phylum Platyhelminthes 891

Flatworms and the origins of the animal kingdom 892

Phylum Rotifera 892

Phylum Nematoda 893

Phylum Annelida 895

Phylum Mollusca 897

Box A Gutless worms 897

Phylum Mollusca, classes Amphineura and Monoplacophora 898

Phylum Mollusca, classes Bivalvia, Gastropoda, and Cephalopoda 899

Phylum Arthropoda 899

Diversification of arthropods 900

Ancient arthropods and modern descendants 901

Phylum Arthropoda: arachnids, crustaceans, and myriapods 902

Phylum Arthropoda, class Insecta 903

The lophophorate animals 905

Phylum Echinodermata 906

Classes of the echinoderms 908

Phylum Hemichordata 909

Phylum Chordata 909

Phylum Chordata, subphylum Vertebrata 910

Origin of the vertebrates 911

Phylum Chordata, subphylum Vertebrata, class Agnatha 911

Phylum Chordata, subphylum Vertebrata, class

Placodermi 912

Phylum Chordata, subphylum Vertebrata, class

Chondrichthyes 913

Phylum Chordata, subphylum Vertebrata, class

Osteichthyes 913

Phylum Chordata, subphylum Vertebrata, class Amphibia 915

Phylum Chordata, subphylum Vertebrata, class Reptilia 916

Phylum Chordata, subphylum Vertebrata, class Aves 918

The origins of mammals 920

Phylum Chordata, subphylum Vertebrata, class Mammalia 921

PART SIX: THE STRATEGY OF EVOLUTION

CHAPTER THIRTY-SIX

THE PROCESSES OF EVOLUTION 931

The structure of populations 932

The Hardy-Weinberg law 933

Variability within populations 934

Agents of evolution 937

Sexual recombination 937

Mutation pressure 938

Genetic drift 938

Gene flow 940

Natural selection 940

Frequency-dependent selection 941

Fitness 942

Levels of natural selection 942

Box A Why do daughter wasps stay home and help their mothers rear younger siblings? 943

How much of genetic variability is adaptive? 944

Microevolution: industrial melanism 946

The sickle-cell trait 948

House sparrows in North America 950

Camelina in flax fields 951

Box A Allometric growth 963

Where do species divide? 964

Ecological adjustments 965

CHAPTER THIRTY-EIGHT

MACROEVOLUTION 969

The fossil record 971

The formation of fossils 972

Patterns in the fossil record 973

The Cenozoic 976

Human evolution 977

The rise of *Homo* 977

Homo sapiens 978

The changing pace of evolution 980

Rates of evolution of nonfossilized traits 982

Macroevolutionary mechanisms 984

South American mammals: isolation and competition 985

Continental drift and macroevolution 986

Speciation and adaptive radiation 988

Natural selection and stasis 989

How predictable is evolution? 991

CHAPTER THIRTY-NINE

ECOSYSTEMS 994

Climates on Earth 995

Global atmospheric circulation 996

Global oceanic circulation 998

Biogeochemical cycles 1000

The oceanic system 1000

Fresh waters 1000

The atmospheric system 1002

The land 1003

CHAPTER THIRTY-SEVEN

THE MULTIPLICATION OF SPECIES 953

The species concept 954

Weaknesses of the species concept 955

Barriers to exchange 955

Geographical speciation 956

Parapatric speciation 958

Sympatric speciation 958

Maintaining separate gene pools 960

Genetic changes accompanying speciation 961

Plants and soils	1005
Carbon and nitrogen cycles	1005
Human activity and aquatic cycles	1007
Acid precipitation	1009
Alterations of the carbon cycle	1009
Energy flow through ecosystems	1010
Body maintenance and energy flow	1014
Agriculture and ecosystem productivity	1016
Ecosystem stability	1016

CHAPTER FORTY GROWTH AND DYNAMICS OF POPULATIONS 1020

Life history as a concept	1020
Births and deaths	1022
Exponential growth	1024
Logistic growth	1026
Evolution of birth and death rates	1027
Age distribution	1029
Populations in patchy environments	1031
Habitat selection	1032
Population density and habitat selection	1033
Dispersal	1034
Population regulation	1035
Population regulation and management	1039

CHAPTER FORTY-ONE INTERACTIONS AMONG POPULATIONS 1043

Predator-prey interactions	1044
Types of predators and prey	1045
Foraging theory	1047
Short-term consequences of predator-prey interactions	1048
Mimicry	1050
Stability of predator-prey interactions	1053
Theory of competition	1053
Competition in nature	1054
Commensalism and mutualism	1056
Plant-animal mutualisms	1058
Ecological niches	1062

CHAPTER FORTY-TWO ECOLOGICAL COMMUNITIES 1066

Macrodescriptors	1067
Plant growth forms	1067
Plant height	1068
Plant dependencies and mutualisms	1071

Folivores	1072
Flower visitors	1074
Frugivores	1076
Granivores	1078
Wood eaters	1079
Food subwebs	1079
Biomes	1081
Tundra	1081
Boreal forest	1082
Temperate deciduous forest	1083
Grassland	1084
Cold deserts	1085
Hot deserts	1085
Mediterranean biome	1086
Thorn forest	1086
Tropical deciduous forest	1087
Tropical evergreen forest	1088
Tropical montane forest	1088
Aquatic communities	1088
Rivers and lakes	1090
Marine communities	1091

CHAPTER FORTY-THREE BIOGEOGRAPHY 1097

Shaping of the modern world	1098
Historical biogeography	1099
Ecological biogeography	1105
Tests of biogeographical theory	1107
Habitat islands	1107
Patterns of species richness	1108
Community convergence	1110
Convergence in Mediterranean-type vegetation	1112
Species introductions	1113
Outbreaks of pests	1114
The future of species introductions	1115
The preservation of genetic diversity	1116

GLOSSARY 1121

CREDITS 1155

INDEX 1159