

Contents in Brief

1	Introduction to Genetics	1
2	Chromosomes and Cellular Reproduction	15
3	Basic Principles of Heredity	41
4	Sex Determination and Sex-Linked Characteristics	69
5	Extensions and Modifications of Basic Principles	93
6	Pedigree Analysis, Applications, and Genetic Testing	127
7	Quantitative Genetics	153
8	Linkage, Recombination, and Eukaryotic Gene Mapping	185
9	Bacterial and Viral Genetic Systems	225
10	Chromosome Variation	259
11	DNA: The Chemical Nature of the Gene	289
12	Chromosome Structure and Transposable Elements	309
13	DNA Replication and Recombination	339
14	Transcription	369
15	RNA Molecules and RNA Processing	393
16	The Genetic Code and Translation	419
17	Control of Gene Expression in Prokaryotes	447
18	Control of Gene Expression in Eukaryotes	475
19	Gene Mutations and DNA Repair	495
20	Molecular Genetic Analysis and Biotechnology	525
21	Genomics and Proteomics	567
22	Organelle DNA	601
23	Developmental Genetics and Immunogenetics	621
24	Cancer Genetics	647
25	Population Genetics	669
26	Evolutionary Genetics	697
	Reference Guide to Model Genetic Organisms	A1

Contents

Letter from the Author xv

Preface xvi

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 2
 - 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 Genetics for Thousands of Years 7
 - The Early Use and Understanding of Heredity 7
 - The Rise of the Science of Genetics 9
 - The Future of Genetics 10
- 1.3 A Few Fundamental Concepts Are Important for the Start of Our Journey into Genetics 11

Chapter 2 Chromosomes and Cellular Reproduction 15

THE BLIND MEN'S RIDDLE 15

- 2.1 Prokaryotic and Eukaryotic Cells Differ in a Number of Genetic Characteristics 17
 - 2.2 Cell Reproduction Requires the Copying of the Genetic Material, Separation of the Copies, and Cell Division 18
 - Prokaryotic Cell Reproduction 18
 - Eukaryotic Cell Reproduction 18
 - The Cell Cycle and Mitosis 21
 - Genetic Consequences of the Cell Cycle 24

 - Connecting Concepts: Counting Chromosomes and DNA Molecules 25
- 2.3 Sexual Reproduction Produces Genetic Variation Through the Process of Meiosis 25
 - Meiosis 26
 - Sources of Genetic Variation in Meiosis 29

 - Connecting Concepts: Mitosis and Meiosis Compared 31

The Separation of Sister Chromatids and Homologous Chromosomes 31

Meiosis in the Life Cycles of Animals and Plants 33

Chapter 3 Basic Principles of Heredity 41

THE GENETICS OF RED HAIR 41

- 3.1 Gregor Mendel Discovered the Basic Principles of Heredity 42
 - Mendel's Success 43
 - Genetic Terminology 44
 - 3.2 Monohybrid Crosses Reveal the Principle of Segregation and the Concept of Dominance 45
 - What Monohybrid Crosses Reveal 46

 - Connecting Concepts: Relating Genetic Crosses to Meiosis 47
 - Predicting the Outcomes of Genetic Crosses 49
 - The Testcross 53
 - Genetic Symbols 53
-
- 3.3 Dihybrid Crosses Reveal the Principle of Independent Assortment 54
 - Dihybrid Crosses 54
 - The Principle of Independent Assortment 54
 - Relating the Principle of Independent Assortment to Meiosis 55
 - Applying Probability and the Branch Diagram to Dihybrid Crosses 55
 - The Dihybrid Testcross 57
- 3.4 Observed Ratios of Progeny May Deviate from Expected Ratios by Chance 59
 - The Goodness-of-Fit Chi-Square Test 59

Chapter 4 Sex Determination and Sex-Linked Characteristics 69

THE STRANGE CASE OF PLATYPUS SEX 69

- 4.1 Sex Is Determined by a Number of Different Mechanisms 70
 - Chromosomal Sex-Determining Systems 71
 - Genic Sex Determination 73

Environmental Sex Determination 73
 Sex Determination in *Drosophila melanogaster* 74
 Sex Determination in Humans 75

4.2 Sex-Linked Characteristics Are Determined by Genes on the Sex Chromosomes 77

X-Linked White Eyes in *Drosophila* 77
 Nondisjunction and the Chromosome Theory of Inheritance 78
 X-Linked Color Blindness in Humans 80
 Symbols for X-Linked Genes 81
 Z-Linked Characteristics 81
 Y-Linked Characteristics 82

Connecting Concepts: Recognizing Sex-Linked Inheritance 84

4.3 Dosage Compensation Equalizes the Amount of Protein Produced by X-Linked Genes in Males and Females 84

Lyon Hypothesis 85
 Mechanism of Random X Inactivation 86
 Dosage Imbalance Between X-Linked Genes and Autosomal Genes 86

Chapter 5 Extensions and Modifications of Basic Principles 93

CUÉNOT'S ODD YELLOW MICE 93

5.1 Additional Factors at a Single Locus Can Affect the Results of Genetic Crosses 94

Types of Dominance 94
 Penetrance and Expressivity 97
 Lethal Alleles 97
 Multiple Alleles 98

5.2 Gene Interaction Takes Place When Genes at Multiple Loci Determine a Single Phenotype 100

Gene Interaction That Produces Novel Phenotypes 100
 Gene Interaction with Epistasis 101

Connecting Concepts: Interpreting Ratios Produced by Gene Interaction 105

Complementation: Determining Whether Mutations Are at the Same Locus or at Different Loci 107
 The Complex Genetics of Coat Color in Dogs 107

5.3 Sex Influences the Inheritance and Expression of Genes in a Variety of Ways 109

Sex-Influenced and Sex-Limited Characteristics 109
 Cytoplasmic Inheritance 111

Genetic Maternal Effect 113
 Genomic Imprinting 114

5.4 Anticipation Is the Stronger or Earlier Expression of Traits in Succeeding Generations 116

5.5 The Expression of a Genotype May Be Affected by Environmental Effects 117

Environmental Effects on the Phenotype 117
 The Inheritance of Continuous Characteristics 118

Chapter 6 Pedigree Analysis, Applications, and Genetic Testing 127

HUTCHINSON–GILFORD SYNDROME AND THE SECRET OF AGING 127

6.1 The Study of Genetics in Humans Is Constrained by Special Features of Human Biology and Culture 128

6.2 Geneticists Often Use Pedigrees to Study the Inheritance of Characteristics in Humans 129

Symbols Used in Pedigrees 129
 Analysis of Pedigrees 129
 Autosomal Recessive Traits 130
 Autosomal Dominant Traits 131
 X-Linked Recessive Traits 131
 X-Linked Dominant Traits 133
 Y-Linked Traits 134

6.3 Studying Twins and Adoptions Can Help Assess the Importance of Genes and Environment 135

Types of Twins 135
 Concordance in Twins 136
 A Twin Study of Asthma 137
 Adoption Studies 138

6.4 Genetic Counseling and Genetic Testing Provide Information to Those Concerned about Genetic Diseases and Traits 138

Genetic Counseling 138
 Genetic Testing 140
 Interpreting Genetic Tests 144
 Direct-to-Consumer Genetic Testing 145

6.5 Comparison of Human and Chimpanzee Genomes Is Helping to Reveal Genes That Make Humans Unique 145

Chapter 7 Quantitative Genetics 153**CORN OIL AND QUANTITATIVE GENETICS 153****7.1 Quantitative Characteristics Vary Continuously and Many Are Influenced by Alleles at Multiple Loci 154**

The Relation Between Genotype and Phenotype 155

Types of Quantitative Characteristics 156

Polygenic Inheritance 156

Kernel Color in Wheat 157

Determining Gene Number for a Polygenic Characteristic 158

7.2 Statistical Methods Are Required for Analyzing Quantitative Characteristics 159

Distributions 159

Samples and Populations 160

The Mean 160

The Variance and Standard Deviation 161

Correlation 162

Regression 163

Applying Statistics to the Study of a Polygenic Characteristic 165

7.3 Heritability Is Used to Estimate the Proportion of Variation in a Trait That Is Genetic 166

Phenotypic Variance 166

Types of Heritability 168

Calculating Heritability 168

The Limitations of Heritability 170

Locating Genes That Affect Quantitative Characteristics 172

7.4 Genetically Variable Traits Change in Response to Selection 174

Predicting the Response to Selection 174

Limits to Selection Response 176

Correlated Responses 177

Chapter 8 Linkage, Recombination, and Eukaryotic Gene Mapping 185**LINKED GENES AND BALD HEADS 185****8.1 Linked Genes Do Not Assort Independently 186****8.2 Linked Genes Segregate Together and Crossing Over Produces Recombination Between Them 187**

Notation for Crosses with Linkage 188

Complete Linkage Compared with Independent Assortment 188

Crossing Over with Linked Genes 190

Calculating Recombination Frequency 191

Coupling and Repulsion 192

Connecting Concepts: Relating Independent Assortment, Linkage, and Crossing Over 193

Evidence for the Physical Basis of Recombination 194

Predicting the Outcomes of Crosses with Linked Genes 195

Testing for Independent Assortment 196

Gene Mapping with Recombination Frequencies 198

Constructing a Genetic Map with the Use of Two-Point Testcrosses 199

8.3 A Three-Point Testcross Can Be Used to Map Three Linked Genes 200

Constructing a Genetic Map with the Three-Point Testcross 201

Connecting Concepts: Stepping Through the Three-Point Cross 206

Effect of Multiple Crossovers 208

Mapping Human Genes 209

Mapping with Molecular Markers 210

Locating Genes with Genomewide Association Studies 210

8.4 Physical-Mapping Methods Are Used to Determine the Physical Positions of Genes on Particular Chromosomes 211

Deletion Mapping 212

Somatic-Cell Hybridization 212

Physical Chromosome Mapping Through Molecular Analysis 214

8.5 Recombination Rates Exhibit Extensive Variation 215**Chapter 9 Bacterial and Viral Genetic Systems 225****LIFE IN A BACTERIAL WORLD 225****9.1 Genetic Analysis of Bacteria Requires Special Methods 226**

Bacterial Diversity 226

Techniques for the Study of Bacteria 227

The Bacterial Genome 228

Plasmids 228

9.2 Bacteria Exchange Genes Through Conjugation, Transformation, and Transduction 230

Conjugation 230

Natural Gene Transfer and Antibiotic Resistance 237

Transformation in Bacteria 238
 Bacterial Genome Sequences 240
 Horizontal Gene Transfer 240

9.3 Viruses Are Simple Replicating Systems Amenable to Genetic Analysis 241

Techniques for the Study of Bacteriophages 241
 Transduction: Using Phages to Map Bacterial Genes 242

Connecting Concepts: Three Methods for Mapping Bacterial Genes 245

Gene Mapping in Phages 245
 Fine-Structure Analysis of Bacteriophage Genes 246
 RNA Viruses 249
 Human Immunodeficiency Virus and AIDS 249
 Influenza Virus 251

Chapter 10 Chromosome Variation 259

TRISOMY 21 AND THE DOWN-SYNDROME CRITICAL REGION 259

10.1 Chromosome Mutations Include Rearrangements, Aneuploids, and Polyploids 260

Chromosome Morphology 260
 Types of Chromosome Mutations 261

10.2 Chromosome Rearrangements Alter Chromosome Structure 262

Duplications 262
 Deletions 264
 Inversions 266
 Translocations 268
 Fragile Sites 271
 Copy-Number Variations 272

10.3 Aneuploidy Is an Increase or Decrease in the Number of Individual Chromosomes 272

Types of Aneuploidy 272
 Effects of Aneuploidy 272
 Aneuploidy in Humans 274
 Uniparental Disomy 277
 Mosaicism 277

10.4 Polyploidy Is the Presence of More than Two Sets of Chromosomes 278

Autopolyploidy 278
 Allopolyploidy 280
 The Significance of Polyploidy 281

10.5 Chromosome Variation Plays an Important Role in Evolution 282

Chapter 11 DNA: The Chemical Nature of the Gene 289

NEANDERTHAL'S DNA 289

11.1 Genetic Material Possesses Several Key Characteristics 290

11.2 All Genetic Information Is Encoded in the Structure of DNA or RNA 290

Early Studies of DNA 290
 DNA As the Source of Genetic Information 292
 Watson and Crick's Discovery of the Three-Dimensional Structure of DNA 295
 RNA As Genetic Material 296

11.3 DNA Consists of Two Complementary and Antiparallel Nucleotide Strands That Form a Double Helix 297

The Primary Structure of DNA 297
 Secondary Structures of DNA 299

Connecting Concepts: Genetic Implications of DNA Structure 302

11.4 Special Structures Can Form in DNA and RNA 303

Chapter 12 Chromosome Structure and Transposable Elements 309

JUMPING GENES IN ELONGATED TOMATOES 309

12.1 Large Amounts of DNA Are Packed into a Cell 310

Supercoiling 310
 The Bacterial Chromosome 311
 Eukaryotic Chromosomes 311
 Changes in Chromatin Structure 315

12.2 Eukaryotic Chromosomes Possess Centromeres and Telomeres 317

Centromere Structure 317
 Telomere Structure 318
 Artificial Chromosomes 319

12.3 Eukaryotic DNA Contains Several Classes of Sequence Variation 319

The Denaturation and Renaturation of DNA 319
 Types of DNA Sequences in Eukaryotes 320

12.4 Transposable Elements Are DNA Sequences Capable of Moving 321

- General Characteristics of Transposable Elements 321
- Transposition 321
- The Mutagenic Effects of Transposition 324
- The Regulation of Transposition 326

12.5 Different Types of Transposable Elements Have Characteristic Structures 326

- Transposable Elements in Bacteria 326
- Transposable Elements in Eukaryotes 328

Connecting Concepts: Classes of Transposable Elements 332

12.6 Transposable Elements Have Played an Important Role in Genome Evolution 332

- The Evolution of Transposable Elements 332
- Domestication of Transposable Elements 333

Chapter 13 DNA Replication and Recombination 339

TOPOISOMERASE, REPLICATION, AND CANCER 339

13.1 Genetic Information Must Be Accurately Copied Every Time a Cell Divides 340

13.2 All DNA Replication Takes Place in a Semiconservative Manner 340

- Meselson and Stahl's Experiment 341
- Modes of Replication 343
- Requirements of Replication 346
- Direction of Replication 347

Connecting Concepts: The Direction of Replication in Different Models of Replication 347

13.3 Bacterial Replication Requires a Large Number of Enzymes and Proteins 348

- Initiation 348
- Unwinding 348
- Elongation 350
- Termination 353
- The Fidelity of DNA Replication 353

Connecting Concepts: The Basic Rules of Replication 354

13.4 Eukaryotic DNA Replication Is Similar to Bacterial Replication but Differs in Several Aspects 354

- Eukaryotic Origins 354
- The Licensing of DNA Replication 355
- Unwinding 355

- Eukaryotic DNA Polymerases 355
- Nucleosome Assembly 356
- The Location of Replication Within the Nucleus 357
- DNA Synthesis and the Cell Cycle 357
- Replication at the Ends of Chromosomes 358
- Replication in Archaea 360

13.5 Recombination Takes Place Through the Breakage, Alignment, and Repair of DNA Strands 360

- Models of Recombination 361
- Enzymes Required for Recombination 362
- Gene Conversion 363

Chapter 14 Transcription 369

DEATH CAP POISONING 369

14.1 RNA, Consisting of a Single Strand of Ribonucleotides, Participates in a Variety of Cellular Functions 370

- An Early RNA World 370
- The Structure of RNA 370
- Classes of RNA 371

14.2 Transcription Is the Synthesis of an RNA Molecule from a DNA Template 372

- The Template 373
- The Substrate for Transcription 375
- The Transcription Apparatus 375

14.3 The Process of Bacterial Transcription Consists of Initiation, Elongation, and Termination 377

- Initiation 377
- Elongation 379
- Termination 380

Connecting Concepts: The Basic Rules of Transcription 381

14.4 Eukaryotic Transcription Is Similar to Bacterial Transcription but Has Some Important Differences 382

- Transcription and Nucleosome Structure 382
- Promoters 382
- Initiation 383
- Elongation 385
- Termination 385

14.5 Transcription in Archaea Is More Similar to Transcription in Eukaryotes than to Transcription in Eubacteria 386

Chapter 15 RNA Molecules and RNA Processing 393

SEX THROUGH SPLICING 393

15.1 Many Genes Have Complex Structures 394

Gene Organization 394

Introns 395

The Concept of the Gene Revisited 396

15.2 Messenger RNAs, Which Encode the Amino Acid Sequences of Proteins, Are Modified after Transcription in Eukaryotes 397

The Structure of Messenger RNA 398

Pre-mRNA Processing 398

The Addition of the 5' Cap 399

The Addition of the Poly(A) Tail 399

RNA Splicing 400

Alternative Processing Pathways 403

RNA Editing 405

Connecting Concepts: Eukaryotic Gene Structure and Pre-mRNA Processing 406

15.3 Transfer RNAs, Which Attach to Amino Acids, Are Modified after Transcription in Bacterial and Eukaryotic Cells 407

The Structure of Transfer RNA 408

Transfer RNA Gene Structure and Processing 409

15.4 Ribosomal RNA, a Component of the Ribosome, Also Is Processed after Transcription 410

The Structure of the Ribosome 410

Ribosomal RNA Gene Structure and Processing 411

15.5 Small RNA Molecules Participate in a Variety of Functions 412

RNA Interference 412

Types of Small RNAs 413

Processing and Function of MicroRNAs 413

Chapter 16 The Genetic Code and Translation 419

HUTTERITES, RIBOSOMES, AND BOWEN–CONRAD SYNDROME 419

16.1 Many Genes Encode Proteins 420

The One Gene, One Enzyme Hypothesis 420

The Structure and Function of Proteins 423

16.2 The Genetic Code Determines How the Nucleotide Sequence Specifies the Amino Acid Sequence of a Protein 425

Breaking the Genetic Code 426

The Degeneracy of the Code 428

The Reading Frame and Initiation Codons 429

Termination Codons 430

The Universality of the Code 430

Connecting Concepts: Characteristics of the Genetic Code 430

16.3 Amino Acids Are Assembled into a Protein Through the Mechanism of Translation 430

The Binding of Amino Acids to Transfer RNAs 431

The Initiation of Translation 432

Elongation 434

Termination 435

Connecting Concepts: A Comparison of Bacterial and Eukaryotic Translation 437

16.4 Additional Properties of RNA and Ribosomes Affect Protein Synthesis 438

The Three-Dimensional Structure of the Ribosome 438

Polyribosomes 439

Messenger RNA Surveillance 439

The Posttranslational Modifications of Proteins 441

Translation and Antibiotics 441

Nonstandard Protein Synthesis 441

Chapter 17 Control of Gene Expression in Prokaryotes 447

STRESS, SEX, AND GENE REGULATION IN BACTERIA 447

17.1 The Regulation of Gene Expression Is Critical for All Organisms 448

Genes and Regulatory Elements 449

Levels of Gene Regulation 449

DNA-Binding Proteins 450

17.2 Operons Control Transcription in Bacterial Cells 451

Operon Structure 451

Negative and Positive Control: Inducible and Repressible Operons 452

The *lac* Operon of *E. coli* 454

lac Mutations 457

Positive Control and Catabolite Repression 461

The *trp* Operon of *E. coli* 462

- 17.3 Some Operons Regulate Transcription Through Attenuation, the Premature Termination of Transcription 464
 Attenuation in the *trp* Operon of *E. coli* 464
 Why Does Attenuation Take Place in the *trp* Operon? 467

- 17.4 RNA Molecules Control the Expression of Some Bacterial Genes 467
 Antisense RNA 467
 Riboswitches 468
 Riboswitches That Function As Ribozymes 469

Chapter 18 Control of Gene Expression in Eukaryotes 475

HOW A PARASITE CHANGES ITS SPOTS 475

- 18.1 Eukaryotic Cells and Bacteria Have Many Features of Gene Regulation in Common, but They Differ in Several Important Ways 476
- 18.2 Changes in Chromatin Structure Affect the Expression of Genes 476
 DNase I Hypersensitivity 476
 Histone Modification 477
 Chromatin Remodeling 478
 DNA Methylation 479
- 18.3 Epigenetic Effects Often Result from Alterations in Chromatin Structure 479
 Epigenetic Effects 479
 Molecular Mechanisms of Epigenetic Changes 480
 The Epigenome 480
- 18.4 The Initiation of Transcription Is Regulated by Transcription Factors and Transcriptional Regulator Proteins 481
 Transcriptional Activators and Coactivators 482
 Transcriptional Repressors 483
 Enhancers and Insulators 484
 Regulation of Transcriptional Stalling and Elongation 484
 Coordinated Gene Regulation 485
- 18.5 Some Genes Are Regulated by RNA Processing and Degradation 486
 Gene Regulation Through RNA Splicing 486
 The Degradation of RNA 487
- 18.6 RNA Interference Is an Important Mechanism of Gene Regulation 488
 Small Interfering RNAs and MicroRNAs 488
 Mechanisms of Gene Regulation by RNA Interference 489
 The Control of Development by RNA Interference 490

- 18.7 Some Genes Are Regulated by Processes That Affect Translation or by Modifications of Proteins 490

Connecting Concepts: A Comparison of Bacterial and Eukaryotic Gene Control 490

Chapter 19 Gene Mutations and DNA Repair 495

A FLY WITHOUT A HEART 495

- 19.1 Mutations Are Inherited Alterations in the DNA Sequence 496
 The Importance of Mutations 496
 Categories of Mutations 496
 Types of Gene Mutations 497
 Phenotypic Effects of Mutations 499
 Suppressor Mutations 500
 Mutation Rates 504
- 19.2 Mutations Are Potentially Caused by a Number of Different Natural and Unnatural Factors 505
 Spontaneous Replication Errors 505
 Spontaneous Chemical Changes 507
 Chemically Induced Mutations 508
 Radiation 511
- 19.3 Mutations Are the Focus of Intense Study by Geneticists 512
 Detecting Mutations with the Ames Test 512
 Radiation Exposure in Humans 512
- 19.4 A Number of Pathways Repair Changes in DNA 514
 Mismatch Repair 515
 Direct Repair 516
 Base-Excision Repair 516
 Nucleotide-Excision Repair 517
-
- Connecting Concepts: The Basic Pathway of DNA Repair 518
-
- Repair of Double-Strand Breaks 518
 Translesion DNA Polymerases 518
 Genetic Diseases and Faulty DNA Repair 519

Chapter 20 Molecular Genetic Analysis and Biotechnology 525

HELPING THE BLIND TO SEE 525

- 20.1 Techniques of Molecular Genetics Have Revolutionized Biology 526

The Molecular Genetics Revolution	526
Working at the Molecular Level	526
20.2 Molecular Techniques Are Used to Isolate, Recombine, and Amplify Genes	527
Cutting and Joining DNA Fragments	527
Viewing DNA Fragments	529
Locating DNA Fragments with Southern Blotting and Probes	530
Cloning Genes	531
Amplifying DNA Fragments with the Polymerase Chain Reaction	535
Application: The Genetic Engineering of Plants with Pesticides	537
20.3 Molecular Techniques Can Be Used to Find Genes of Interest	539
Gene Libraries	539
In Situ Hybridization	541
Positional Cloning	541
In Silico Gene Discovery	543
Application: Isolating the Gene for Cystic Fibrosis	543
20.4 DNA Sequences Can Be Determined and Analyzed	545
Restriction Fragment Length Polymorphisms	545
DNA Sequencing	546
Next-Generation Sequencing Technologies	549
DNA Fingerprinting	550
Application: Identifying People Who Died in the Collapse of the World Trade Center	552
20.5 Molecular Techniques Are Increasingly Used to Analyze Gene Function	553
Forward and Reverse Genetics	553
Creating Random Mutations	553
Site-Directed Mutagenesis	553
Transgenic Animals	554
Knockout Mice	555
Silencing Genes with RNAi	557
Application: Using RNAi for the Treatment of Human Disease	557
20.6 Biotechnology Harnesses the Power of Molecular Genetics	559
Pharmaceutical Products	559
Specialized Bacteria	559
Agricultural Products	559
Genetic Testing	560
Gene Therapy	560

Chapter 21 Genomics and Proteomics 567

DECODING THE WAGGLE DANCE: THE GENOME OF THE HONEYBEE 567

21.1 Structural Genomics Determines the DNA Sequences of Entire Genomes	568
Genetic Maps	568
Physical Maps	570
Sequencing an Entire Genome	571
The Human Genome Project	572
Single-Nucleotide Polymorphisms	575
Copy-Number Variations	577
Expressed-Sequence Tags	577
Bioinformatics	577
Metagenomics	579
Synthetic Biology	580
21.2 Functional Genomics Determines the Function of Genes by Using Genomic-Based Approaches	580
Predicting Function from Sequence	580
Gene Expression and Microarrays	581
Gene Expression and Reporter Sequences	584
Genomewide Mutagenesis	584
21.3 Comparative Genomics Studies How Genomes Evolve	585
Prokaryotic Genomes	585
Eukaryotic Genomes	587
Comparative <i>Drosophila</i> Genomics	590
The Human Genome	591
21.4 Proteomics Analyzes the Complete Set of Proteins Found in a Cell	592
Determination of Cellular Proteins	592
Affinity Capture	594
Protein Microarrays	594
Structural Proteomics	594

Chapter 22 Organelle DNA 601

THE DONKEY: A WILD ASS OR A HALF ASS? 601

22.1 Mitochondria and Chloroplasts Are Eukaryotic Cytoplasmic Organelles	602
Mitochondrion and Chloroplast Structure	602
The Genetics of Organelle-Encoded Traits	603
The Endosymbiotic Theory	606

- 22.2 Mitochondrial DNA Varies Widely in Size and Organization 607**
 The Gene Structure and Organization of Mitochondrial DNA 607
 Nonuniversal Codons in Mitochondrial DNA 609
 The Replication, Transcription, and Translation of Mitochondrial DNA 609
 The Evolution of Mitochondrial DNA 610
 Mitochondrial DNA Variation and Human History 611

22.3 Chloroplast DNA Exhibits Many Properties of Eubacterial DNA 611

- The Gene Structure and Organization of Chloroplast DNA 612
 The Replication, Transcription, and Translation of Chloroplast DNA 613
 The Evolution of Chloroplast DNA 613

Connecting Concepts: Genome Comparisons 614

22.4 Through Evolutionary Time, Genetic Information Has Moved Between Nuclear, Mitochondrial, and Chloroplast Genomes 615

22.5 Damage to Mitochondrial DNA Is Associated with Aging 615

Chapter 23 Developmental Genetics and Immunogenetics 621

HOW A CAVEFISH LOST ITS EYES 621

23.1 Development Takes Place Through Cell Determination 622

- Cloning Experiments on Plants 622
 Cloning Experiments on Animals 623

23.2 Pattern Formation in *Drosophila* Serves As a Model for the Genetic Control of Development 623

- The Development of the Fruit Fly 623
 Egg-Polarity Genes 624
 Segmentation Genes 628
 Homeotic Genes in *Drosophila* 629
 Homeobox Genes in Other Organisms 630

Connecting Concepts: The Control of Development 631

Epigenetic Changes in Development 631

23.3 Genes Control the Development of Flowers in Plants 631

- Flower Anatomy 632
 Genetic Control of Flower Development 632

23.4 Programmed Cell Death Is an Integral Part of Development 633

23.5 The Study of Development Reveals Patterns and Processes of Evolution 635

23.6 The Development of Immunity Is Through Genetic Rearrangement 636

- The Organization of the Immune System 636
 Immunoglobulin Structure 638
 The Generation of Antibody Diversity 639
 T-Cell-Receptor Diversity 640
 Major Histocompatibility Complex Genes 641
 Genes and Organ Transplants 641

Chapter 24 Cancer Genetics 647

PALLADIN AND THE SPREAD OF CANCER 647

24.1 Cancer Is a Group of Diseases Characterized by Cell Proliferation 648

- Tumor Formation 648
 Cancer As a Genetic Disease 649
 The Role of Environmental Factors in Cancer 651

24.2 Mutations in a Number of Different Types of Genes Contribute to Cancer 652

- Oncogenes and Tumor-Suppressor Genes 652
 Genes That Control the Cycle of Cell Division 654
 DNA-Repair Genes 658
 Genes That Regulate Telomerase 658
 Genes That Promote Vascularization and the Spread of Tumors 658
 MicroRNAs and Cancer 659
 The Cancer Genome Project 660

24.3 Changes in Chromosome Number and Structure Are Often Associated with Cancer 660

24.4 Viruses Are Associated with Some Cancers 662

24.5 Epigenetic Changes Are Often Associated with Cancer 663

24.6 Colorectal Cancer Arises Through the Sequential Mutation of a Number of Genes 664

Chapter 25 Population Genetics 669

GENETIC RESCUE OF BIGHORN SHEEP 669

25.1 Genotypic and Allelic Frequencies Are Used to Describe the Gene Pool of a Population 670

- Calculating Genotypic Frequencies 671
 Calculating Allelic Frequencies 671

25.2 The Hardy–Weinberg Law Describes the Effect of Reproduction on Genotypic and Allelic Frequencies 673

- Genotypic Frequencies at Hardy–Weinberg Equilibrium 673
- Closer Examination of the Assumptions of the Hardy–Weinberg Law 674
- Implications of the Hardy–Weinberg Law 674
- Extensions of the Hardy–Weinberg Law 675
- Testing for Hardy–Weinberg Proportions 675
- Estimating Allelic Frequencies with the Hardy–Weinberg Law 676

25.3 Nonrandom Mating Affects the Genotypic Frequencies of a Population 677

25.4 Several Evolutionary Forces Potentially Cause Changes in Allelic Frequencies 680

- Mutation 680
- Migration 681
- Genetic Drift 682
- Natural Selection 685

Connecting Concepts: The General Effects of Forces That Change Allelic Frequencies 690

Chapter 26 Evolutionary Genetics 697

TASTER GENES IN SPITTING APES 697

26.1 Organisms Evolve Through Genetic Change Taking Place Within Populations 698

26.2 Many Natural Populations Contain High Levels of Genetic Variation 699

- Molecular Variation 700

- Protein Variation 700
- DNA Sequence Variation 702

26.3 New Species Arise Through the Evolution of Reproductive Isolation 705

- The Biological Species Concept 705
- Reproductive Isolating Mechanisms 705
- Modes of Speciation 707
- Genetic Differentiation Associated with Speciation 711

26.4 The Evolutionary History of a Group of Organisms Can Be Reconstructed by Studying Changes in Homologous Characteristics 712

- The Alignment of Homologous Sequences 713
- The Construction of Phylogenetic Trees 713

26.5 Patterns of Evolution Are Revealed by Changes at the Molecular Level 714

- Rates of Molecular Evolution 714
- The Molecular Clock 715
- Genome Evolution 716

Reference Guide to Model Genetic Organisms A1

- The Fruit Fly *Drosophila melanogaster* A2
- The Bacterium *Escherichia coli* A4
- The Nematode Worm *Caenorhabditis elegans* A6
- The Plant *Arabidopsis thaliana* A8
- The Mouse *Mus musculus* A10
- The Yeast *Saccharomyces cerevisiae* A12

Glossary B1

Answers to Selected Questions and Problems C1

Index D1