

教育部 高等教育司 推荐  
国外优秀生命科学教学用书

PEARSON  
Prentice  
Hall

# ESSENTIALS OF GENETICS

Seventh Edition

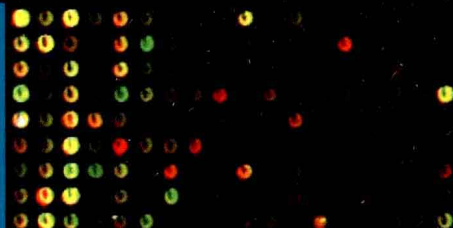
## 遗传学基础

(第7版) (影印版)

William S. Klug  
Michael R. Cummings  
Charlotte A. Spencer  
Michael A. Palladino



高等教育出版社  
HIGHER EDUCATION PRESS





教育部高等教育司推荐  
国外优秀生命科学教学用书

PEARSON  
Prentice  
Hall

# ESSENTIALS OF GENETICS

Seventh Edition

## 遗传学基础

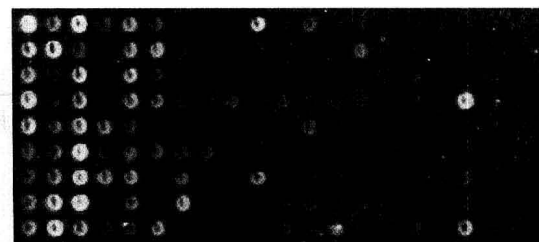
YICHUANXUE JICHU

(第7版)(影印版)

William S. Klug  
Michael R. Cummings  
Charlotte A. Spencer  
Michael A. Palladino



高等教育出版社·北京  
HIGHER EDUCATION PRESS BEIJING



图字：01 - 2010 - 6740 号

Original edition, entitled ESSENTIALS OF GENETICS, 7E, 9780321618696 by KLUG, WILLIAM S.; CUMMINGS, MICHAEL R.; SPENCER, CHARLOTTE; PALLADINO, MICHAEL A., published by Pearson Education, Inc., publishing as Benjamin Cummings, Copyright © 2010 by Pearson Education, Inc..

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage retrieval system, without permission from Pearson Education, Inc.

Chinese Simplified Language edition published by PEARSON EDUCATION ASIA LTD., and HIGHER EDUCATION PRESS Copyright © 2011.

This edition is manufactured in the People's Republic of China, and is authorized for sale and distribution in the People's Republic of China exclusively (except Taiwan, Hong Kong SAR and Macau SAR).

本书原版为培生教育出版集团出版 ESSENTIALS OF GENETICS, 7E, 作者为 KLUG, WILLIAM S.; CUMMINGS, MICHAEL R.; SPENCER, CHARLOTTE; PALLADINO, MICHAEL A.。著作权© 2010。

版权所有。未经培生教育出版集团许可, 任何部分不得以任何形式、任何途径(电子版或纸质版)复制或传播, 包括影印、录制或信息存储及检索系统。

此英文影印版由培生教育出版集团和高等教育出版社合作出版。著作权© 2011。

此英文影印版在中国出版发行, 仅限于在中华人民共和国境内(但不允许在中国香港、澳门特别行政区和中国台湾地区)销售。

## 图书在版编目(CIP)数据

遗传学基础 = Essentials of Genetics: 第7版: 英文/  
(美)克卢格(Klug, W. S.)等编著. —影印本. —北京:  
高等教育出版社, 2011.2

ISBN 978 - 7 - 04 - 031727 - 5

I. ①遗… II. ①克… III. ①遗传学 - 高等学校 - 教材 - 英文 IV. ①Q3

中国版本图书馆CIP数据核字(2011)第009735号

策划编辑 潘超 责任编辑 高新景 封面设计 张楠 责任印制 尤静

出版发行 高等教育出版社  
社址 北京市西城区德外大街4号  
邮政编码 100120

经 销 蓝色畅想图书发行有限公司  
印 刷 北京铭成印刷有限公司

开 本 889 × 1194 1/16  
印 张 38.25  
字 数 1 000 000

购书热线 010 - 58581118  
咨询电话 400 - 810 - 0598  
网 址 <http://www.hep.edu.cn>  
<http://www.hep.com.cn>  
网上订购 <http://www.landaco.com>  
<http://www.landaco.com.cn>  
畅想教育 <http://www.widedu.com>

版 次 2011年2月第1版  
印 次 2011年2月第1次印刷  
定 价 76.00元

本书如有缺页、倒页、脱页等质量问题, 请到所购图书销售部门联系调换。

版权所有 侵权必究

物料号 31727 - 00

# About the Authors

**William S. Klug** is currently Professor of Biology at the College of New Jersey (formerly Trenton State College) in Ewing, New Jersey. He served as Chair of the Biology Department for 17 years, a position to which he was first elected in 1974. He received his B.A. degree in Biology from Wabash College in Crawfordsville, Indiana, and his Ph.D. from Northwestern University in Evanston, Illinois. Prior to coming to the College of New Jersey, he was on the faculty of Wabash College as an Assistant Professor. His research interests have involved ultrastructural and molecular genetic studies of oogenesis in *Drosophila*. He has taught the genetics course as well as the senior capstone seminar course in human and molecular genetics to undergraduate biology majors for each of the last 35 years. In 2002, he was the recipient of the initial teaching award given at the College of New Jersey granted to the faculty member who most challenges students to achieve high standards. He also received the 2004 Outstanding Professor Award from the Sigma Pi International, and in the same year, he was nominated as the Educator of the Year, an award given by the Research and Development Council of New Jersey.

**Michael R. Cummings** is currently Research Professor in the Department of Biological, Chemical and Physical Sciences at Illinois Institute of Technology, Chicago, Illinois. For more than 25 years, he was a faculty member in the Department of Biological Sciences and in the Department of Molecular Genetics at the University of Illinois at Chicago. He has also served on the faculties of Northwestern University and Florida State University. He received his B.A. from St. Mary's College in Winona, Minnesota, and his M.S. and Ph.D. from Northwestern University in Evanston, Illinois. In addition to *Essentials of Genetics* and its companion volumes, he has also authored several texts in human genetics and general biology for nonmajors. His research interests center on the molecular organization and physical mapping of the heterochromatic regions of human acrocentric chromosomes. At the undergraduate level, he teaches courses in Mendelian and molecular genetics, human genetics, and general biology, and has received numerous awards for teaching excellence given by university faculty, student organizations, and graduating seniors.

**Charlotte A. Spencer** is currently Adjunct Associate Professor in the Department of Oncology at the University of Alberta in Edmonton, Alberta, Canada. She has also served as a faculty member in the Department of Biochemistry at the University of Alberta. She received her B.Sc. in Microbiology from the University of British Columbia and her Ph.D. in Genetics from the University of Alberta, followed by postdoctoral training at the Fred Hutchinson Cancer Research Center in Seattle, Washington. Her research interests involve the regulation of RNA polymerase II transcription in cancer cells, cells infected with DNA viruses, and cells traversing the mitotic phase of the cell cycle. She has authored booklets in the Prentice Hall Exploring Biology series.

**Michael A. Palladino** is Dean of the School of Science and Associate Professor of Biology at Monmouth University in West Long Branch, New Jersey. He received his B.S. degree in Biology from Trenton State College (now known as The College of New Jersey) and his Ph.D. in Anatomy and Cell Biology from the University of Virginia. He directs an active laboratory of undergraduate student researchers studying molecular mechanisms involved in innate immunity of mammalian male reproductive organs and genes involved in oxygen homeostasis and ischemic injury of the testis. He has taught a wide range of courses for both majors and nonmajors and currently teaches genetics, biotechnology, endocrinology, and laboratory in cell and molecular biology. He has received several awards for research and teaching, including the 2009 Young Investigator Award from the American Society of Andrology, the 2005 Distinguished Teacher Award from Monmouth University, and the 2005 Caring Heart Award from the New Jersey Association for Biomedical Research. In addition to *Essentials of Genetics* and its companion volumes, he is co-author of the undergraduate textbook *Introduction to Biotechnology*, Series Editor for the Benjamin Cummings Special Topics in Biology booklet series, and author of the first booklet in the series, *Understanding the Human Genome Project*.

# 前言

《遗传学基础》是应课程设置的需要而编写的，与内容更为广泛的姊妹篇《遗传学概念》相比，它更为短小，也更为基础，但仍然覆盖全面，内容新颖，尤其适合于低年级生物专业的学生以及农业、化学、工程、林业、心理和野生生物保护等专业的学生。由于篇幅比其他很多书都短，本书更适合于单季课程和一学期课程。

## 目标

本书的目标与前几版相同，明确地说，就是：

- 强调概念，而不是过多的细节；
- 通过清楚、直接的描述，提供给学生关于复杂主题的易于理解的诠释；
- 在章节内部和章节之间建立细致的组织架构；
- 传播遗传学的丰富历史，完美阐述在学科形成和发展过程中，信息如何获得和扩充；
- 强调问题的解决，引导学生分析思考，应用和扩充他们的遗传学知识；
- 提供本领域最新的、最前沿的知识；
- 绘制引人入胜的，同时有助于教学的全彩色图，再加上同样有益的照片，为概念的发展提供支持；
- 提供出色的在线资源指南，引导学生通过动画、指导练习及自测工具来理解重要的概念。

这些目标是《遗传学基础》的基石，为达成这些目标，就要求教科书适应不同形式的课程安排。尽管本书提供了一个联成一体的内容列表，它代表了一种遗传学教学安排，但各章的编写是相互独立的，允许教员打乱原来的顺序自主安排。

## 第7版的新特点

第7版有很多新的重要特征，连同其新颖的内容，使得本书更加适于学习遗传学的学生。本书的这些改进，建立了一个促进学生更加深入思考的平台，使得他们对刚刚学过的知识有更加全面深入的理解。

**探索基因组** 第12章的“探索基因组”是第7版的新内容，它对遗传学的大多数领域都持续产生影响。每一条目都要求学生进入一个或多个公众资源库

和数据库中与基因组相关的网站，通过交互演练，以确保熟悉可用的基因组和蛋白组信息类型。“练习”指导学生如何搜索特定的题目以及如何进入重要的数据库；“问题”引导学生做进一步探索，学着自己应用那些网站。尤其重要的是，“探索基因组”部分将基因组的信息融合到整个书中，为学生在课上或课下的学习提供了基础。

**案例分析** 每章都有一个新栏目，叫做“案例分析”，作为课堂交流的提高内容。每一栏目都提供了一个与本章某一项内容相联系的案例，并就案例提出问题。这就要求把新获得的知识应用于实际生活中。在教学中可以采取小组讨论或个人作业的方式。

**主要知识点** 在概括每章所有主要内容的总结中，我们新增加了一项内容，叫做“主要知识点”。这些知识点都在各章中频繁出现，言简意赅地概括了各章的主旨。把这些知识点整合到各章，它们就可以作为学生阅读或复习各章内容的“路标”。

**遗传学、技术和社会短文** 第7版中我们继续提供一些针对性很强的短文，但是以一种新的交互方式呈现。在每一篇短文后，有一项新内容叫做“轮到你了”，其中向学生提出一些问题，并同时提供各种资源以帮助解答问题。这种改进提供了另外一种加强课堂交流的方式。所有以前的短文主题都经过了修订和更新，并加入了两篇新短文：“唐氏综合征，产前诊断和新优生学”（第6章）和“1000美元的基因组——个人基因组计划和种族”（第19章）。

**主题现代化** 如同每次修订一样，我们的主要努力都放在书中各方面内容的更新上，尤其是基因组学和蛋白组学方面（第18章），以及分子遗传学的各领域，包括基因表达调控（第15章）和癌的遗传学（第16章）。而 Sarah Ward 又一次加入了保护遗传学（第24章）的内容。

**新章节** 我们时刻关注遗传学中新近出现的相应领域，由此我们增添了新的一章——“遗传学与行为”（第21章）。这一章反映了我们对基因在生物体行为的方方面面所起作用的不断增加的认识。学生会这一章很感兴趣，因为围绕这个问题的发现与我们对自身的认识有关。

**更新的教师和学生资源** 教师和学生资源都已更



新,以反映新版的变化。对讲授和其他教学活动的支持包括:书中图片和表格的电子版、教学资源 DVD 中大量的各种 ppt。经过更新后的配套网站上的资源,反映了正在形成的一个共识,即今天的学生应该尽可能明智地利用他们有限的学习时间。学生网站也提供了引导学生去做概括、比较和评估的一些问题。

## 重视概念和问题的解决

《遗传学基础》关注于遗传学的概念以及通过解决问题加深对这些概念的理解。我们的经验显示,首先关注于基本概念的那些学生,更容易领会和掌握随后课程中遗传学的重要思想。最重要的,将概念阐述和解决问题联系起来,得以增强生物学的解析观念。为帮助学生确定重要主题所涉及的概念,每一章均以一个小节开始,列出了即将出现的最重要的概念。

另外一个有价值的教学特色就是在第 6 版首次引入每一章中的“我们如何得知”。这些条目要求学生通晓每章中出现的最重要生物学概念的实验基础。“科学是求知之路”作为生物学学习的延伸,加强学生对每一章许多关键主题的理解。

“现在来解决问题”这个条目在每章都数次出现,它要求学生把理解概念和解决问题更及时地联系起来。每一个都将学生引向本章结尾的一个问题,每个问题都与课文中的讨论密切相关。

此外,每一章都以“观察与解答”这个最受欢迎又行之有效的小节作为结语。本小节提供例题和解析,对如何做遗传分析进行示范,帮助学生形成分析的思维以及实验推理能力。消化“观察与解答”中的信息,为学生进入每章最后那较难的“问题和讨论议题”一节做了先期准备。在最后这节,我们给出了复习本章各个主题的议题和要求学生进行分析思考与遗传概念应用的问题。问题的难度逐级增加,越往后的问题要求越高。

## 致谢

### 审稿人员

所有的综合性教科书,都有赖于许多同仁的倾力投入。以下人员给予本书第 7 版宝贵的建议和建设性批评或/和意见:

Althea K. Alton, *Western Illinois University*

Thomas H. Alton, *Western Illinois University*

Brian Ashburner, *University of Toledo*

Mark Brick, *Colorado State University*

Susan Capasso, *St. Vincent's College*

Aaron Cassill, *University of Texas-San Antonio*

Steve Denison, *Eckerd College*

John P. Doucet, *Nicholls State University*

Kurt Elliott, *Northwest Vista College*

Lehman L. Ellis, *Our Lady of Holy Cross College*

Victor Fet, *Marshall University*

Clarence E. Fouche, *Virginia Intermont College*

Gail Fraizer, *Kent State University*

Alexandros Georgakilas, *East Carolina University*

Edward F. Golenberg, *Wayne State University*

John Gray, *University of Toledo*

Danielle Hamill, *Ohio Wesleyan University*

David Kass, *Eastern Michigan University*

Mary Kimble, *Northeastern Illinois University*

Joan Kuh, *University of Hawaii*

Jospeh Kulkosky, *Chestnut Hill College*

Alan C. Leonard, *Florida Institute of Technology*

Janet Lewis, *Michigan State University*

Jeannette M. Loutsch, *University of Science and Arts of Oklahoma*

Roy B. Mason, *Mt. San Jacinto College*

Shawn Meagher, *Western Illinois University*

Philip McClean, *North Dakota State University*

Sudhir Nayak, *The College of New Jersey*

Harry Nickla, *Creighton University*

Phillip A. Ortiz, *Empire State College*

Terrence Puryear, *Northeastern Illinois University*

Thomas F. Savage, *Oregon State University*

Brian W. Schwartz, *Columbus State University*

Thomas Smith, *Southern Arkansas University*

Allan Showalter, *Ohio University*

Tatiana Tatum, *Saint Xavier University*

Paul Wilson, *Trent University*

对书中的任何错误,我们负全部责任。我们衷心感谢以上人员的帮助。

### 贡献人员

我们首先特别感谢为本书作出直接贡献的同仁。特别感谢科罗拉多州立大学的 Sarah Ward 写了保护遗传学一章,新泽西大学的 Sudhir Nayak 写了基因组的内容,东密歇根大学的 David Kass、耶鲁医学院的

Katherine Uyhazi 和 North Hennepin Community 大学的 Tamara Mans 对遗传学、技术、社会短文部分的诸多贡献；亚利桑那州立大学的 Elliott Goldstein 对分子遗传学方面的投入，LightCone Interactive 的 Mike Guidry 以及田纳西大学的 Karen Hughes 在媒体程序方面贡献颇多。我们也特别感谢最近刚从 Creighton 大学退休的 Harry Nickla，在他所作的《学生手册》和《教员指南》中，写了很多新题目，并给出了选定题目的答案（见附录 A）。

我们衷心感谢上述同仁，不仅在于分享他们的遗传学专业知识，而且在于他们对本书的贡献以及与他们互动的美好经历。

### 编辑和出版人员

在 Benjamin-Cummings，我们向执行编辑 Gary Carlson 表示感谢和敬意。我们也感谢 Préparé Inc. 的各位在本书出版上所付出的努力，他们精益求精的精神在本书得到了体现。Imagineering of Toronto 为本书

制作了漂亮插图。

校对长达 600 页的教科书，对其贡献的感激之情不是言语所能表达的。我们最深的感谢献给 4 位人士，他们以耐心和勤奋完成了这个工作。他们是 Michael Rossa, Susan Baglino, Cheryl Ingram-Smith 和 Thomas H. Alton。此外，Betty Pessagno 负责编辑整个手稿，她对整部书的质量所作出的贡献值得特别感谢。

将上述各位的工作整合起来，并非凡人可以为之，我们有幸拥有一位天才 Dusty Friedman——我们的策划编辑。她不但使工作顺利进行，而且一直秉承愉悦有序的风范。

如同上述的致谢所清楚体现的那样，本书是集体智慧的结晶，上面的所有人都值得分享本书付梓的喜悦。我们不吝篇幅来叙述各位的贡献，仅以此表明我们对他们每个人都一样深怀感谢之情。

（佟向军 译）

# Brief Contents

1	Introduction to Genetics	1
2	Mitosis and Meiosis	17
3	Mendelian Genetics	37
4	Modification of Mendelian Ratios	60
5	Sex Determination and Sex Chromosomes	92
6	Chromosome Mutations: Variation in Number and Arrangement	111
7	Linkage and Chromosome Mapping in Eukaryotes	132
8	Genetic Analysis and Mapping in Bacteria and Bacteriophages	159
9	DNA Structure and Analysis	181
10	DNA Replication and Recombination	203
11	Chromosome Structure and DNA Sequence Organization	224
12	The Genetic Code and Transcription	240
13	Translation and Proteins	261
14	Gene Mutation, Transposition, and DNA Repair	284
15	Regulation of Gene Expression	308
16	Cancer and Regulation of the Cell Cycle	334
17	Recombinant DNA Technology and Gene Cloning	351
18	Genomics, Bioinformatics, and Proteomics	375
19	Applications and Ethics of Genetic Engineering and Biotechnology	407
20	Developmental Genetics	433
21	Genetics and Behavior	450
22	Quantitative Genetics and Multifactorial Traits	465
23	Population and Evolutionary Genetics	483
24	Conservation Genetics	507

APPENDIX A ANSWERS TO SELECTED PROBLEMS A-1

APPENDIX B SELECTED READINGS B-1

GLOSSARY G-1

PHOTO CREDITS C-1

INDEX I-1



# Contents

## PREFACE xii

## CHAPTER 1

### Introduction to Genetics 1

- 1.1 Genetics Has a Rich and Interesting History 2
- 1.2 Genetics Progressed from Mendel to DNA in Less Than a Century 4
- 1.3 Discovery of the Double Helix Launched the Era of Molecular Genetics 6
- 1.4 Development of Recombinant DNA Technology Began the Era of DNA Cloning 8
- 1.5 The Impact of Biotechnology Is Continually Expanding 9
- 1.6 Genomics, Proteomics, and Bioinformatics Are New and Expanding Fields 12
- 1.7 Genetic Studies Rely on the Use of Model Organisms 12
- 1.8 We Live in the Age of Genetics 14

#### GENETICS, TECHNOLOGY, AND SOCIETY

#### Genetics and Society: The Application and Impact of Science and Technology 15

#### EXPLORING GENOMICS

#### Internet Resources for Learning about Genomics, Bioinformatics, and Proteomics 15

#### Case Study: Extending essential ideas of genetics beyond the classroom 16

#### Problems and Discussion Questions 16

## CHAPTER 2

### Mitosis and Meiosis 17

- 2.1 Cell Structure Is Closely Tied to Genetic Function 18
- 2.2 Chromosomes Exist in Homologous Pairs in Diploid Organisms 20
- 2.3 Mitosis Partitions Chromosomes into Dividing Cells 22
- 2.4 Meiosis Reduces the Chromosome Number from Diploid to Haploid in Germ Cells and Spores 26
- 2.5 The Development of Gametes Varies during Spermatogenesis and Oogenesis 30
- 2.6 Meiosis Is Critical to the Sexual Reproduction Cycle of All Diploid Organisms 32
- 2.7 Electron Microscopy Has Revealed the Cytological Nature of Mitotic and Meiotic Chromosomes 33

#### EXPLORING GENOMICS

#### PubMed: Exploring and Retrieving Biomedical Literature 34

#### Case Study: Timing is everything 35

#### Insights and Solutions 35

#### Problems and Discussion Questions 36

## CHAPTER 3

### Mendelian Genetics 37

- 3.1 Mendel Used a Model Experimental Approach to Study Patterns of Inheritance 38
- 3.2 The Monohybrid Cross Reveals How One Trait Is Transmitted from Generation to Generation 39
- 3.3 Mendel's Dihybrid Cross Generated a Unique F<sub>2</sub> Ratio 42
  - How Mendel's Peas Become Wrinkled: A Molecular Explanation 43
- 3.4 The Trihybrid Cross Demonstrates That Mendel's Principles Apply to Inheritance of Multiple Traits 44
- 3.5 Mendel's Work Was Rediscovered in the Early Twentieth Century 46
- 3.6 Independent Assortment Leads to Extensive Genetic Variation 48
  - Tay-Sachs Disease: The Molecular Basis of a Recessive Disorder in Humans 48
- 3.7 Laws of Probability Help to Explain Genetic Events 49
- 3.8 Chi-Square Analysis Evaluates the Influence of Chance on Genetic Data 49
- 3.9 Pedigrees Reveal Patterns of Inheritance of Human Traits 52

#### EXPLORING GENOMICS

#### Online Mendelian Inheritance in Man 54

#### Case Study: To test or not to test 55

#### Insights and Solutions 55

#### Problems and Discussion Questions 57

## CHAPTER 4

### Modification of Mendelian Ratios 60

- 4.1 Alleles Alter Phenotypes in Different Ways 61
- 4.2 Geneticists Use a Variety of Symbols for Alleles 62
- 4.3 Neither Allele Is Dominant in Incomplete, or Partial, Dominance 62
- 4.4 In Codominance, the Influence of Both Alleles in a Heterozygote Is Clearly Evident 63
- 4.5 Multiple Alleles of a Gene May Exist in a Population 64
- 4.6 Lethal Alleles Represent Essential Genes 65
  - The Molecular Basis of Dominance and Recessiveness: The Agouti Gene 66
- 4.7 Combinations of Two Gene Pairs with Two Modes of Inheritance Modify the 9:3:3:1 Ratio 66

- 4.8 Phenotypes Are Often Affected by More Than One Gene 67
- 4.9 Complementation Analysis Can Determine If Two Mutations Causing a Similar Phenotype Are Alleles of the Same Gene 72
- 4.10 Expression of a Single Gene May Have Multiple Effects 73
- 4.11 X-Linkage Describes Genes on the X Chromosome 73
- 4.12 In Sex-Limited and Sex-Influenced Inheritance, an Individual's Sex Influences the Phenotype 76
- 4.13 Genetic Background and the Environment Affect Phenotypic Expression 77
- 4.14 Extranuclear Inheritance Modifies Mendelian Patterns 80

---

#### GENETICS, TECHNOLOGY, AND SOCIETY

##### Improving the Genetic Fate of Purebred Dogs 84

Case Study: A twin difference 85

Insights and Solutions 85

Problems and Discussion Questions 87

#### CHAPTER 5

### Sex Determination and Sex Chromosomes 92

- 5.1 Life Cycles Depend on Sexual Differentiation 93
- 5.2 X and Y Chromosomes Were First Linked to Sex Determination Early in the Twentieth Century 96
- 5.3 The Y Chromosome Determines Maleness in Humans 97
- 5.4 The Ratio of Males to Females in Humans Is Not 1.0 101
- 5.5 Dosage Compensation Prevents Excessive Expression of X-Linked Genes in Humans and Other Mammals 102
- 5.6 The Ratio of X Chromosomes to Sets of Autosomes Determines Sex in *Drosophila* 104
- 5.7 Temperature Variation Controls Sex Determination in Reptiles 106

---

#### GENETICS, TECHNOLOGY, AND SOCIETY

##### A Question of Gender: Sex Selection in Humans 107

Case Study: Doggone it! 108

Insights and Solutions 108

Problems and Discussion Questions 109

#### CHAPTER 6

### Chromosome Mutations: Variation in Number and Arrangement 111

- 6.1 Variation in Chromosome Number: Terminology and Origin 112
- 6.2 Monosomy and Trisomy Result in a Variety of Phenotypic Effects 113
- 6.3 Polyploidy, in Which More Than Two Haploid Sets of Chromosomes Are Present, Is Prevalent in Plants 116

- 6.4 Variation Occurs in the Composition and Arrangement of Chromosomes 119
- 6.5 A Deletion Is a Missing Region of a Chromosome 119
- 6.6 A Duplication Is a Repeated Segment of a Chromosome 121
- 6.7 Inversions Rearrange the Linear Gene Sequence 123
  - Copy Number Variants (CNVs)—Duplications and Deletions at the Molecular Level 123
- 6.8 Translocations Alter the Location of Chromosomal Segments in the Genome 125
- 6.9 Fragile Sites in Human Chromosomes Are Susceptible to Breakage 127

---

#### GENETICS, TECHNOLOGY, AND SOCIETY

##### Down Syndrome, Prenatal Testing, and the New Eugenics 128

Case Study: Fish tales 129

Insights and Solutions 129

Problems and Discussion Questions 130

### Linkage and Chromosome Mapping in Eukaryotes 132

- 7.1 Genes Linked on the Same Chromosome Segregate Together 133
- 7.2 Crossing Over Serves as the Basis of Determining the Distance between Genes during Mapping 136
- 7.3 Determining the Gene Sequence during Mapping Requires the Analysis of Multiple Crossovers 139
- 7.4 As the Distance between Two Genes Increases, Mapping Estimates Become More Inaccurate 145
- 7.5 Lod Score Analysis and Somatic Cell Hybridization Were Historically Important in Creating Human Chromosome Maps 147
- 7.6 Chromosome Mapping Is Now Possible Using DNA Markers and Annotated Computer Databases 148
- 7.7 Linkage and Mapping Studies Can Be Performed in Haploid Organisms 149
- 7.8 Other Aspects of Genetic Exchange 150
- 7.9 Did Mendel Encounter Linkage? 152
  - Why Didn't Gregor Mendel Find Linkage? 152

---

#### EXPLORING GENOMICS

##### Human Chromosome Maps on the Internet 153

Case Study: Links to autism 153

Insights and Solutions 154

Problems and Discussion Questions 155

#### CHAPTER 7

### Genetic Analysis and Mapping in Bacteria and Bacteriophages 159

- 8.1 Bacteria Mutate Spontaneously and Grow at an Exponential Rate 160

- 8.2 Conjugation Is One Means of Genetic Recombination in Bacteria 161
- 8.3 Rec Proteins Are Essential to Bacterial Recombination 168
- 8.4 The F Factor Is an Example of a Plasmid 168
- 8.5 Transformation Is Another Process Leading to Genetic Recombination in Bacteria 169
- 8.6 Bacteriophages Are Bacterial Viruses 170
- 8.7 Transduction Is Virus-Mediated Bacterial DNA Transfer 173
- 8.8 Bacteriophages Undergo Intergenic Recombination 175

#### GENETICS, TECHNOLOGY, AND SOCIETY

From Cholera Genes to Edible Vaccines 177

Case Study: To treat or not to treat 178

Insights and Solutions 178

Problems and Discussion Questions 179

#### CHAPTER 9

### DNA Structure and Analysis 181

- 9.1 The Genetic Material Must Exhibit Four Characteristics 182
- 9.2 Until 1944, Observations Favored Protein as the Genetic Material 183
- 9.3 Evidence Favoring DNA as the Genetic Material Was First Obtained during the Study of Bacteria and Bacteriophages 183
- 9.4 Indirect and Direct Evidence Supports the Concept that DNA Is the Genetic Material in Eukaryotes 188
- 9.5 RNA Serves as the Genetic Material in Some Viruses 189
- 9.6 The Structure of DNA Holds the Key to Understanding Its Function 190
  - Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid 195
- 9.7 Alternative Forms of DNA Exist 196
- 9.8 The Structure of RNA Is Chemically Similar to DNA, but Single-Stranded 197
- 9.9 Many Analytical Techniques Have Been Useful during the Investigation of DNA and RNA 197

#### EXPLORING GENOMICS

Introduction to Bioinformatics: BLAST 200

Case Study: Zigs and zags of the smallpox virus 201

Insights and Solutions 201

Problems and Discussion Questions 201

#### CHAPTER 10

### DNA Replication and Recombination 203

- 10.1 DNA Is Reproduced by Semiconservative Replication 204

- 10.2 DNA Synthesis in Bacteria Involves Five Polymerases, as Well as Other Enzymes 208
- 10.3 Many Complex Issues Must Be Resolved during DNA Replication 211
- 10.4 A Coherent Model Summarizes DNA Replication 214
- 10.5 Replication Is Controlled by a Variety of Genes 214
- 10.6 Eukaryotic DNA Replication Is Similar to Replication in Prokaryotes, but Is More Complex 215
- 10.7 The Ends of Linear Chromosomes Are Problematic during Replication 217
- 10.8 DNA Recombination, Like DNA Replication, Is Directed by Specific Enzymes 219

#### GENETICS, TECHNOLOGY, AND SOCIETY

Telomeres: The Key to Immortality? 221

Case Study: At loose ends 222

Insights and Solutions 222

Problems and Discussion Questions 222

#### CHAPTER 11

### Chromosome Structure and DNA Sequence Organization 224

- 11.1 Viral and Bacterial Chromosomes Are Relatively Simple DNA Molecules 225
- 11.2 Mitochondria and Chloroplasts Contain DNA Similar to Bacteria and Viruses 226
- 11.3 Specialized Chromosomes Reveal Variations in the Organization of DNA 229
- 11.4 DNA Is Organized into Chromatin in Eukaryotes 231
- 11.5 Eukaryotic Genomes Demonstrate Complex Sequence Organization Characterized by Repetitive DNA 234
- 11.6 The Vast Majority of a Eukaryotic Genome Does Not Encode Functional Genes 236

#### EXPLORING GENOMICS

Database of Genomic Variants: Structural Variations in the Human Genome 237

Case Study: Art inspires learning 238

Insights and Solutions 238

Problems and Discussion Questions 238

#### CHAPTER 12

### The Genetic Code and Transcription 240

- 12.1 The Genetic Code Exhibits a Number of Characteristics 241
- 12.2 Early Studies Established the Basic Operational Patterns of the Code 242

- 12.3 Studies by Nirenberg, Matthaei, and Others  
Deciphered the Code 242
- 12.4 The Coding Dictionary Reveals the Function of the  
64 Triplets 246
- 12.5 The Genetic Code Has Been Confirmed in Studies  
of Bacteriophage MS2 248
- 12.6 The Genetic Code Is Nearly Universal 248
- 12.7 Different Initiation Points Create Overlapping  
Genes 249
- 12.8 Transcription Synthesizes RNA on a DNA  
Template 249
- 12.9 RNA Polymerase Directs RNA Synthesis 250
- 12.10 Transcription in Eukaryotes Differs from  
Prokaryotic Transcription in Several  
Ways 252
- 12.11 The Coding Regions of Eukaryotic Genes Are  
Interrupted by Intervening Sequences Called  
Introns 254
- 12.12 Transcription Has Been Visualized by Electron  
Microscopy 257

#### GENETICS, TECHNOLOGY, AND SOCIETY

---

Nucleic Acid-Based Gene Silencing: Attacking  
the Messenger 257

Case Study: A drug that sometimes works 258

Insights and Solutions 258

Problems and Discussion Questions 259

#### CHAPTER 13

### Translation and Proteins 261

- 13.1 Translation of mRNA Depends on Ribosomes and  
Transfer RNAs 262
- 13.2 Translation of mRNA Can Be Divided into Three  
Steps 265
- 13.3 Crystallographic Analysis Has Revealed Many  
Details about the Functional Prokaryotic  
Ribosome 269
- 13.4 Translation Is More Complex in Eukaryotes 269
- 13.5 The Initial Insight that Proteins Are Important in  
Heredity Was Provided by the Study of Inborn Errors  
of Metabolism 270
- 13.6 Studies of *Neurospora* Led to the One-Gene:One-  
Enzyme Hypothesis 271
- 13.7 Studies of Human Hemoglobin Established that One  
Gene Encodes One Polypeptide 273
- 13.8 Variation in Protein Structure Is the Basis of  
Biological Diversity 276
- 13.9 Proteins Function in Many Diverse Roles 279

#### EXPLORING GENOMICS

---

Translation Tools and Swiss-Prot for Studying Protein  
Sequences 280

Case Study: Lost in translation 281

Insights and Solutions 281

Problems and Discussion Questions 282

#### CHAPTER 14

### Gene Mutation, Transposition, and DNA Repair 284

- 14.1 Gene Mutations Are Classified in Various Ways 285
- 14.2 Spontaneous Mutations Arise from Replication  
Errors and Base Modifications 287
- 14.3 Induced Mutations Arise from DNA Damage Caused  
by Chemicals and Radiation 289
- 14.4 Organisms Use DNA Repair Systems to Counteract  
Mutations 292
- 14.5 The Ames Test Is Used to Assess the Mutagenicity of  
Compounds 296
- 14.6 DNA Sequencing Has Enhanced Our Understanding  
of Mutations in Humans 297
- 14.7 Geneticists Use Mutations to Identify Genes and  
Study Gene Function 298
- 14.8 Transposable Elements Move within the Genome and  
May Create Mutations 299

#### EXPLORING GENOMICS

---

Sequence Alignment to Identify a Mutation 303

Case Study: Genetic dwarfism 304

Insights and Solutions 305

Problems and Discussion Questions 305

#### CHAPTER 15

### Regulation of Gene Expression 308

- 15.1 Prokaryotes Regulate Gene Expression in Response  
to Both External and Internal Conditions 309
- 15.2 Lactose Metabolism in *E. coli* Is Regulated by an  
Inducible System 309
- 15.3 The Catabolite-Activating Protein (CAP) Exerts  
Positive Control over the *lac* Operon 314
- 15.4 The Tryptophan (*trp*) Operon in *E. coli* Is a  
Repressible Gene System 315
- 15.5 Attenuation Is a Regulatory Mechanism in Some  
Prokaryotic Operons 317
- 15.6 Eukaryotic Gene Regulation Differs from That in  
Prokaryotes 317
- 15.7 Eukaryotic Gene Expression Is Influenced by  
Chromosome Organization and Chromatin  
Modifications 318
- 15.8 Eukaryotic Transcription Is Regulated at Specific  
*Cis*-Acting Sites 320
- 15.9 Eukaryotic Transcription Is Regulated by Transcription  
Factors that Bind to *Cis*-Acting Sites 323
- 15.10 Transcription Factors Bind to *Cis*-Acting sites and  
Interact with Basal Transcription Factors and Other  
Regulatory Proteins 324
- 15.11 Posttranscriptional Gene Regulation Occurs at All  
the Steps from RNA Processing to Protein  
Modification 325
- 15.12 RNA-induced Gene Silencing Controls Gene  
Expression in Several Ways 328



## EXPLORING GENOMICS

## Tissue-Specific Gene Expression 330

Case Study: A mysterious muscular dystrophy 330

Insights and Solutions 331

Problems and Discussion Questions 331

## CHAPTER 16

## Cancer and Regulation of the Cell Cycle 334

16.1 Cancer Is a Genetic Disease at the Level of Somatic Cells 335

16.2 Cancer Cells Contain Genetic Defects Affecting Genomic Stability, DNA Repair, and Chromatin Modifications 337

16.3 Cancer Cells Contain Genetic Defects Affecting Cell-Cycle Regulation 338

16.4 Proto-oncogenes and Tumor-suppressor Genes Are Altered in Cancer Cells 340

16.5 Cancer Cells Metastasize, Invading Other Tissues 343

16.6 Predisposition to Some Cancers Can Be Inherited 344

16.7 Viruses Contribute to Cancer in Both Humans and Animals 345

16.8 Environmental Agents Contribute to Human Cancers 346

## GENETICS, TECHNOLOGY, AND SOCIETY

## Breast Cancer: The Double-Edged Sword of Genetic Testing 347

Case Study: I thought it was safe 348

Insights and Solutions 348

Problems and Discussion Questions 349

## CHAPTER 17

## Recombinant DNA Technology and Gene Cloning 351

17.1 An Overview of Recombinant DNA Technology 352

17.2 Constructing Recombinant DNA Molecules Requires Several Steps 352

17.3 Cloning DNA in Host Cells 356

17.4 The Polymerase Chain Reaction Makes DNA Copies without Host Cells 357

17.5 Recombinant Libraries Are Collections of Cloned Sequences 359

17.6 Specific Clones Can Be Recovered from a Library 361

17.7 Cloned Sequences Can Be Analyzed in Several Ways 362

17.8 DNA Sequencing Is the Ultimate Way to Characterize a Clone 366

## EXPLORING GENOMICS

## Manipulating Recombinant DNA: Restriction Mapping and Designing a Recombinant DNA Experiment 369

Case Study: Should we worry about recombinant DNA technology? 370

Insights and Solutions 371

Problems and Discussion Questions 371

## CHAPTER 18

## Genomics, Bioinformatics, and Proteomics 375

18.1 Whole-Genome Shotgun Sequencing Is a Widely Used Method for Sequencing and Assembling Entire Genomes 376

18.2 DNA Sequence Analysis Relies on Bioinformatics Applications and Genome Databases 380

18.3 Functional Genomics Attempts to Identify Potential Functions of Genes and Other Elements in a Genome 383

18.4 The Human Genome Project Reveals Many Important Aspects of Genome Organization in Humans 384

18.5 The “Omics” Revolution Has Created a New Era of Biological Research Methods 386

18.6 Prokaryotic and Eukaryotic Genomes Display Common Structural and Functional Features and Important Differences 387

18.7 Comparative Genomics Analyzes and Compares Genomes from Different Organisms 390

18.8 Metagenomics Applies Genomics Techniques to Environmental Samples 394

18.9 Transcriptome Analysis Reveals Profiles of Expressed Genes in Cells and Tissues 396

18.10 Proteomics Identifies and Analyzes the Protein Composition of Cells 398

## EXPLORING GENOMICS

## Contigs and Shotgun Sequencing 403

Case Study: Bioprospecting in Darwin’s wake 404

Insights and Solutions 404

Problems and Discussion Questions 405

## CHAPTER 19

## Applications and Ethics of Genetic Engineering and Biotechnology 407

19.1 Genetically Engineered Organisms Synthesize a Wide Range of Biological and Pharmaceutical Products 408

19.2 Genetic Engineering of Plants Has Revolutionized Agriculture 411

19.3 Transgenic Animals with Genetically Enhanced Characteristics Have the Potential to Serve Important Roles in Agriculture and Biotechnology 414

- 19.4 Genetic Engineering and Genomics Are Transforming Medical Diagnosis 415
- 19.5 Genetic Engineering and Genomics Promise New, More Targeted Medical Therapies 421
- 19.6 DNA Profiles Identify Individuals 424
- 19.7 Genetic Engineering, Genomics, and Biotechnology Create Ethical, Social, and Legal Questions 427

---

GENETICS, TECHNOLOGY, AND SOCIETY

Personal Genome Projects and the Race for the \$1000 Genome 429

Case Study: A first for gene therapy 430  
 Insights and Solutions 430  
 Problems and Discussion Questions 431

CHAPTER 20

## Developmental Genetics 433

- 20.1 Evolutionary Conservation of Developmental Mechanisms Can Be Studied Using Model Organisms 434
- 20.2 Genetic Analysis of Embryonic Development in *Drosophila* Reveals How the Body Axis of Animals Is Specified 434
- 20.3 Zygotic Genes Program Segment Formation in *Drosophila* 437
- 20.4 Homeotic Selector Genes Specify Parts of the Adult Body 439
- 20.5 Plants Have Evolved Developmental Systems That Parallel Those of Animals 442
- 20.6 Cell–Cell Interactions in Development Are Modeled in *C. elegans* 444
- 20.7 Transcriptional Networks Control Gene Expression in Development 446

---

GENETICS, TECHNOLOGY, AND SOCIETY

Stem Cell Wars 446

Case Study: One foot or another 447  
 Insights and Solutions 448  
 Problems and Discussion Questions 448

CHAPTER 21

## Genetics and Behavior 450

- 21.1 Behavioral Differences between Genetic Strains Can Be Identified 451
- 21.2 The Behavior-First Approach Can Establish Genetic Strains with Behavioral Differences 453
- 21.3 The Gene-First Approach Uses Analysis of Mutant Alleles to Study Molecular Mechanisms That Underlie Behavior 455
- 21.4 Human Behavior Has Genetic Components 459

---

EXPLORING GENOMICS

HomoloGene: Searching for Behavioral Genes 462

Case Study: Primate models for human disorders 462  
 Insights and Solutions 463  
 Problems and Discussion Questions 463

CHAPTER 22

## Quantitative Genetics and Multifactorial Traits 465

- 22.1 Not All Polygenic Traits Show Continuous Variation 466
- 22.2 Quantitative Traits Can Be Explained in Mendelian Terms 467
- 22.3 The Study of Polygenic Traits Relies on Statistical Analysis 469
- 22.4 Heritability Values Estimate the Genetic Contribution to Phenotypic Variability 471
- 22.5 Twin Studies Allow an Estimation of Heritability in Humans 475
- 22.6 Quantitative Trait Loci Can Be Mapped 476

---

GENETICS, TECHNOLOGY, AND SOCIETY

The Green Revolution Revisited: Genetic Research with Rice 477

Case Study: A flip of the genetic coin 478  
 Insights and Solutions 478  
 Problems and Discussion Questions 480

CHAPTER 23

## Population and Evolutionary Genetics 483

- 23.1 Genetic Variation Is Present in Most Populations and Species 484
- 23.2 The Hardy–Weinberg Law Describes Allele Frequencies and Genotype Frequencies in Populations 486
- 23.3 The Hardy–Weinberg Law Can Be Applied to Human Populations 488
- 23.4 Natural Selection Is a Major Force Driving Allele Frequency Change 491
- 23.5 Mutation Creates New Alleles in a Gene Pool 493
- 23.6 Migration and Gene Flow Can Alter Allele Frequencies 494
- 23.7 Genetic Drift Causes Random Changes in Allele Frequency in Small Populations 494
- 23.8 Nonrandom Mating Changes Genotype Frequency but Not Allele Frequency 496
- 23.9 Reduced Gene Flow, Selection, and Genetic Drift Can Lead to Speciation 497
- 23.10 Genetic Differences Can Be Used to Reconstruct Evolutionary History 499

## EXPLORING GENOMICS

---

The Y Chromosome Haplotype Reference Database (YHRD) 503

Case Study: An unexpected outcome 504

Insights and Solutions 504

Problems and Discussion Questions 504

## CHAPTER 24

## Conservation Genetics 507

- 24.1 Genetic Diversity Is the Goal of Conservation Genetics 509
- 24.2 Population Size Has a Major Impact on Species Survival 511
- 24.3 Genetic Effects Are More Pronounced in Small, Isolated Populations 512
- 24.4 Genetic Erosion Threatens Species' Survival 515

- 24.5 Conservation of Genetic Diversity Is Essential to Species Survival 516

---

GENETICS, TECHNOLOGY, AND SOCIETY

Gene Pools and Endangered Species: The Plight of the Florida Panther 519

Case Study: The flip side of the green revolution 520

Insights and Solutions 520

Problems and Discussion Questions 521

APPENDIX A ANSWERS TO SELECTED PROBLEMS A-1

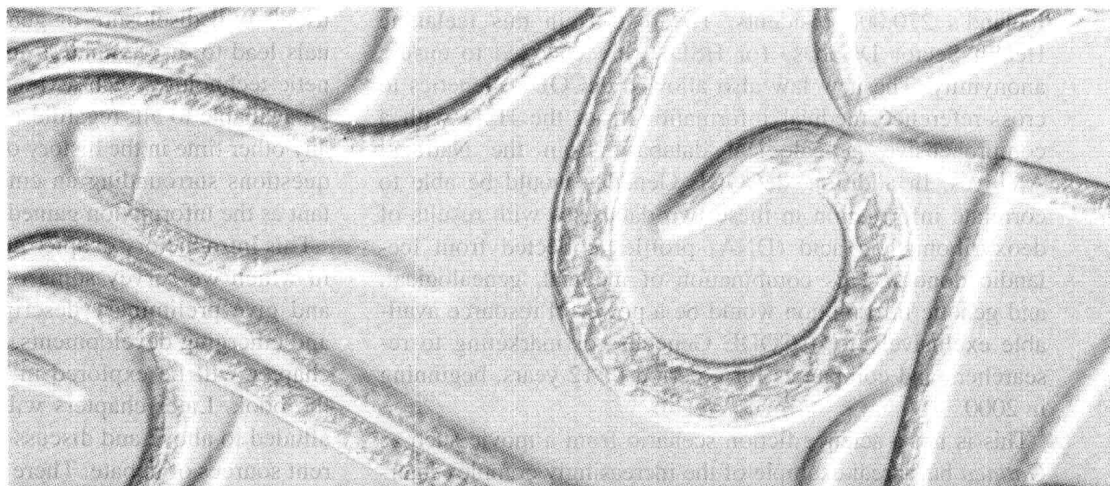
APPENDIX B SELECTED READINGS B-1

GLOSSARY G-1

CREDITS C-1

INDEX I-1

Newer model organisms in genetics include the roundworm *C. elegans*, the plant *A. thaliana*, and the zebrafish, *D. rerio*.



# 1

## CHAPTER CONCEPTS

# Introduction to Genetics

- Transmission genetics is the general process by which traits controlled by factors (genes) are transmitted through gametes from generation to generation. Its fundamental principles were first put forward by Gregor Mendel in the mid-nineteenth century. Later work by others showed that genes are on chromosomes and that mutant strains can be used to map genes on chromosomes.
- The recognition that DNA encodes genetic information, the discovery of DNA's structure, and elucidation of the mechanism of gene expression form the foundation of molecular genetics.
- Recombinant DNA technology, which allows scientists to prepare large quantities of specific DNA sequences, has revolutionized genetics, laying the foundation for new fields—and for endeavors such as the Human Genome Project—that combine genetics with information technology.
- Biotechnology includes the use of genetically modified organisms and their products in a wide range of activities involving agriculture, medicine, and industry.
- Some of the model organisms used in genetics research since the early part of the twentieth century are now used in combination with recombinant DNA technology and genomics to study human diseases.
- Genetic technology is developing faster than the policies, laws, and conventions that govern its use.



In December 1998, following months of heated debate, the Icelandic Parliament passed a law granting deCODE Genetics, a biotechnology company with headquarters in Iceland, a license to create and operate a database containing detailed information drawn from medical records of all of Iceland's 270,000 residents. The records in this Icelandic Health Sector Database (or HSD) were encoded to ensure anonymity. The new law also allowed deCODE Genetics to cross-reference medical information from the HSD with a comprehensive genealogical database from the National Archives. In addition, deCODE Genetics would be able to correlate information in these two databases with results of deoxyribonucleic acid (DNA) profiles collected from Icelandic donors. This combination of medical, genealogical, and genetic information would be a powerful resource available exclusively to deCODE Genetics for marketing to researchers and companies for a period of 12 years, beginning in 2000.

This is not a science fiction scenario from a movie such as *Gattaca* but a real example of the increasingly complex interaction of genetics and society at the beginning of the twenty-first century. The development and use of these databases in Iceland have generated similar projects in other countries as well. The largest is the "UK Biobank" effort launched in Great Britain in 2003. There, a huge database containing the genetic information of 500,000 Britons will be compiled from an initial group of 1.2 million residents. The database will be used to search for susceptibility genes that control complex traits. Other projects have since been announced in Estonia, Latvia, Sweden, Singapore, and the Kingdom of Tonga, while in the United States, smaller-scale programs, involving tens of thousands of individuals, are underway at the Marshfield Clinic in Marshfield, Wisconsin; Northwestern University in Chicago, Illinois; and Howard University in Washington, D.C.

deCODE Genetics selected Iceland for this unprecedented project because the people of Iceland have a level of genetic uniformity seldom seen or accessible to scientific investigation. This high degree of genetic relatedness derives from the founding of Iceland about 1000 years ago by a small population drawn mainly from Scandinavian and Celtic sources. Subsequent periodic population reductions by disease and natural disasters further reduced genetic diversity there, and until the last few decades, few immigrants arrived to bring new genes into the population. Moreover, because Iceland's health-care system is state-supported, medical records for all residents go back as far as the early 1900s. Genealogical information is available in the National Archives and church records for almost every resident and for more than 500,000 of the estimated 750,000 individuals who have ever lived in Iceland. For all these reasons, the Icelandic data are a tremendous asset for geneticists in search of genes that control complex disorders. The project already has a number of successes to its credit. Scientists at deCODE Genetics have isolated genes associated with 12 common diseases including asthma, heart disease, stroke, and osteoporosis.

On the flip side of these successes are questions of privacy, consent, and commercialization—issues at the heart of many controversies arising from the applications of genetic

technology. Scientists and nonscientists alike are debating the fate and control of genetic information and the role of law, the individual, and society in decisions about how and when genetic technology is used. For example, how will knowledge of the complete nucleotide sequence of the human genome be used? Will disclosure of genetic information about individuals lead to discrimination in jobs or insurance? Should genetic technology such as prenatal diagnosis or gene therapy be available to all, regardless of ability to pay? More than at any other time in the history of science, addressing the ethical questions surrounding an emerging technology is as important as the information gained from that technology.

This introductory chapter provides an overview of genetics in which we survey some of the high points of its history and give preliminary descriptions of its central principles and emerging developments. All the topics discussed in this chapter will be explored in far greater detail elsewhere in the book. Later chapters will also revisit the controversies alluded to above and discuss many other issues that are current sources of debate. There has never been a more exciting time to be part of the science of inherited traits, but never has the need for caution and awareness of social consequences been more apparent. This text will enable you to achieve a thorough understanding of modern-day genetics and its underlying principles. Along the way, enjoy your studies, but take your responsibilities as a novice geneticist very seriously.

## 1.1 Genetics Has a Rich and Interesting History

We don't know when people first recognized the existence of heredity, but archeological evidence (e.g., primitive art, preserved bones and skulls, and dried seeds) documents the successful domestication of animals and cultivation of plants thousands of years ago by artificial selection of genetic variants within populations. Between 8000 and 1000 B.C. horses, camels, oxen, and various breeds of dogs (derived from the wolf family) had been domesticated, and selective breeding soon followed. Cultivation of many plants, including maize, wheat, rice, and the date palm, began around 5000 B.C. Remains of maize dating to this period have been recovered in caves in the Tehuacan Valley of Mexico. Such evidence documents our ancestors' successful attempts to manipulate the genetic composition of species.

While few, if any, significant ideas were put forward to explain heredity during prehistoric times, during the Golden Age of Greek culture, philosophers wrote about this subject as it relates to humans. This is evident in the writings of the Hippocratic School of Medicine (500–400 B.C.), and of the philosopher and naturalist Aristotle (384–322 B.C.). The Hippocratic treatise *On the Seed* argued that active "humors" in various parts of the body served as the bearers of hereditary traits. Drawn from various parts of the male body to the semen and passed on to offspring, these humors could be healthy or diseased, the diseased condition accounting for the appearance of