

Contents in Brief

- 1** Introduction to Genetics 1
 - 2** Chromosomes and Cellular Reproduction 17
 - 3** Basic Principles of Heredity 46
 - 4** Extensions and Modifications of Basic Principles 79
 - 5** Linkage, Recombination, and Eukaryotic Gene Mapping 122
 - 6** Chromosome Variation 158
 - 7** Bacterial and Viral Genetic Systems 188
 - 8** DNA: The Chemical Nature of the Gene 222
 - 9** DNA Replication and Recombination 251
 - 10** From DNA to Proteins: Transcription and RNA Processing 278
 - 11** From DNA to Proteins: Translation 309
 - 12** Control of Gene Expression 330
 - 13** Gene Mutations and DNA Repair 368
 - 14** Molecular Genetic Analysis and Biotechnology 397
 - 15** Genomics and Proteomics 429
 - 16** Cancer Genetics 452
 - 17** Quantitative Genetics 470
 - 18** Population and Evolutionary Genetics 493
- Glossary G-1
- Index I-1

Contents

Letter from the Author xii

Preface xiii

CHAPTER 1 Introduction to Genetics 1

Albinism in the Hopis 1

1.1 Genetics Is Important to Us Individually, to Society, and to the Study of Biology 3

The Role of Genetics in Biology 4

Genetic Diversity and Evolution 4

Divisions of Genetics 5

Model Genetic Organisms 5

1.2 Humans Have Been Using Genetic Techniques for Thousands of Years 7

The Early Use and Understanding of Heredity 7

The Rise of the Science of Genetics 9

The Cutting Edge of Genetics 11

1.3 A Few Fundamental Concepts Are Important for the Start of Our Journey into Genetics 11

CHAPTER 2 Chromosomes and Cellular Reproduction 17

The Blind Men's Riddle 17

2.1 Prokaryotic and Eukaryotic Cells Differ in a Number of Genetic Characteristics 19

2.2 Cell Reproduction Requires the Copying of the Genetic Material, Separation of the Copies, and Cell Division 20

Prokaryotic Cell Reproduction by Binary Fission 20

Eukaryotic Cell Reproduction 20

The Cell Cycle and Mitosis 23

Genetic Consequences of the Cell Cycle 24

* CONNECTING CONCEPTS Counting Chromosomes and DNA Molecules 26

2.3 Sexual Reproduction Produces Genetic Variation Through the Process of Meiosis 27

Meiosis 27

Sources of Genetic Variation in Meiosis 28

* CONNECTING CONCEPTS Mitosis and Meiosis Compared 32

The Separation of Sister Chromatids and Homologous Chromosomes 33

Meiosis in the Life Cycles of Animals and Plants 33

CHAPTER 3 Basic Principles of Heredity 46

The Genetics of Blond Hair in the South Pacific 46

3.1 Gregor Mendel Discovered the Basic Principles of Heredity 47

Mendel's Success 48

Genetic Terminology 49

3.2 Monohybrid Crosses Reveal the Principle of Segregation and the Concept of Dominance 50

What Monohybrid Crosses Reveal 51

The Molecular Nature of Alleles 53

Predicting the Outcomes of Genetic Crosses 53

* CONNECTING CONCEPTS Relating Genetic Crosses to Meiosis 53

The Testcross 57

Genetic Symbols 58

* CONNECTING CONCEPTS Ratios in Simple Crosses 58

3.3 Dihybrid Crosses Reveal the Principle of Independent Assortment 59

Dihybrid Crosses 59

The Principle of Independent Assortment 59

Relating the Principle of Independent Assortment to Meiosis 60

Applying Probability and the Branch Diagram
to Dihybrid Crosses 61
The Dihybrid Testcross 62

3.4 Observed Ratios of Progeny May Deviate from Expected Ratios by Chance 64

The Chi-Square (χ^2) Goodness-of-Fit Test 64

3.5 Geneticists Often Use Pedigrees to Study the Inheritance of Characteristics in Humans 67

Symbols Used in Pedigrees 67

Analysis of Pedigrees 67

CHAPTER 4 Extensions and Modifications of Basic Principles 79

The Odd Genetics of Left-Handed Snails 79

4.1 Sex Is Determined by a Number of Different Mechanisms 80

Chromosomal Sex-Determining Systems 81

Genic Sex Determination 83

Environmental Sex Determination 83

Sex Determination in *Drosophila melanogaster* 83

Sex Determination in Humans 84

4.2 Sex-Linked Characteristics Are Determined by Genes on the Sex Chromosomes 85

X-Linked White Eyes in *Drosophila* 85

MODEL GENETIC ORGANISM The Fruit Fly *Drosophila melanogaster* 86

X-Linked Color Blindness in Humans 88

Symbols for X-Linked Genes 90

Dosage Compensation 90

Y-Linked Characteristics 92

* CONNECTING CONCEPTS Recognizing Sex-Linked Inheritance 92

4.3 Additional Factors at a Single Locus Can Affect the Results of Genetic Crosses 93

Types of Dominance 93

Penetrance and Expressivity 94

Lethal Alleles 95

Multiple Alleles 96

4.4 Gene Interaction Takes Place When Genes at Multiple Loci Determine a Single Phenotype 97

Gene Interaction That Produces Novel Phenotypes 98

Gene Interaction with Epistasis 99

* CONNECTING CONCEPTS Interpreting Phenotypic Ratios Produced by Gene Interaction 101

Complementation: Determining Whether Mutations Are at the Same Locus or at Different Loci 103

4.5 Sex Influences the Inheritance and Expression of Genes in a Variety of Ways 104

Sex-Influenced and Sex-Limited Characteristics 104

Cytoplasmic Inheritance 104

Genetic Maternal Effect 106

Genomic Imprinting 107

4.6 The Expression of a Genotype May Be Influenced by Environmental Effects 108

Environmental Effects on the Phenotype 108

The Inheritance of Continuous

Characteristics 109

CHAPTER 5 Linkage, Recombination, and Eukaryotic Gene Mapping 122

Mapping Fear and Aggression in Dogs 122

5.1 Linked Genes Do Not Assort Independently 123

5.2 Linked Genes Segregate Together, While Crossing Over Produces Recombination Between Them 125

Notation for Crosses with Linkage 125

Complete Linkage Compared with Independent Assortment 126

Crossing Over Between Linked Genes 127

Calculating Recombination Frequency 129

Coupling and Repulsion 130

* CONNECTING CONCEPTS Relating Independent Assortment, Linkage, and Crossing Over 131

Predicting the Outcomes of Crosses with Linked Genes 132

Testing for Independent Assortment 133

Gene Mapping with Recombination

Frequencies 135

Constructing a Genetic Map with a Two-Point Testcross 136

5.3 A Three-Point Testcross Can Be Used to Map Three Linked Genes 137

Constructing a Genetic Map with a Three-Point Testcross 138

- * **CONNECTING CONCEPTS** Stepping Through the Three-Point Cross 143
 - Effects of Multiple Crossovers 145
 - Mapping with Molecular Markers 146

5.4 Locating Genes with Genome-Wide Association Studies 146

CHAPTER 6 Chromosome Variation 158

The Complex Genome of Wheat 158

6.1 Chromosome Mutations Include Rearrangements, Aneuploidy, and Polyploidy 159

- Chromosome Morphology 159
- Types of Chromosome Mutations 160

6.2 Chromosome Rearrangements Alter Chromosome Structure 161

- Duplications 162
- Deletions 165
- Inversions 166
- Translocations 168
- Fragile Sites 169
- Copy-Number Variations 170

6.3 Aneuploidy Is an Increase or a Decrease in the Number of Individual Chromosomes 171

- Types of Aneuploidy 172
- Effects of Aneuploidy 172
- Aneuploidy in Humans 172

6.4 Polyploidy Is the Presence of More Than Two Sets of Chromosomes 175

- Autopolyploidy 175
- Allopolyploidy 176
- The Significance of Polyploidy 178
- The Importance of Polyploidy in Evolution 179

CHAPTER 7 Bacterial and Viral Genetic Systems 188

The Genetics of Medieval Leprosy 188

7.1 Bacteria and Viruses Have Important Roles in Human Society and the World Ecosystem 189

- Bacterial Diversity 189

7.2 The Genetic Analysis of Bacteria Requires Special Methods 190

- Techniques for the Study of Bacteria 190
- The Bacterial Genome 191
- Plasmids 192

7.3 Bacteria Exchange Genes Through Conjugation, Transformation, and Transduction 193

- Conjugation 195
- Natural Gene Transfer and Antibiotic Resistance 199
- Transformation in Bacteria 200
- Bacterial Genome Sequences 201

7.4 Bacterial Defense Mechanisms 201

- Restriction-Modification Systems 202
- CRISPR-Cas Systems 202

MODEL GENETIC ORGANISM The Bacterium *Escherichia coli* 203

7.5 Viruses Are Simple Replicating Systems Amenable to Genetic Analysis 205

- Techniques for the Study of Bacteriophages 206
- Transduction 206

* **CONNECTING CONCEPTS** Three Methods for Mapping Bacterial Genes 208

- Gene Mapping in Phages 209
- Plant and Animal Viruses 210
- Human Immunodeficiency Virus and AIDS 212
- Influenza 213
- COVID-19 and Coronaviruses 214

CHAPTER 8 DNA: The Chemical Nature of the Gene 222

Hominin History in Ancient DNA 222

8.1 The Genetic Material Possesses Several Key Characteristics 223

8.2 All Genetic Information Is Encoded in the Structure of DNA or RNA 223

- Early Studies of DNA 224
- DNA as the Source of Genetic Information 224
- Watson and Crick's Discovery of the Three-Dimensional Structure of DNA 227

8.3 DNA Consists of Two Complementary and Antiparallel Nucleotide Strands That Form a Double Helix 229

- The Primary Structure of DNA 230
- Secondary Structures of DNA 233

* **CONNECTING CONCEPTS** Genetic Implications of DNA Structure 234

8.4 Large Amounts of DNA Are Packed into a Cell 235

- Supercoiling 236
- The Bacterial Chromosome 237
- Eukaryotic Chromosomes 237

- 8.5 Eukaryotic Chromosomes Possess Centromeres and Telomeres 240**
 Centromere Structure 240
 Telomere Structure 241
- 8.6 Eukaryotic DNA Contains Several Classes of Sequence Variation 242**
 Types of DNA Sequences in Eukaryotes 242
 Organization of Genetic Information in Eukaryotes 242

CHAPTER 9 DNA Replication and Recombination 251

The Importance of a Good Start 251

- 9.1 Genetic Information Must Be Accurately Copied Every Time a Cell Divides 252**
- 9.2 All DNA Replication Takes Place in a Semiconservative Manner 252**
 Meselson and Stahl's Experiment 253
 Modes of Replication 254
 Requirements of Replication 256
 Direction of Replication 257
- 9.3 Bacterial Replication Requires a Large Number of Enzymes and Proteins 259**
 Initiation 259
 Unwinding 259
 Elongation 261
 Termination 263
 The Fidelity of DNA Replication 263
- * CONNECTING CONCEPTS The Basic Rules of Replication 264**
- 9.4 Eukaryotic DNA Replication Is Similar to Bacterial Replication but Differs in Several Aspects 264**
 Eukaryotic Origins of Replication 264
 The Licensing of DNA Replication 264
 Unwinding 265
 Eukaryotic DNA Polymerases 265
 Replication at the Ends of Chromosomes 266
 Replication in Archaea 268
- 9.5 Recombination Takes Place Through the Alignment, Breakage, and Repair of DNA Strands 268**

CHAPTER 10 From DNA to Proteins: Transcription and RNA Processing 278

Wrecks on the DNA Highway 278

- 10.1 RNA, Consisting of a Single Strand of Ribonucleotides, Participates in a Variety of Cellular Functions 279**
 An Early RNA World 279
 The Structure of RNA 280
 Classes of RNA 280
- 10.2 Transcription Is the Synthesis of an RNA Molecule from a DNA Template 282**
 The Template 282
 The Substrate for Transcription 284
 The Transcription Apparatus 285
- 10.3 Bacterial Transcription Consists of Initiation, Elongation, and Termination 286**
 Initiation 286
 Elongation 287
 Termination 288
- * CONNECTING CONCEPTS The Basic Rules of Transcription 290**
- 10.4 Many Genes Have Complex Structures 290**
 Gene Organization 290
 Introns 291
 The Concept of the Gene Revisited 292
- 10.5 Many RNA Molecules Are Modified after Transcription in Eukaryotes 293**
 Messenger RNA Processing 293
- * CONNECTING CONCEPTS Eukaryotic Gene Structure and Pre-mRNA Processing 297**
 The Structure and Processing of Transfer RNA 298
 The Structure and Processing of Ribosomal RNA 299
 Small RNA Molecules and RNA Interference 299
 CRISPR RNA 300
 Long Noncoding RNAs Regulate Gene Expression 300
- MODEL GENETIC ORGANISM The Nematode Worm *Caenorhabditis elegans* 300**

CHAPTER 11 From DNA to Proteins: Translation 309

A Child Without a Spleen 309

11.1 The Genetic Code Determines How the Nucleotide Sequence Specifies the Amino Acid Sequence of a Protein 310

The Structure and Function of Proteins 310
Breaking the Genetic Code 312
Characteristics of the Genetic Code 313

* CONNECTING CONCEPTS Characteristics of the Genetic Code 315

11.2 Amino Acids Are Assembled into a Protein Through Translation 316

The Binding of Amino Acids to Transfer RNAs 316
The Initiation of Translation 317
Elongation 318
Termination 320

* CONNECTING CONCEPTS A Comparison of Bacterial and Eukaryotic Translation 321

11.3 Additional Properties of Translation and Proteins 322

Polyribosomes 322
Folding and Posttranslational Modifications of Proteins 323
Translation and Antibiotics 323

CHAPTER 12 Control of Gene Expression 330

Operons and the Noisy Cell 330

12.1 The Regulation of Gene Expression Is Critical for All Organisms 331

Genes and Regulatory Elements 332
Levels of Gene Regulation 332

12.2 Transcription in Bacterial Cells Is Regulated by Operons 333

Operon Structure 333
Negative and Positive Control: Inducible and Repressible Operons 334
The *lac* Operon of *E. coli* 336
Mutations Affecting the *lac* Operon 338
Positive Control and Catabolite Repression 342
The *trp* Operon of *E. coli* 344

12.3 Gene Regulation in Eukaryotic Cells Takes Place at Multiple Levels 345

Changes in Chromatin Structure 345
Transcription Factors 347

Gene Regulation by RNA Processing and Degradation 349

RNA Interference and Gene Regulation 351
Gene Regulation in the Course of Translation and Afterward 352

* CONNECTING CONCEPTS A Comparison of Bacterial and Eukaryotic Gene Control 353

MODEL GENETIC ORGANISM The Plant *Arabidopsis thaliana* 353

12.4 Epigenetic Effects Influence Gene Expression 355

Molecular Mechanisms of Epigenetic Changes 356
Epigenetic Effects 357
The Epigenome 359

CHAPTER 13 Gene Mutations and DNA Repair 368

Lou Gehrig and Expanding Nucleotide Repeats 368

13.1 Mutations Are Inherited Alterations in the DNA Sequence 369

The Importance of Mutations 369
Categories of Mutations 370
Types of Gene Mutations 371
Functional Effects of Mutations 372
Suppressor Mutations 374
Mutation Rates 376

13.2 Mutations May Be Caused by a Number of Different Factors 378

Spontaneous Replication Errors 378
Spontaneous Chemical Changes 380
Chemically Induced Mutations 381
Radiation 383
Detecting Mutagens with the Ames Test 384

13.3 Transposable Elements Can Cause Mutations 385

General Characteristics of Transposable Elements 385
The Process of Transposition 386
The Mutagenic Effects of Transposition 386
Evolutionary Significance of Transposable Elements 388

13.4 A Number of Pathways Repair DNA 388

Types of DNA Repair 388
Genetic Diseases and Faulty DNA Repair 389

CHAPTER 14 Molecular Genetic Analysis and Biotechnology 397

Editing the Genome with CRISPR-Cas9 397

14.1 Genetics Has Been Transformed by the Development of Molecular Techniques 398

Key Innovations in Molecular Genetics 398
Working at the Molecular Level 399

14.2 Molecular Techniques Are Used to Cut and Visualize DNA Sequences 399

Recombinant DNA Technology 399
Restriction Enzymes 399
Engineered Nucleases 401
CRISPR-Cas Genome Editing 402
Separating and Viewing DNA Fragments 404

14.3 Specific DNA Fragments Can Be Amplified 405

The Polymerase Chain Reaction 405
Gene Cloning 406

14.4 Molecular Techniques Can Be Used to Find Genes of Interest 409

DNA Libraries 409

14.5 DNA Sequences Can Be Determined and Analyzed 411

Dideoxy Sequencing 411
Next-Generation Sequencing Technologies 413
DNA Fingerprinting 415

14.6 Molecular Techniques Are Increasingly Used to Analyze Gene Function 416

Forward and Reverse Genetics 416
Transgenic Animals 416
Knockout Mice 418

MODEL GENETIC ORGANISM The Mouse *Mus musculus* 418

Silencing Genes with RNAi 420

14.7 Biotechnology Harnesses the Power of Molecular Genetics 420

Pharmaceutical Products 420
Specialized Bacteria 420
Agricultural Products 420
Genetic Testing 421
Gene Therapy 421

CHAPTER 15 Genomics and Proteomics 429

Sequencing the Tree of Life 429

15.1 Structural Genomics Determines the DNA Sequences and Organization of Entire Genomes 430

Genetic Maps 431
Physical Maps 431
Sequencing an Entire Genome 432
The Human Genome Project 432
Single-Nucleotide Polymorphisms 436
Bioinformatics 437
Metagenomics 437
Synthetic Biology 438

15.2 Functional Genomics Determines the Functions of Genes by Using Genomic Approaches 438

Predicting Function from Sequence 438
Gene Expression and Microarrays 439
RNA Sequencing 441

15.3 Comparative Genomics Studies How Genomes Evolve 441

Prokaryotic Genomes 441
Eukaryotic Genomes 442
The Human Genome 444

15.4 Proteomics Analyzes the Complete Set of Proteins Found in a Cell 445

The Determination of Cellular Proteins 445

CHAPTER 16 Cancer Genetics 452

Four Families and the Guardian of the Genome 452

16.1 Cancer Is a Group of Diseases Characterized by Cell Proliferation 454

Tumor Formation 454
Cancer as a Genetic Disease 455
The Role of Environmental Factors in Cancer 457

16.2 Mutations in Several Types of Genes Contribute to Cancer 458

Oncogenes and Tumor-Suppressor Genes 458
Genes That Control the Cell Cycle 460
DNA-Repair Genes 461
Genes That Regulate Telomerase 461
Genes That Promote Vascularization and the Spread of Tumors 462
Epigenetic Changes Are Often Associated with Cancer 462

Colorectal Cancer Arises Through the Sequential Mutation of a Number of Genes 462

16.3 Changes in Chromosome Number and Structure Are Often Associated with Cancer 463

16.4 Viruses Are Associated with Some Cancers 465

CHAPTER 17 Quantitative Genetics 470

Corn Oil and Quantitative Genetics 470

17.1 Quantitative Characteristics Are Influenced by Alleles at Multiple Loci 471

The Relation Between Genotype and Phenotype 471

Types of Quantitative Characteristics 473

Polygenic Inheritance 473

Kernel Color in Wheat 473

17.2 Statistical Methods Are Required for Analyzing Quantitative Characteristics 475

Distributions 476

The Mean 476

The Variance 477

Applying Statistics to the Study of a Polygenic Characteristic 478

17.3 Heritability Is Used to Estimate the Proportion of Variation in a Trait That Is Genetic 478

Phenotypic Variance 479

Types of Heritability 480

Calculating Heritability 480

The Limitations of Heritability 481

Locating Genes That Affect Quantitative Characteristics 483

17.4 Genetically Variable Traits Change in Response to Selection 483

Predicting the Response to Selection 484

Limits to the Response to Selection 485

CHAPTER 18 Population and Evolutionary Genetics 493

The Wolves of Isle Royale 493

18.1 Genotypic and Allelic Frequencies Are Used to Describe the Gene Pool of a Population 494

Calculating Genotypic Frequencies 495

Calculating Allelic Frequencies 495

18.2 The Hardy–Weinberg Law Describes the Effect of Reproduction on Genotypic and Allelic Frequencies 497

Genotypic Frequencies at Hardy–Weinberg Equilibrium 497

Closer Examination of the Hardy–Weinberg Law 498

Implications of the Hardy–Weinberg Law 498

Testing for Hardy–Weinberg Proportions 498

Estimating Allelic Frequencies with the Hardy–Weinberg Law 500

Nonrandom Mating Alters Genotype Frequencies 500

18.3 Several Evolutionary Forces Can Change Allelic Frequencies 500

Mutation 500

Migration 501

Genetic Drift 502

Natural Selection 504

* CONNECTING CONCEPTS The General Effects of Forces That Change Allelic Frequencies 506

18.4 Evolution Occurs Through Genetic Change Within Populations 507

Biological Evolution 507

Evolution as a Two-Step Process 507

Types of Evolution 507

18.5 New Species Arise Through the Evolution of Reproductive Isolation 507

The Biological Species Concept 508

Reproductive Isolating Mechanisms 508

Modes of Speciation 509

18.6 The Evolutionary History of a Group of Organisms Can Be Reconstructed by Studying Changes in Homologous Characteristics 512

Interpreting Phylogenetic Trees 513

The Construction of Phylogenetic Trees 513

18.7 Patterns of Evolution Are Revealed by Molecular Changes 514

Rates of Molecular Evolution 514

The Molecular Clock 515

Evolution Through Changes in Gene Regulation 516

Genome Evolution 516

Glossary G-1

Index I-1