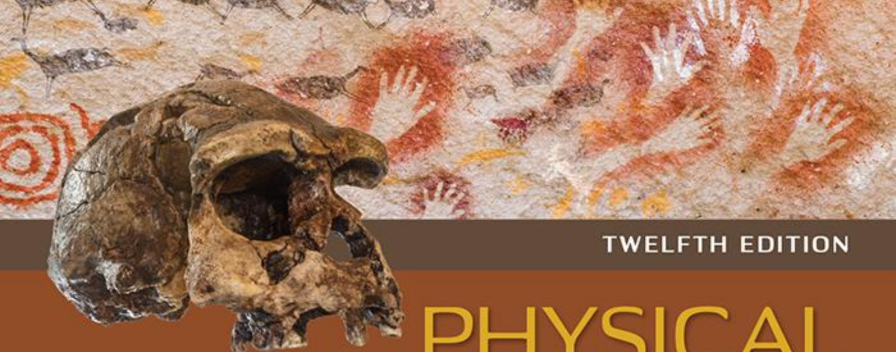

TWELFTH EDITION

PHYSICAL ANTHROPOLOGY

PHILIP L. STEIN | BRUCE M. ROWE | BRIAN PIERSON

Mc Graw Hill Education

Physical Anthropology

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Physical Anthropology

Twelfth Edition

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PHYSICAL ANTHROPOLOGY, TWELFTH EDITION

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To our families and in the memory of

Carol Freed Stein

Margaret Anderson Freed

Eleanor Frances Blumenthal

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Preface

WHAT IS NEW IN THE TWELFTH EDITION?

Physical anthropology is a dynamic field. We have updated the entire book on the basis of new information. This is seen most clearly in the chapters on human genetics (Chapters 2 and 3). In the last several years, our knowledge of human genetics has increased enormously. We reorganized, rewrote, and streamlined Chapters 2 and 3 to reflect the new information in genetics that was relevant to physical anthropology. Other areas of significant revision were the chapters on the fossil record of human evolution (Chapters 12 to 15). Again, we included new information that has been published in recent years, but not all of that information. The fact that new information and ideas are published does not necessarily mean that the significants of those finding and concepts are immediately known. So, we did not include every new finding and idea in this edition. An example of why we choose not to include everything might be made clear with something that happened just as the 10th edition of this book was being prepared, a 47-million-year-old fossil, *Darwinius massillae,* which was nicknamed "Ida," was touted as "the missing link" in human evolution. The Internet and print media were full of claims and speculation, much of which either was not true or played on the public's misunderstanding of evolution, especially the misconception of a "missing link." Ida has little significance to the understanding of human evolution. We hope that after students complete a course in Physical Anthropology, they will recognize illogical or factually incorrect statements made in the name of evolutionary theory in the popular media. (*D. massillae* is discussed in Chapter 12 on early primate evolution, along with a photograph.)

In addition to the changes that were mentioned above, we updated all chapters where necessary. Some of the more specific changes are as follows:

- The section in Chapter 1, *Evolution and Anti-Evolution Movements*, was expanded.
- The concept of group selection was explained in Chapter 5.
- The chapters on nonhuman primates (Chapters 7 to 9) were updated throughout. For example, new information was added on endangered primates and the genetic relationship of humans and chimpanzees.
- In Chapter 10, there is new material on ape-language research.
- In Chapter 11, there is new information on *Orrorin tugenensis*.
- In Chapter 14, we added discussions of paramastication and neuroplasticity.
- In Chapter 15, there is a new discussion of the origin of modern *Homo sapiens* including a new evaluation of the "Mitochondrial Eve" hypothesis. There is also an added discussion of *Homo naledi* and the questions its discovery bring up about the relationship of the species of hominins living at the same time that it did.
- The forensic anthropology section of Chapter 16 has been updated.
- Chapter 18 has been extensively updated to reflect new information on climate change and many other topics. A new box has been added: *Ocean Waste*.

In addition to content changes, we made major changes to the book's illustrations.

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Especially, we would like to thank Rebecca Frank of Los Angeles Valley College who reviewed all of the chapters on nonhuman primates.

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Philip L. Stein has been teaching continuously at Pierce College since 1964. He received his BA in Zoology and MA in Anthropology from UCLA in 1961 and 1963, respectively. He has held a variety of positions at Pierce College, both as an instructor and as an administrator. He has contributed articles and chapters and has made presentations on the teaching of physical anthropology, including "The Teaching of Physical Anthropology," in C. Kottak et al. (eds.), *The Teaching of Anthropology: Problems, Issues, and Decisions* (Mountain View, CA: Mayfield, 1996), pp. 183–188; and "Teaching Anthropology in the Community College," in A. S. Ryan (ed.), *A Guide to Careers in Physical Anthropology* (Westport, CT: Bergin & Garvey, 2002), pp. 43–51. He has written the fourth edition of *The Anthropology of Religion, Magic, and Witchcraft* (Routledge, 2017) with his daughter, Rebecca Stein, an instructor at Los Angeles Valley College. Professor Stein is a fellow of the American Anthropological Association and a member of the American Association of Physical Anthropologists and other professional organizations. He is active in the Society for Anthropology in Community Colleges, in which he served as President in 1995 to 1996.

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©Christine L. Rowe

Bruce M. Rowe is Emeritus Professor of Anthropology at Los Angeles Pierce College, where he has taught since 1970. In addition to teaching physical and cultural anthropology courses, he teaches sociology and linguistics classes. He has coauthored the 11 previous editions of *Physical Anthropology* and two editions of *Physical Anthropology: The Core.* Professor Rowe also has authored four editions of *The College Survival Guide: Hints and References to Aid College Students* and *The College Awareness Guide: What Students Need to Know to Succeed in College.* He is the coauthor of five editions of *A Concise Introduction to Linguistics* (with Diane P. Levine) and has contributed articles to two editions of *Strategies in Teaching Anthropology.* Professor Rowe has received numerous awards for teaching. He has been a fellow of the American Anthropological Association and a member of the American Association of Physical Anthropologists and the Society for Anthropology in Community Colleges.

Brian Pierson

Los Angeles Pierce College

©Brian Pierson

Brian Pierson has been a professor at Pierce College since 2013. He earned his BA in Anthropology from UCLA in 2004, his MA in Physical Anthropology from Tulane University in 2009, and his PhD from Tulane University in 2011. In addition to teaching full time, Dr. Pierson has consulted with the Los Angeles County Department of Medical Examiner-Coroner and with the St. Tammany Parish Sheriff's Office of Louisiana on active forensic cases. He has participated as a lecturer for the Los Angeles Special Operations Response Team for their Skeletal Recovery Workshop since 2015 and as a lecturer for the Los Angeles Department of Coroner's West Coast Training Conference in 2012. He has created forensic and paleoanthropological facial reproductions for museums, displays, and publications in the United States and Europe. He has been an invited lecturer at several academic institutions and professional conferences. He is an active member of the American Academy of Forensic Sciences and the American Association of Physical Anthropologists.

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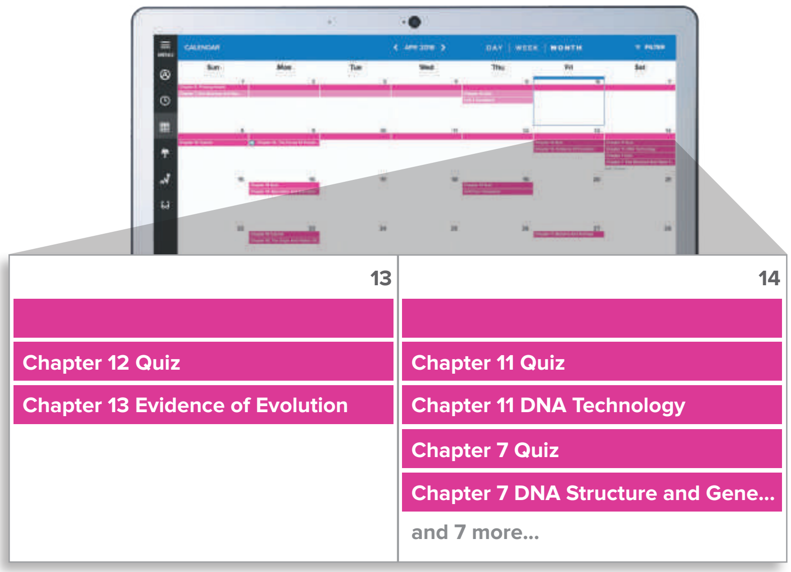

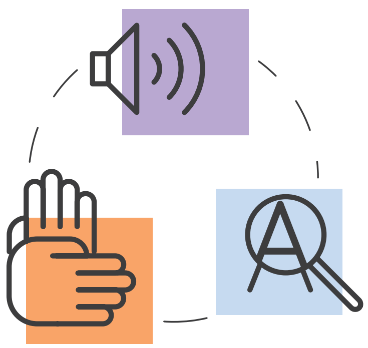

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Chapter 1

Investigating the Nature of Humankind

Evolution is not merely an idea, a theory, or a concept, but is the name of a process in nature, the occurrence of which can be documented by mountains of evidence that nobody has been able to refute. . . It is now actually misleading to refer to evolution as a theory, considering the massive evidence that has been discovered over the last 140 years documenting its existence. Evolution is no longer a theory, it is simply a fact. ●

—Ernst Mayr (1904–2005)[1]

Chapter Outline

After Reading This Chapter, You Should Be Able to Answer These Questions:

1. What are the main areas of interest in physical anthropology, and how does physical anthropology relate to the other subfields of anthropology?
2. What is meant by the term *scientific thinking*, and how does scientific thinking differ from religious thinking?
3. Generally speaking, the average European before the fifteenth century viewed the world much differently than does a modern person employing scientific thinking. In what ways were earlier views of the world different from those of most people in the scientific community today?
4. What are the historical events mentioned in this chapter that led to the changing view of the world? Specifically, what were the contributions of Nicolaus Copernicus, Carolus Linnaeus, Georges-Louis Leclerc de Buffon, Jean-Baptiste de Lamarck, Charles Lyell, William Smith, Jacques Boucher de Crèvecoeur de Perthes, Louis Pasteur, Charles Darwin, and Alfred Russel Wallace?
5. What is the concept of intelligent design, and what are the arguments against it?

---

[1] Mayr, E., *What Evolution Is*. New York: Basic Books, 2001, 275.

"We have now seen that man is variable in body and mind; and that the variations are induced, either directly or indirectly, by the same general causes; and obey the same general laws, as with the lower animals."[2] These words were revolutionary for Charles Darwin's time. Darwin's message was that humans, like all animals, were not specially created and that human characteristics arise from the actions of the same natural forces that affect all life.

Darwin is thought to have been a great discoverer of new facts and ideas, and indeed he was. On the other hand, Darwin's ideas, like all ideas, were formed, nurtured, and brought to maturity in the context of particular intellectual backgrounds. The things we think, the relationships we see, and the very process of creativity are determined, in part, by our cultural environment. The knowledge that a person has at any one time represents the accumulation of information and ideas from his or her whole lifetime and from the people who lived in times past. The theory of evolution was not developed by one person. It was part of a chain of intellectual events, each link being necessary to the continuity of that chain.

One of the disciplines that studies the theory of evolution is physical anthropology. We will begin our voyage of discovery by exploring the field of physical anthropology and its place in the world of anthropology.

THE WORLD OF PHYSICAL ANTHROPOLOGY

The anthropologist is an explorer in pursuit of answers to such questions as: What is it to be human? How did humans evolve? What is the nature of humankind? **Anthropology** is such a broad discipline, however, that it is divided into several subfields or branches. One of the oldest subfields is that of **physical anthropology**, which includes the study of human biological evolution, the process of biological change by which populations of organisms come to differ from their ancestral populations.

anthropology The broad-scope scientific study of people from all periods of time and in all areas of the world. Anthropology focuses on both biological and cultural characteristics and variation as well as biological and cultural evolution.

physical anthropology A branch of anthropology concerned with human biology and evolution.

Studies of Physical Anthropology

Physical anthropology is a very diverse field. Some areas of interest lie within the realm of biology and medical science; others are more tuned to cultural anthropology and archaeology.

Many anthropologists specialize in the study of human biology, and anthropologists are often found on the faculty of schools and departments of biology, public health, medicine, and dentistry. Many specialize in the study of anatomy, physiology, growth and development, aging, nutrition, health, and other related fields. Forensic anthropologists apply this knowledge to the analysis of skeletal remains from crime scenes to determine biological factors about the victim, such as sex and age at death, as well as to determine the probable cause of death.

Anthropologists join with their colleagues in biology in the study of evolutionary theory. Anthropologists are particularly interested in the reconstruction of human and nonhuman primate evolution. Key evidence in these studies is the evidence provided through the fossil record (paleontology) and through analysis of cultural remains (archaeology). Paleontology and archaeology join to create the study of paleoanthropology (Figure 1.1).

A major key in understanding evolutionary processes is an understanding of the mechanisms of heredity—the field called genetics. Many anthropologists are active in studying topics in many subfields of genetics, including human and primate genetics. More recently the comparative study of DNA, the heredity material, has become one of the focuses of the field of comparative genomics, the comparison of all of the genetic information gathered on one species with other species. This has brought forth new understandings about the relationships among contemporary organisms and the relationship of extinct species to living species.

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[2] Darwin, C., *The Descent of Man*, 2nd rev. ed., London: J. Murray, 1874, 47.

Figure 1.1 The Study of the Fossil Record Paleoanthropologist David Lordkipanidze excavates an early hominin site at Dmanisi, Republic of Georgia.

As we will see later, the critical unit of evolution is the population, a group of closely related organisms. Anthropologists carefully document the characteristics of extant human populations in a number of ways. From these studies, we can learn about how different human populations adapt to their environments. The study of human variation is especially important in our shrinking world as more and more people from diverse parts of the world economically and politically influence one another.

The members of the animal kingdom most closely related to humans in an evolutionary sense are the primates, a group of animals that include the living prosimians, monkeys, apes, and humans in addition to a wide variety of now-extinct forms. Many anthropologists are in the field studying primate behavior and ecology while others are in the lab working on problems in primate anatomy and evolution (Figure 1.2).

cultural anthropology The study of the learned patterns of behavior and knowledge characteristic of a society and of how they vary.

culture Learned, nonrandom, systematic behavior and knowledge that can be transmitted from generation to generation.

Physical Anthropology in the World of Anthropology

Physical anthropology, which is also called biological anthropology, is one of four main branches of the study of people; the others are cultural anthropology, archaeology, and linguistic anthropology. Many anthropologists see applied anthropology as a fifth field. While traditionally anthropologists are trained in all four of the main fields and see anthropology as a holistic discipline, in recent years, the discipline of anthropology has become more and more diverse and specialized, and many new anthropologists are given minimal training outside their own specializations. This has become very much the case in physical anthropology.

Cultural anthropology is the study of human social organization and culture. A central concept in cultural anthropology is that of **culture**. Culture is learned, transmittable behavior that employs the use of symbols, such as words. Cultural behavior, the focus of Chapter 10, is the main way by which humans adjust to their environments.

Figure 1.2 The Study of Primates Primatologist Dian Fossey seen with one of her young subjects. Her life is recounted in the book and the movie *Gorillas in the Mist*.

archaeology The scientific study of the past and current cultures through the analysis of artifacts and the context in which they are found.

linguistic anthropology The study of language in cross-cultural perspective; the origin and evolution of language.

applied anthropology A branch of anthropology devoted to applying anthropological theory to practical problems.

Archaeology is the study of the material remains of human activity, artifacts, and the context in which they are found. Both artifacts and their context are used to reconstruct how different cultures have adjusted to varying situations through time and to explain stability and change. Although some archaeologists study contemporary societies, most archaeologists study the cultures of the past. **Linguistic anthropology** examines the history, function, structure, and physiology of one of people's most definitive characteristics—language. **Applied anthropology** is concerned with the application of anthropological ideas to current human problems.

Conclusion

This text deals with many issues about the nature of humanity, a very complex and difficult topic. There are no simple answers to the many questions that are raised in this book. The purpose of the book is to provide a basic understanding of humans, their evolution, and their place in nature. We cannot promise that all your questions about people will be answered; in fact, we can promise that they will not. A great deal has been learned about human nature over the centuries, especially in the last century and a half, yet anthropology is still a dynamic subject. With each publication of a research project, new information is added to our knowledge of humanity. In other words, data that are needed to answer crucial questions about the human species are still being uncovered.

Why study anthropology? Because anthropology provides empirical knowledge about the human condition. On one level, this serves to feed our curiosity about ourselves. However, anthropological studies also provide data useful to the fields of medicine, environmental maintenance, urban planning, education, and so forth. Anthropology also attempts to provide a profile of human potentials and limitations. For instance, it explores the question of whether humans are violent by nature.

THE NATURE OF SCIENCE

science A way of learning about the world by applying the principles of scientific thinking, which includes making empirical observations, proposing hypotheses to explain those observations, and testing those hypotheses in valid and reliable ways; also refers to the organized body of knowledge that results from scientific study.

empirical Received through the senses (sight, touch, smell, hearing, taste), either directly or through extensions of the senses (such as a microscope).

The physicist investigating the relationship between time and space, the chemist exploring the properties of a new substance, the biologist probing the mysteries of the continuity of life, and the anthropologist searching for human origins share a common trait—curiosity. This is not to say that nonscientists are not curious; most people possess curiosity. The scientist, however, uses scientific reasoning as a specific method to delve into enigmatic problems.

So just what is **science**? Here is where the dictionary fails, for science is not something that can be easily defined. It is an activity, a search, and a method of discovery that results in a body of knowledge. Scientific investigations are based on observations. These observations may be the results of an experiment or simply an observation of something in nature, like a fossil tooth. The observations that we make must be **empirical**. By *empirical* we mean that we must be able to experience the object of study through our senses, although instruments, such as a microscope or an electronic scanning device, may be used to extend our senses.

Such empirical observations lead to the formation of questions about our world. However, scientific investigations can deal only with questions that are capable of being answered. Thus science cannot answer questions about morality or the supernatural.

Hypotheses and Testing Hypotheses

hypothesis An informed supposition about the relationship of one variable to another.

variable Any property that may be displayed in different values.

A **hypothesis** is a tentative answer to a question posed about an observation. A hypothesis, however, is not any explanation. It must be logical and testable; that is, there must be an objective way to find out whether the hypothesis is correct or incorrect. Another way of stating this is that there must be some way to prove that the hypothesis is not true, although the result may show that the hypothesis is indeed correct.

In testing a hypothesis, one looks at the factors that characterize the observation; these factors are called **variables**. A variable is any factor or property of a phenomenon that may be displayed in different ways or values. For example, automobiles that use gasoline vary in the amount of miles they can travel on a gallon of gasoline. The miles per gallon for different cars is a variable. An example of a variable from physical anthropology would be the volume of the brain case, the part of the skull that houses the brain. It may measure 400 cubic centimeters in one animal and 1300 cubic centimeters in another—it can vary. For a variable to be the subject of a scientific study, we must be able to measure it precisely. And different people measuring the same variable must arrive at the same value.

A hypothesis can be a statement about the relationship of one variable to another. Is one variable independent of the other variable, does one variable cause another variable to change, or does a third variable cause the two variables to change in a systematic way? For example, one might hypothesize that as the average size of the human brain increased through time, so did the complexity of technology. Brain size is one variable, and technological complexity is a second variable. The hypothesis proposes a direct relationship between the two variables: As one increases, so does the other. While this particular hypothesis proposes a relationship between two variables, it does not propose that one variable causes the other to occur.

Once proposed, the hypothesis must be tested against reality. One way to do this is to test the predictive value of the hypothesis by comparing it to all known data gathered from nature. In the previous example, we could measure brain case size in fossil skulls and count the number of certain types of stone tools found in association with each skull. If, upon analysis, we find that as the average size of the brain case increases so does the number of tool types, we have identified one line of evidence that supports the validity of the hypothesis. New discoveries will either support the hypothesis or contradict it.

A second way to test a hypothesis is through experimentation. An **experiment** compares one situation with a second situation in which one variable has been altered by the experimenter. For instance, a geneticist could formulate a hypothesis about the function of a specific unit of inheritance. The geneticist could then conduct an experiment that rendered that unit inactive in one group of test subjects and left it alone in another group of test subjects. Analysis of the resulting data (observations) provides evidence of the validity of the hypothesis, disproves the hypothesis, or leads to a modification of the hypothesis. Experiments must be repeatable, and the validity of the original experiment depends on whether, when repeated, it yields the same results as did the initial experiment.

experiment A test of the predictive value of a hypothesis. A controlled experiment compares two situations in which only one variable differs.

A third possible way to test a hypothesis is to compare one phenomenon to other phenomena to determine relationships between them. The phenomena can be just about anything—rocks, stars, languages, living organisms. Although we cannot experiment directly with things that existed only in the past, we can compare living organisms to each other and look for patterns that indicate past evolutionary events and relationships. Comparative studies of anatomy have shown that chimpanzees and humans are more closely related to each other than humans are to monkeys. However, humans and monkeys are anatomically more closely related to each other than humans are to dogs. In Chapter 8, we will discuss comparative studies of genetics and biological molecules. In Chapters 9 and 10, we will talk about comparative behavioral studies.

After a number of studies exploring the relationships of all the variables have been completed, we might develop some generalizations. For instance, we might suggest that an increase in the volume of the brain case is correlated with a whole range of behaviors that differentiate earlier humanlike populations from later ones. Each of these new hypotheses would have to be tested by some research design. Each test might reveal hidden variables that will disprove or modify the original and related hypotheses. This hypothesis-test-hypothesis-test cycle is a self-corrective feature of science. Scientists realize that results are never final.

Theory Science is cumulative. After many tests have been conducted on a set of similar hypotheses with confirming results, a **theory** may be proposed. For example, the testing of thousands of hypotheses on the reasons for progressive change in anatomy and behavior has led to great confidence in the theory of evolution.

theory A step in the scientific method in which a statement is generated on the basis of highly confirmed hypotheses and used to generalize about conditions not yet tested.

Theory is a frequently misunderstood term. Many nonscientists equate theory with *hypothesis* or *speculation*. In popular usage, to say that something is "just a theory" means that it is just a vague and possibly erroneous sort of fact.

In reality, a scientific theory is a statement of extremely high validity—usually some general law or principle. The distinction between fact and theory is often subtle. For example, that evolution has occurred is a fact. The mechanisms, such as natural selection, that explain how and why evolution has occurred constitute a theory. The validity of evolution as a fact has not been an issue in science for well over 100 years, but the theories that explain the mechanisms of evolutionary change are still very much discussed and are important areas of ongoing research. So, when we refer to evolutionary theory, we are referring to the mechanisms that are responsible for evolutionary change. In recent years, the words *hypothesis*, *theory*, and *fact*, especially as those terms are used in science, have been confused more than ever in the media and by people in public office.

Science and Religion

The theologian deeply involved in an interpretation of scriptures, the bereaved individual looking to scripture to explain death, and the shaman dancing for rain are putting their trust in traditional doctrines that, for the most part, they do not question. In contrast, the biologist examining cell structure, the anthropologist studying death rituals, and the meteorologist investigating the weather rely on methods and techniques that are aimed at producing new information and validating or correcting old explanations. Thus, they build a body of knowledge from which accurate predictions about natural occurrences can be made. The credibility of scientific conclusions is based on the concepts of accuracy, validity, and reliability; belief in religious doctrines is based on faith.

Scientists can attempt to answer only some questions; others cannot be subjected to scientific inquiry and are therefore not in the domain of empirical or objective research. For example, science cannot deal with the question of the existence of an omnipotent force. In order for an experiment to be carried out, a **control**, a situation that differs from the situation being tested, must be possible. If a phenomenon is present always and everywhere, how can its absence be tested?

control In the experimental method, a situation in which a comparison can be made between a specific situation and a second situation that differs, ideally, in only one aspect from the first.

Scientists do not claim that their conclusions are final. They realize that their statements are only as good as the data they have and that new information may alter their concepts. A religious belief can change in response to personal interpretation and public opinion, but such interpretation or new information is not necessarily linked to new empirical facts. To a believer, his or her religious belief or faith is taken as being absolutely true, whereas at no time is a scientific statement considered totally and irrefutably correct.

The scientific approach has been consciously and consistently used in Western societies since the 1600s; however, it is not just the industrial societies that practice science. All people make conclusions on the basis of experiments and observations. The phenomena that they can treat in this way make up their objective knowledge; the more mysterious facets of life are treated religiously or magically. For example, the Trobriand Islanders of the Pacific do two types of fishing: one in the shallow coastal pools and the other far out at sea. The first type is safe and is undertaken by men, women, and children; the second, filled with the unknown, is dangerous and is considered a male activity. Since shallow fishing is undertaken with regularity, time is spent making observations of fish behavior and experiments are performed on how best to catch the prey. Nothing is done religiously or magically to protect the fishing party. The story is different with deep-sea fishing. Men occasionally do not return from the expeditions, and so elaborate rituals are performed to appease or appeal to the gods of the unpredictable seas.

In conclusion, a scientific statement asserts the natural causality of phenomena. One thing happens because of preceding events that led up to it. Things happen and conditions exist because of the physical, chemical, biological, behavioral, and/or cultural and social characteristics of the thing in question and the context in which it is found. Religious or magical statements assert causality beyond the natural; when natural causality cannot be determined or is not sought, spiritual causality is often assumed.

Summary

Science is the activity of seeking out reliable explanations for phenomena. Science is also the search for order and a method for discovery. The result of the activity of science is a body of empirical knowledge that can be used to better understand the universe and to predict the processes, structure, form, and function of natural occurrences. Scientific thinking provides a systematic method of investigation and includes the identification of variables, hypothesis formation, and tests of the validity of the hypothesis and of postulating theories. All scientific statements are tentative. It is because new evidence is always possible that a scientific statement can never be completely proved.

The scientist and the theologian are both interested in giving answers. However, the scientist proceeds by testing questions about the nature of empirical observation, whereas the theologian consults the philosophy of his or her particular religion and interprets the meaning of that philosophy for a particular situation. Scientific statements are never considered absolute, but at any one time religious doctrine is. All people have a body of scientific knowledge, but for the things they fear or cannot understand in an empirical way, religion and magic provide a measure of comfort and assurance.

VIEWS ON THE ESSENCE OF HUMANS, NATURE, AND TIME

There were many variations in the early ideas about the universe. Biological evolutionary thought goes back to ancient times with some Greek, Roman, Chinese, and medieval Islamic scholars proposing ideas about how species change over time. However, many of the ideas held by people in Europe up until relatively recent times were the opposite of those embodied in present evolutionary thinking. These ideas had to be challenged before a new concept of reality could arise.

First among these views was the idea of **anthropocentricity**. This is the belief that people are the center of the universe and that all the celestial bodies revolve around them. Humans placed themselves on a pedestal, believing that God provided the animals and plants for people's use and fancy. The similarities that people observed between humans and animals and among various animal species were seen as reflecting the design of the Creator. Many people believed that certain shapes patterns, and numbers are pleasing to God and that God therefore used these as models for all creations.

anthropocentricity The belief that humans are the most important elements in the universe.

People of earlier times, as well as many people today whose beliefs are based on a literal interpretation of the Bible, thought that life had been formed from nonlife at the will of the Creator. Some believed that this process of creation continued even after the original six days of Genesis. This concept is known as **spontaneous generation**, whereby living organisms could arise from nonliving material. People also believed that once a type of organism is created, its descendants will remain **immutable**, in the same form as the original, from generation to generation.

spontaneous generation An old and incorrect idea that complex life-forms could be spontaneously created from nonliving material.

immutable Unchanging.

The original creation, as described in Genesis, supposedly took place a few thousand years before the Greek and Roman empires. Archbishop James Ussher of Armagh, Ireland (1581–1656), used the generations named in the Bible to calculate that the earth's creation took place on the night before October 23, 4004 B.C. The idea of a spontaneously created and static life, a life brought into being only 6000 years ago, is directly counter to modern evolutionary theory. The development of evolutionary theory depended on an increasing disbelief in these old ideas.

Questioning the Old Ideas

What a shock it must have been to European scholars of the sixteenth century when Nicolaus Copernicus (1473–1543) showed that the earth was not the center of the universe; it is not even the center of the solar system! This was but one of a series of revelations that were to bombard the old ideas.

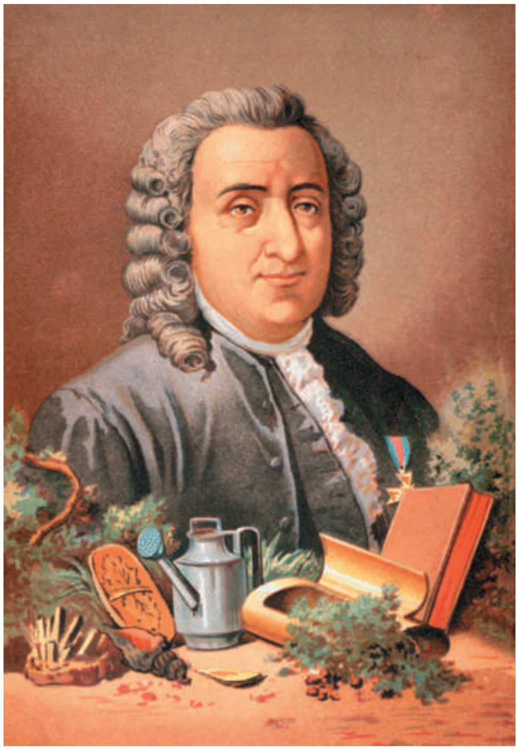

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Figure 1.3 Carolus Linnaeus (1707–1778) Portrait of Carolus Linnaeus. A Swedish naturalist and botanist, he established what became the modern method of naming the living world.

A tired, lost sea captain who was fearful that he was going to fall off the edge of the earth might have been both elated and confused at the greeting he received from an exotic people living on a shore that he thought could not possibly exist. The Age of Exploration, which began for Europeans in the late 1400s with the voyages of explorers such as Christopher Columbus and Vasco da Gama, revealed variations of life not dreamed of before. By 1758, 4235 species of animals were cataloged. Today, almost 2 million species have been formally described. This is only a small percentage of the estimated number of living species of animals thought to exist. During the Age of Exploration, strange animals never mentioned in the Bible were seen by Europeans for the first time. Naturalists were overwhelmed by the quantity of new discoveries and the problems of organizing this rapidly growing wealth of data.

Carolus Linnaeus's Classification Although all cultures classify plants and animals into some kind of scheme, it was not until the seventeenth and eighteenth centuries that comprehensive written classifications were made. The Swedish naturalist Carolus Linnaeus (1707–1778) succeeded in classifying every kind of animal and plant known to him into a system of categories (Figure 1.3). This type of classification is absolutely necessary for a scientific understanding of the relationship of one plant or animal to the next. Yet at first it reinforced traditional ideas. Linnaeus saw each category as fixed and immutable, the result of divine creation.

Linnaeus's scheme became important to modern biological sciences for many reasons. First, it imposed order on nature's infinite variation. Linnaeus saw that the analysis of anatomical structures could be used to group plants and animals into categories. The most specific categories included organisms that were very much alike, whereas the more general levels encompassed these specific groups, thereby representing a wider range of variation. Linnaeus wrote that the first order of science is to distinguish one thing from the other; his classification helped do just that.

Second, although Linnaeus considered organisms to be immutable, paradoxically his classification provided a means for "seeing" changes and possible ancestral relationships. Scientists wondered whether similar organisms were related by common ancestry. If two or more types had a common origin but were now somewhat different, it followed that evolution must have occurred. Linnaeus, who had been so emphatic about the idea of unchanging species, began in later life to question this concept of fixity. He had observed new types of plants resulting from crossbreeding, and he had decided that perhaps all living things were not immutable.

Third, Linnaeus included people in his classification. Although he did not contend that humans are related to other animals, his placement of humans in this scheme was sure to raise the question.

Could Nature Be Dynamic? Many people in the eighteenth century were intrigued with the rapidly increasing information brought to the fore by exploration. Not only were new varieties of plants and animals being discovered, so were new people. Who were the Native Americans, the Polynesians, the Africans? Were they human, or were they part human and part ape? Credible answers to these and other questions could not be supplied by traditional explanations.

The effect of exploration in guiding people to new realities was intensified by the great revolutions of the eighteenth and nineteenth centuries. These revolutions included technological changes in the Industrial Age as well as political upheavals, such as the American and French revolutions. Technological and political developments that brought about major social changes created an atmosphere in which the idea of immutability could be questioned. If people could change their social systems so rapidly, if human life could be so dynamic, then perhaps so was nature. It was in the late eighteenth century that the first modern theories of organic evolution emerged.

A Brief History of the Development of Modern Evolutionary Theory

Georges-Louis Leclerc, Comte de Buffon (1707–1788), a contemporary of Linnaeus, proposed many major points that Darwin would later include in *On the Origin of Species, or the Preservation of Favoured Races in the Struggle for Life* (which is usually just referred to as *On the Origin of Species*). Buffon recognized the tendency of populations to increase at a faster rate than their food supply, hence the struggle for survival. He noted the variations within species and speculated on methods of inheritance. He questioned spontaneous creation. He also challenged the church's dating of the earth, proposing that the earth is much older than 6000 years. Buffon's importance was diminished by his lack of conciseness, but he might have been vague and apologetic about his thoughts for fear of being considered a heretic.

Although Buffon was one of the first people to scientifically investigate evolution, it was left to Jean-Baptiste de Lamarck (1744–1829) to articulate a systematic theory of evolution as an explanation of organic diversity. Lamarck, who coined the word *biology*, used the previous nonevolutionary idea that organisms could be ranked in a progressive order, with humans at the top. He envisioned evolution as a constant striving toward perfection and believed deviations were due to local adaptations to specific environments.

principle of use and disuse Concept popularized by Lamarck that proposes that parts of the body that are used are often strengthened and improved, whereas parts of the body that are not used become weak and ultimately may disappear.

principle of acquired characteristics Concept, popularized by Lamarck, that traits gained during a lifetime can then be passed on to the next generation by genetic means; considered invalid today.

catastrophism Idea that the earth has experienced a series of catastrophic destructions and creations and that fossil forms found in each layer of the earth are bounded by a creation and destruction event.

Lamarck is remembered by many for his explanation of the cause of these deviations. He proposed that an organism acquired new characteristics in its lifetime by virtue of using or not using different parts of its body. Lamarck believed that frequent use of a part of the body improved it whereas the lack of use of a body part weakened it, in some cases to the point where it disappeared altogether. This is called the **principle of use and disuse**. For instance, if an animal constantly had to stretch its neck to get at food in the branches of a tree, its neck would get longer. If the trees were to get taller, the animal would then have to stretch more, and its neck would get longer still. This was Lamarck's explanation of the giraffe. He believed that a trait, once acquired, would be passed on to the next generation. This concept is known as the **principle of acquired characteristics**.

Lamarck's importance lies in his proposal that life is dynamic and that there is a mechanism in nature that promotes ongoing change. The method of change he suggested, however, is generally incorrect. There are some circumstances whereby environmental influences on an individual might be transmitted to the next generation and we will talk about those in Chapter 3. Yet, acquired characteristics are generally not transmitted to offspring. A person who is very muscular as a result of lifting weights will not be more likely to have a muscle-bound child because of their behavior of working out (Figure 1.4).

Catastrophism The work of Lamarck and other early evolutionists, along with increasing evidence that changes had occurred in the living world, prompted thinkers to attempt to reconcile the traditional view of a divinely created changeless world with new evidence and ideas. The French scholar Georges Cuvier (1769–1832) is known for developing the idea of **catastrophism**. Cuvier recognized the fact that as we dig down into the earth, we see different assemblages of plants and animals. In many cases, specific layers of flora and fauna seem to be almost totally replaced by new types overlying them. Cuvier believed that the living organisms represented in each layer were destroyed by a catastrophic event and that the next set of plants and animals represented a new creation event. Although Cuvier did not construct his ideas to bolster a literal interpretation of the Bible, others saw the last catastrophic event as the biblical flood.

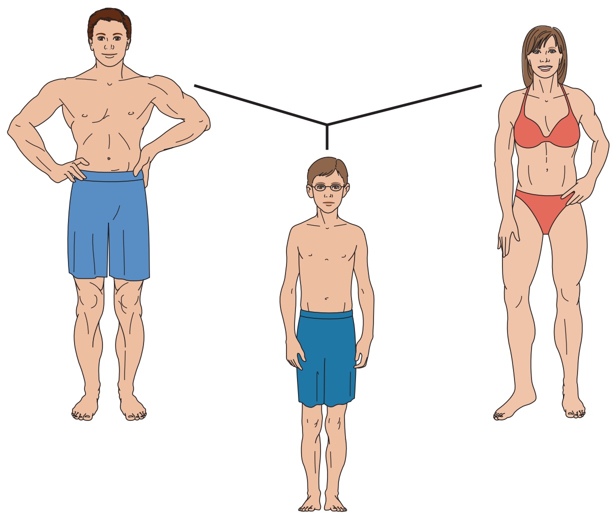

Figure 1.4 Inheritance of Acquired Characteristics
Today biologists do not believe that the increase or decrease in the size or strength of parts of the body due to use or disuse is transmitted to offspring. For example, if a couple lift weights and become muscular, their newly acquired physical condition will not be passed on genetically to their offspring.

According to the proponents of catastrophism, not all plants and animals need be destroyed by a cataclysmic event. For instance, the animals that were collected by Noah survived the flood. Also, Cuvier believed that catastrophes could be localized. Organisms that survived in an area not affected by the cataclysm could then migrate into the areas left vacant by the catastrophe.

In Cuvier's time, all living organisms were seen as being organized into a **great chain of being**, or ***scala naturae***, from the least to the most perfect. Biologists were moving away from the idea of a fixed chain of organisms, with humans at the top, and were starting to think of the chain as being more like a ladder whereby organisms progress from a lesser to a greater state of perfection. Some saw evolution as being driven from lesser to greater perfection. In 1817, Cuvier published his classification of animals, which broke from this tradition by dividing animals into four large groups based on their anatomy. He saw these groups as being of equal rank. In spite of the work of Cuvier and those who followed, the idea embedded in the *scala naturae* still permeates our thinking. We traditionally place humans at the top of the evolutionary tree and see evolutionary change as a progression from simple to complex, even though both of these concepts are illogical and inaccurate.

Of course some catastrophic events, such as meteorites that hit the earth, can be the catalyst of major evolutionary events, such as the mass extinctions of plants and animals and ensuing rapid evolutionary changes in some of the surviving populations. However, catastrophic events are not primary causes of evolutionary change. Large-scale evolution results from the gradual accumulation of small changes over time.

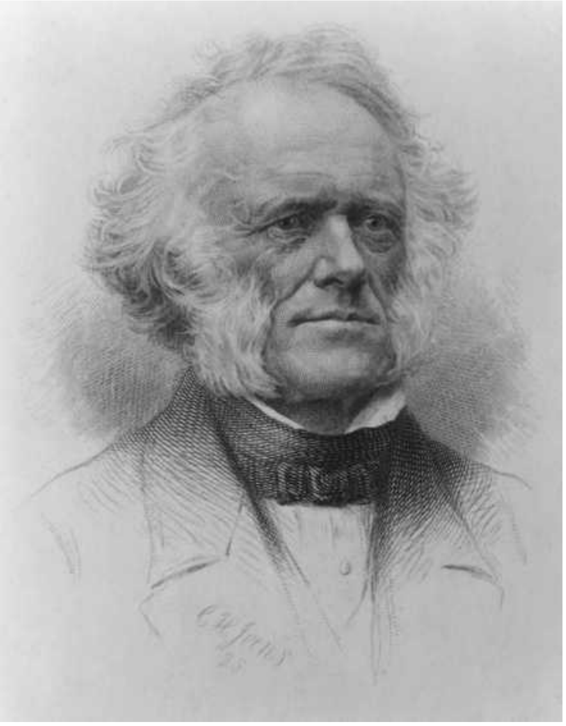

Figure 1.5 Charles Lyell (1797–1875) The main purpose of his book *Principles of Geology* was to establish the principle of uniformitarianism, as the book's subtitle indicates: "Being an attempt to explain the former changes of the earth's surface, by reference to causes now in operation."

What Is the Age of the Earth?

great chain of being (*scala naturae*) The idea that organisms are arranged in a hierarchy from lesser to greater state of perfection.

uniformitarianism Principle that states that physical forces working today to alter the earth were also in force and working in the same way in former times.

strata Layers of sedimentary rocks.

By the early nineteenth century, masses of new data had been gathered that threw doubt on traditional interpretations. Charles Lyell (1797–1875) synthesized this new information in a textbook, *Principles of Geology*, the first of three volumes being published in 1830 (Figure 1.5). In it he popularized the principle of **uniformitarianism**, first proposed by James Hutton (1726–1797), which was a main prerequisite to the development of a credible evolutionary theory. The principle of uniformitarianism states that physical forces, such as wind, rain, heat, cold, moving water, volcanism, and earthquakes, that are at work today altering the earth were also in force, working in the same way, in former times. Therefore, "the present is the key to the past."

Lyell also realized that, as they operate today, the processes resulting in physical alteration of the earth would require very long periods of time to form the layers of the earth known as **strata** (Figure 1.6). Therefore, it could be inferred that the large number and often great thickness of strata formed in the past must have taken a long time to develop. This inference also challenged biblical chronology because it showed that the earth's age was many times greater than previously thought. In popularizing the theory of uniformitarianism, Lyell also was setting the stage for a theory of the evolution of the living world.

William Smith (1769–1839), who was nicknamed "Strata Smith," had found that each stratum was characterized by distinct fossils that could be used to indicate the age of strata. In 1815, he released the first geological map of England (Box 1-1).

Charles Lyell also studied fossil plants and animals that were embedded in the various strata. These and other similar investigations suggested that the earth is extremely

Figure 1.6 Stratigraphy The Grand Canyon shows the various strata that have accumulated over millennia.

Box 1-1 William "Strata" Smith

William Smith (1769–1839) was born at a time when the earth was believed to be less than 6000 years old, an age consistent with that calculated by Bishop James Ussher in 1658. Since the entire world was thought to have been created by God, it followed that strange and unusual objects often found embedded in the earth—objects that today we call minerals, crystals, fossils, and so forth—were created at the same time as the rest of the earth.

However, many of those objects curiously resembled living creatures and parts of creatures. Those fossils were referred to as figured stones because they were clearly composed of a mineral—they were a type of rock that nevertheless resembled something that was once living. Many people of the day saw those figured stones as special creations of God, created in place within the ground. During the eighteenth and nineteenth centuries, figured stones were avidly collected and placed in curio cabinets in fine houses and museums.

Toward the end of the eighteenth century, knowledge of the earth and of figured stones had increased dramatically, and scholars began to realize that certain types of figured stones were always found in particular layers or in certain types of soils. To explain this distribution, scholars took the huge step of proposing that those objects were the real remains of once-living creatures. While some of the remains resembled creatures living at the time, which must have been caught up in the mud and eventually transformed into stone, others resembled creatures that clearly were nothing like anything living on the face of the earth in the eighteenth century. Religious fundamentalists and others explained this observation by referring to Noah's flood or the "Noachian Deluge." The remains of extinct animals were simply those which did not make it to the ark and thereby perished.

William Smith, of humble origins, was a surveyor by trade. He became involved with coal mining and the surveying of routes for the canals that were being constructed all over England as an inexpensive way to get the coal from mine to market. In descending into coal mines, Smith observed what miners knew but, since they were for the most part illiterate, did not write about. The earth underground existed in layers, and each layer could be distinguished by specific characteristics such as texture, color, and the types of fossils embedded within it. Smith noticed that those layers *always* occurred in the same order in every mine he explored. Later, when cutting though hills and excavating tunnels for canals, he noticed the same pattern of layers. His studies of these layers, or strata, gave him his nickname "Strata."

A fact of great importance was that the layers sloped in a very characteristic fashion. As a result different layers appeared on the surface of the earth in certain areas. If a layer on the surface could be recognized, one immediately would know what layers lay beneath—a valuable piece of information for someone looking for coal.

Smith's observations eventually led to the publication of the first geological map of England in 1815, a feat that earned him an important place in history. The documentation of the presence of large numbers of strata, each produced by recognizable processes that look long periods of time to occur, helped establish the ancient age of the earth and presented evidence of earlier forms of life in the past. Today the study of strata, or stratigraphy, is a fundamental part of the study of archaeology and paleontology.

Source: Winchester, S., *The Map That Changed the World: William Smith and the Birth of Modern Geology*. New York: HarperCollins, 2001.

old and that life had existed in various forms, some now extinct, for hundreds of centuries. Lyell himself did not become convinced of the antiquity of living things until later in his life when, in his text *Geological Evidences of the Antiquity of Man* (1863), he supported Charles Darwin's theory of natural selection.

Humans before Adam and Eve?

Fossils of extinct forms of plants and animals had been known long before Lyell's time, and many valid interpretations had been made. However, as often happens, the evidence was more frequently viewed in terms of predispositions and the special interests of the observer; it was not analyzed critically. For instance, early proponents of catastrophism believed that extinct animals were creatures "who did not make the Ark." After Lyell's systematic investigation, some scientists began at last to speculate on the idea of a more dynamic world. Yet the notion of prehistoric people was still heresy. Were not all people descendants of Adam and Eve?

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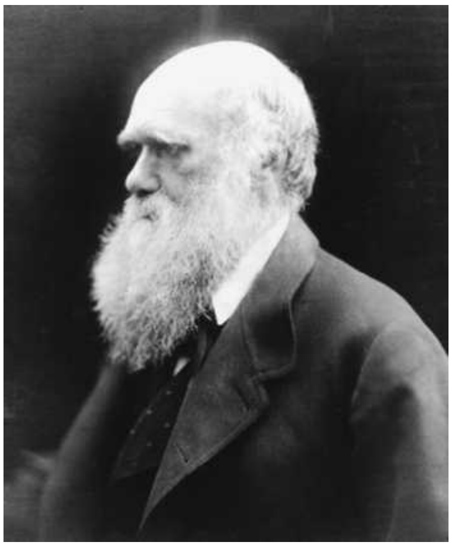
Figure 1.7 Lower Paleolithic Hand Ax
This Acheulean hand ax is from the site of Clacton-on-Sea, England. The 450,000-year-old tool was found associated with the butchered remains of now extinct species of elephant, horse, rhinoceros, bison, and deer.

In the early 1800s, Jacques Boucher de Crèvecoeur de Perthes (1788–1868) made a systematic attempt to demonstrate the existence of a prehistoric period. While digging on the banks of the Somme, a river in southwestern France, he discovered that many stones were not made of the same material as the walls of the pit in which they were uncovered. In addition, the stones had obviously been shaped into specific forms (Figure 1.7). Other people also had observed these types of rocks. They considered them to be "figured stones" of an unknown origin or "lightning stones," petrified lightning cast to the earth by God during thunderstorms. Boucher de Crèvecoeur de Perthes was convinced that they were made by ancient people. To back up this conviction, he collected what he thought was an immense amount of evidence to support his case. He submitted his report in 1838 to various scientific societies, where it was rejected. Not until 20 years later, a year before the publication of Darwin's *On the Origin of Species*, were his conclusions accepted.

By the time of Darwin, the notions of anthropocentrism, immutability, and a date of 4004 B.C. for the earth's origin had been altered or reversed. For most of the scientific community, the final discrediting of spontaneous generation would have to wait until the time of the French chemist Louis Pasteur (1822–1895). Pasteur, who had developed the pasteurization process and vaccinations against anthrax and rabies, also disproved spontaneous generation.

Darwin's Voyage of Discovery

It was Charles Darwin (1809–1882) who proposed a compelling theory for the mechanism of organic evolution that accurately synthesized the available evidence (Figure 1.8). At the age of 22, Darwin was invited to accompany a scientific investigation on the ship HMS *Beagle*. On December 27, 1831, the *Beagle* sailed from Plymouth, England, on what was to become a five-year voyage of discovery. Darwin spent about 18 months of the five years confined on the small ship, which measured 27 meters (90 feet) in length and less than 8 meters (25 feet) at the widest point. He was one of 74 aboard. He spent much of the five years exploring on land while the ship mapped the coastline.



Source: Library of Congress Prints and Photographs Division [LC-USZ62-52389]

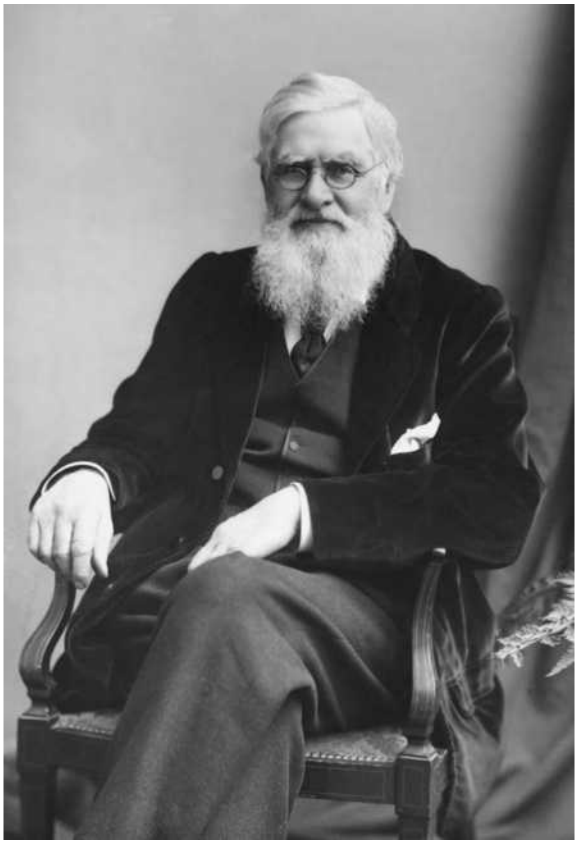
Figure 1.8 Charles Darwin (1809–1882)
The 1250 copies of the first printing of his book *On the Origin of Species* sold out on the day of its issue on November 24, 1859. Darwin's concept of natural selection has been firmly established as a hallmark of modern biological science.

The purpose of the voyage was to chart the southeastern coast of South America and to calculate an accurate fixing of longitude around the world. It was the role of the voyage in Darwin's life, however, that made it one of the most famous journeys in history. On that voyage, Darwin gained new insights into the origin of coral reefs, described in detail fauna and flora, and studied fossilized animals.

In the Andes, Darwin found seashells in rocks at 3962 meters (13,000 feet), and in Valdivia, Chile, he experienced a devastating earthquake that elevated the shore by a meter (3⅓ feet) or more. These and other experiences showed how dynamic the earth is. He realized that the tops of mountains once had been under the sea and that coastlines could be significantly altered by earthquakes.

Throughout his trip, Darwin witnessed the great diversity in nature. His five-week visit to the Galápagos Islands, a volcanic group of islands some 965 kilometers (600 miles) west of Ecuador, possibly provided a major stimulus for his most famous contribution to science: the concept of natural selection. It was there that he observed giant tortoises, seagoing lizards, ground finches, mocking-birds, and other animals that showed variations related to differences in the different island habitats. Ultimately he hypothesized that environmental forces acted to weed out those individuals whose characteristics were not as well suited to a particular situation.

Darwin was not the only person who was developing a theory of evolution based on species adaptation to the environment. As often happens in science, two or more people came up with basically the same conclusion simultaneously. In the summer of 1858, Darwin must have got quite a jolt when he received a paper from Alfred Russel Wallace (1823–1913), another naturalist, with whom he had been corresponding (Figure 1.9). Wallace had come up with basically the same ideas Darwin had been working on for two decades. Wallace asked Darwin to review the paper and refer it for publication. Instead, both men received credit for their ideas at a meeting of the Linnaean Society in 1858. Because Darwin was the first to publish his work, in his book *On the Origin of Species* in 1859, he has since received most of the credit for modern evolutionary theory.



Source: London Stereoscopic & Photographic Company

Figure 1.9 Alfred Russel Wallace (1823–1913)
In June 1858, Charles Darwin received a paper from Wallace outlining a concept of natural selection very much like his own. On July 1, joint presentations of writings by Darwin and Wallace were read at the meeting of the Linnean Society in London. The presentations received little attention at the time.

Darwinian Natural Selection

The concept of **natural selection** emerged from the analysis of the observations made and specimens collected by Charles Darwin on his voyage. Natural selection is the process of favoring or weeding out individuals with different characteristics from a population. Those individuals that are well suited for their environment will be "favored" in the sense that they will pass on their heritable attributes to the next generation at a higher rate than will individuals not as well suited to the environment.

Darwin noted that within any group of plants or animals there existed much variability. Each offspring of a pair of sexually reproducing adults is unique. (Exceptions include identical twins and the results of cloning.) While the majority of organisms resemble some type of average or norm, there will always be individuals that are smaller or larger, are lighter or darker, or possess some unique features compared with the average.

natural selection
Differential fertility and mortality of variants within a population.

Darwin also realized that all living creatures have the capacity to reproduce in great numbers. For example, if one pair of houseflies bred in April and all eggs hatched and in turn lived to reproduce, by August the total number of houseflies descending from the original pair would be 191,010,000,000,000,000,000. Of course, in real life not all eggs do hatch, and not all individuals that are born live do reproduce. However, the numbers of individuals born or hatched tend to be vast.

The consequence to humans of this rapid increase in number was noted by Thomas R. Malthus (1766–1834) in his *An Essay on the Principle of Population*. Malthus wrote that the human population is growing at a faster rate than food production, and famine and economic chaos would result as the population grew and food resources dwindled. In general, populations have the potential of dramatically increasing in numbers. However, such growth is limited by such factors as space, food and the availability of water, predators, and disease.

Because of limitations in population growth, Darwin concluded that only a proportion of animals that are born live to reproduce. Since individuals differ from one another, those individuals who possess features that increase the chance of surviving are likely to pass on these features to the next generation. On the other hand, organisms with traits that reduce the chance of successfully reproducing are less likely to pass on these traits. Thus, populations of organisms changed through time as those features that contributed to survival were inherited by future generations.

A Classic Example of Natural Selection in a Nonhuman Population Natural selection is not some mystical or hypothetical process that exists only in the mathematical formulations of anthropologists and biologists. It can be seen in action.

A classic example of natural selection is described in studies of the peppered moth, *Biston betularia*, made by many scientists over almost a 100-year period. These studies show both how environments can change and how natural selection eliminates disadvantageous traits while increasing the frequency of beneficial traits.

Before the Industrial Revolution which began in the mid-eighteenth century, the English peppered moth rested on light lichen-covered trees. Peppered moths occurred in two varieties, a light form and a dark form (Figure 1.10). The light form, when resting on the trunk or branches of light-colored trees, was effectively camouflaged from predatory birds. The dark form was not camouflaged and was easy prey for the birds. Consequently, the birds eliminated most of the dark form of the moth almost as fast as they arose. The dark form was not adapted to the environment that contained light trees and by one estimate represented about 2 percent of the total population of moths in 1848. However, by 1898 the dark form made up about 98 percent of the moths. Why did this shift in the color of the moth take place? Numerous hypotheses have been forwarded over the years, but the one that accounts for most of the information and has been recently confirmed involves a change in the environment caused by industrialization and a concurrent change in the pattern of bird predation on the moths.

The Industrial Revolution caused the environment to change. Smoke from coal-burning factories and home stoves killed the lichens on nearby trees and darkened the trees with soot. Now the light-colored moths became more conspicuous, and birds consumed them more frequently than the dark ones. The dark moths were more adapted (survived more often) in the new environment. Put another way, the birds now selected the light moths as food more often than the dark ones. That is why the dark moths made up 98 percent of the total peppered moth population by 1898.

This is an example of rapid evolutionary change within a single species initiated by human activity. The light moth was no longer adapted to the altered environment, and so its death rate increased. At the same time, the dark-colored moth became better adapted, its death rate decreased, and eventually it made up most of the population. Several other species of animals have adapted to changes in the environment brought about by industrialization in the same way. The change in a population in an industrial area that results in darker coloration is termed **industrial melanism**.

industrial melanism
A situation in which the frequency of a dark variant of a species increases in relation to a lighter variant in response to changes in the environment due to pollution-caused increasing industrialization.

Darkening of the tree trunks did not take place all over England, and so populations of the light-colored moth continued to exist in some areas while the frequency of the dark form of the moth increased in the industrial areas. Beginning with the passage of the Clean Air Act 1956 in the United Kingdom, the frequency of the dark form of the moth began to decline. According to a study begun in 1959 near Liverpool, the percentage of dark moths dropped dramatically from a high of 94.2 percent in 1960 to 18.7 percent in 1994.[3] A more recent study found that in 2001 the frequency of the dark moth near Cambridge was 12 percent; the frequency had dropped to about 1 percent in 2007.[4]

The rapid changes seen in the peppered moth population resulted from an environmental change caused by human activity. Before the evolution of humans, and in environments not as greatly altered by human activity, changes also took place; but these changes were generally

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[3] B. Grant, D. F. Owen, and C. A. Clarke, "Decline of Melanic Moths," *Nature* 373 (1995), p. 565; and C. A. Clarke, B. Grant, F. M. M. Clarke, and T. Asami, "A Long Term Assessment of *Biston betulara* (L.) in One UK Locality (Caldy Common near West Kirby Wirral), 1959–1993, and Glimpses Elsewhere," *The Linnean* 10 (1994), pp. 18–26.

[4] L. M. Cook, B. S. Grant, I. J. Saccheri, and J. Mallet, "Selective Bird Predation on the Peppered Moth: The Last Experiment of Michael Majerus," *Biology Letters* 8 (August 23, 2012), pp. 609–612.

(a) (b)

Figure 1.10 Industrial Melanism The figure shows a light (a) and a dark (b) colored peppered moth (*Biston betularia*).

not as dramatic or rapid. Consequently, natural selection is usually a much slower and more subtle mechanism.

Evolution and Anti-Evolution Movements

On departing from Plymouth in 1831, the captain of the *Beagle*, Robert Fitzroy, presented Charles Darwin with a gift. That gift, a copy of the newly published first volume of what would be three volumes of *Principles of Geology* by Charles Lyell, influenced the development of Darwin's ideas and was the source of some heated debates between Darwin and Fitzroy, a religious fundamentalist. Had Fitzroy read the book, he might never have given it to Darwin.

After the voyage, Lyell became Darwin's friend. In 1859, Lyell recommended that a partial disclaimer of sorts be added to *On the Origin of Species*, one that would recognize the role of the "Creator" in evolution. The book was first published on November 24, 1859, with no disclaimer; it sold out its first printing that same day. *On the Origin of Species* became the focus of a controversy between those who believed in the divine creation of life (creationists) and those who believed in a natural origin of life (evolutionists).

"Creation-Science" Darwin's concept of natural selection has survived the scrutiny of 160 years of biological study to become one of the foundations of modern biological science. Yet for various reasons that lie outside the realm of science, there are those who feel that the concept of evolution must be disproved in favor of a creationist interpretation. In recent times creationists modified an old strategy. They labeled the concept of the divine creation of life a scientific view, and the term **creation-science** was born.

creation-science The idea that scientific evidence can be and has been gathered for creation as depicted in the Bible. Mainstream scientists, many religious leaders, and the Supreme Court discount any scientific value of "creation-science" statements.

Beginning early in the twentieth century, attempts were made by some state legislatures to mandate the teaching of creationism as an alternative explanation of the diversity of life. Some statutes actually outlawed the teaching of evolution. Perhaps one of the most famous of those laws was the Butler Act passed in 1925 by the Tennessee legislature. The legal challenge to this law was embodied in the Scopes trial, which is described in Box 1-2.

Creation-science advocates began to sue teachers and school districts to force them to teach creation-science alongside evolutionary theory. They also put pressure on publishers to deemphasize evolution in biology textbooks. Under such pressure, several states passed "balanced-treatment acts," which required that teachers present "scientific" evidence for creation along with the teaching of evolution. Because it ultimately came before the United States Supreme Court, the 1981 Balanced Treatment Act of Louisiana became one of the most

Box 1-2 The Scopes Trial

In the early part of the twentieth century many American theologians, as well as much of the public, had reconciled the concept of natural selection and evolution with their religious beliefs. Yet in some quarters there was still strong opposition to what was referred to as Darwinism. As the century progressed, opposition from religious institutions grew, and by the early 1920s, many southern states were considering legislation designed to remove the teaching of evolution from the public school curriculum and textbooks.

The growing opposition to Darwinism was a response to the growing influence of Christian fundamentalism in the United States. Author Richard Antoun describes fundamentalism in general "as an orientation to the modern world . . . that focuses on protest and change and on certain consuming themes: the quest for purity, the search for authenticity, totalism and activism, the necessity for certainty (scripturalism), selective modernization, and the centering of the mythic past in the present."[1]

In 1925, the state of Tennessee passed and signed into law the Butler Act. This was the strongest law up to that time, one that made the teaching of evolution illegal and subject to criminal prosecution. The American Civil Liberties Union (ACLU) quickly saw the danger of the Butler Act and similar proposed legislation to public education and science in the United States. The ACLU developed a simple strategy: create a test case in Tennessee where the defendant would be judged guilty, a foregone conclusion since the defendant would have taught evolution in the classroom in defiance of the law. They would then appeal the ruling to the Tennessee Supreme Court and then to the United States Supreme Court, where the law probably would be ruled unconstitutional. In 1925 the ACLU placed a notice in the *Chattanooga Times:* "We are looking for a Tennessee teacher who is willing to accept our services in testing this law in the courts. Our lawyers think a friendly test case can be arranged without costing a teacher his or her job. Distinguished counsel have volunteered their services."[2]

Soon thereafter a group of prominent citizens in the small town of Dayton decided that they could use a little publicity for the town and decided to offer up a test case. They recruited a young science teacher, John T. Scopes, a friend of one of the prosecuting attorneys. Scopes taught physics, math, and football but had substituted for an absent biology instructor, using a textbook that contained a chapter on evolution. John Scopes was quickly indicted by a special session of the grand jury and released without bond.

One of the most well-known proponents of anti-Darwinism laws was William Jennings Bryan. Bryan had entered Congress in 1890, where his charismatic speaking ability and stands on the issues of the day gave him the title the "Great Commoner." He was nominated as the Democratic candidate for president in 1896, 1900, and 1904. In 1912 he became President Woodrow Wilson's secretary of state, but he eventually resigned in protest of administration policies. Bryan remained in the public eye as an energetic and popular public speaker and author and soon became an important spokesman for the anti-evolution movement.

Always on the lookout for an issue to gain publicity, Bryan offered to join the team prosecuting John Scopes, even though he had not practiced law for 30 years. Seeing the opportunity for even more publicity for the town, the local prosecution attorneys readily accepted the offer. The noted defense attorney from Chicago Clarence Darrow offered to join the defense. Thus, what the ACLU hoped would be a simple test case whose main purpose was to provide a stepping-stone to a review of the Tennessee law by the Supreme Court had become the trial of the decade.

The trial began on July 10, 1925. Bryan's role was to give the closing argument, which he had carefully prepared and was to be one of his greatest speeches. He did not know that the defense planned to waive closing arguments and thereby prevent Bryan from delivering his speech.

The prosecution's case took about one hour to present as it was quickly established that Scopes had taught about evolution in the classroom. The defense began by calling the first of several scientists to testify about the validity of evolution. The prosecution objected: The trial was about whether Scopes had taught evolution, not about the validity of the law. The jury was dismissed while the first scientist was examined, after which the judge ruled that all evidence regarding the validity of the law was inadmissible and that the testimony of the scientists would not be presented to the jury.

Then came the most dramatic part of the trial as the defense called Bryan as an expert on the Bible. Bryan agreed to this over the objections of his fellow prosecutors, and the jury once again was sent out. It is generally conceded that Darrow got the better of Bryan, whose testimony was ruled inadmissible. Since the defense was not permitted to call its expert witnesses, Darrow asked the court to instruct the jury to find the defendant guilty, a task that took the jury nine minutes to accomplish. Scopes was fined $100.

During the following year the case was appealed to the Tennessee Supreme Court, which ruled the law to be constitutional. However, it also overturned the conviction on a technicality, thereby preventing the case from being appealed to the United States Supreme Court.

Largely because of the highly successful play and movie *Inherit the Wind*, a fictionalized account of the Scopes trial, the trial has entered the annals of American folklore. It served to articulate the growing rift between those who accept the principles of evolution and the creationists.

[1] Antoun, R. T., *Understanding Fundamentalism*: *Christian*, *Islamic and Jewish Movements*. Walnut Creek: AltaMira Press, 2001, 2.

[2] "Plan Assault on State Law on Evolution," *Chattanooga Daily Times*, May 4, 1925, 5.

Source: Larson, E. J., *Summer for the Gods*: *The Scopes Trial and America's Continuing Debate over Science and Religion*. Cambridge, MA: Harvard University Press, 1997.

important of those acts. On June 19, 1987, the Supreme Court, by a vote of 7 to 2, declared the Louisiana act, and therefore all others like it, unconstitutional.

Although many biologists believed that creation-science advocates had been dealt a coup de grâce to their legal battle to establish laws that would prohibit or cripple the teaching of evolution, creationists developed other strategies.[5] Between half a dozen and a dozen bills are introduced in state legislatures each year designed to permit teachers in public schools to teach Bible-based concepts on the origins of the earth and living organisms. Many countries ban the teaching of evolution in their schools. In 2017, Turkey, which previously allowed evolution to be taught in their public schools, banned it from being taught.

Intelligent Design Today, the battleground has shifted away from "creation-science" to an approach called **intelligent design (ID) theory**. Modern ID theory is a new version of an old idea that preceded the publication of *On the Origin of Species* by over half a century. In 1802, Reverend William Paley (1743–1805) published *Natural Theology: Evidences of the Existence and Attributes of the Deity*, *Collected from the Appearances of Nature*. Paley argued that one would have to conclude that something as complex as a watch had to have been made by a watchmaker intent on making a watch. By analogy, life, which is much more complex than any watch, also must have been made by some intelligent force intent on creating life.

intelligent design (ID) theory An essentially religious explanation of the world that assumes the existence of a supernatural force that is responsible for the great complexity of life on earth today.

Although there is some variation in its presentation, proponents of ID theory appear to be willing to accept a long history of life on earth and the operation of some evolutionary processes, but only the evolution of small changes over short periods of time. Although disguised as a scientific alternative to evolution, ID predicates the existence of a supernatural force—the designer—who is responsible for the great complexity of life on earth today. And that intelligent force, the designer, was God. Because of its reliance on a supernatural or divine power, it is essentially a religious and not a scientific explanation. (However, some advocates for ID say that it is not a religious idea because the designer may have been not God but an alien life form.)

The core idea of ID theory is that the great complexity of structure and biochemical and physiological processes found in living organisms cannot be explained on the basis of the natural process of evolution. Of course one may argue that the lack of a natural explanation refers to our present ignorance, and those seemingly complex processes in living organisms will someday be understood, just as other ideas were considered to be unknowable in the past. To answer this argument, ID proponents have introduced the concept of **irreducible complexity**. This refers to processes that are so complex that they could not have arisen step by step as postulated by an evolutionary interpretation. This is seen by the "fact" that if one takes away any element of the process, the whole process fails to function.

irreducible complexity Concept that there exist processes and structures that are too complex to have arisen through evolutionary mechanisms but must have arisen by work of a "designer."

Well before the current evolution–ID debate, Charles Darwin addressed this issue. The human eye is a very complex organ. Yet Darwin pointed out that early predecessors to the human eye and other complex eyes—those without lenses, for example—might have simply helped animals position themselves in relationship to light. Modern scientists have found such primitive light-sensing organs in living animals as well as in fossil organisms that appear to represent what might also have been transitional forms to the modern complex eye.

Evolutionary biologists also point out that many complex biological systems exhibit major imperfections or design flaws that should not be present if a divine intelligence were responsible for that design. Design flaws can best be explained as the natural outcome of gradual modification through time through natural selection rather than as the handiwork of a divine force. One example of such a design flaw is the fact that the retina of the human eye is constructed with blood vessels and nerve fibers overlaying the surface that receives the light, so that light

[5] See The National Center for Science Education (NCSE) website at: http://ncse.com/.

Box 1-3 Kitzmiller v. Dover Area School District

Following are extracts from the judge's ruling in *Kitzmiller v. Dover Area School District* (December 20, 2005):

> The proper application of both the endorsement and Lemon tests to the facts of this case makes it abundantly clear that the Board's ID [Intelligent Design] Policy violates the Establishment Clause. In making this determination, we have addressed the seminal question of whether ID is science. We have concluded that it is not, and moreover that ID cannot uncouple itself from its creationist, and thus religious, antecedents
>
> Both Defendants and many of the leading proponents of ID make a bedrock assumption which is utterly false. Their presupposition is that evolutionary theory is antithetical to a belief in the existence of a supreme being and to religion in general. Repeatedly in this trial, Plaintiffs' scientific experts testified that the theory of evolution represents good science, is overwhelmingly accepted by the scientific community, and that it in no way conflicts with, nor does it deny, the existence of a divine creator
>
> To be sure, Darwin's theory of evolution is imperfect. However, the fact that a scientific theory cannot yet render an explanation on every point should not be used as a pretext to thrust an untestable alternative hypothesis grounded in religion into the science classroom or to misrepresent well-established scientific propositions
>
> The citizens of the Dover area were poorly served by the members of the Board who voted for the ID Policy. It is ironic that several of these individuals, who so staunchly and proudly touted their religious convictions in public, would time and again lie to cover their tracks and disguise the real purpose behind the ID Policy
>
> With that said, we do not question that many of the leading advocates of ID have bona fide and deeply held beliefs which drive their scholarly endeavors. Nor do we controvert that ID should continue to be studied, debated, and discussed. As stated, our conclusion today is that it is unconstitutional to teach ID as an alternative to evolution in a public school science classroom
>
> Those who disagree with our holding will likely mark it as the product of an activist judge. If so, they will have erred as this is manifestly not an activist Court. Rather, this case came to us as the result of the activism of an ill-informed faction on a school board, aided by a national public interest law firm eager to find a constitutional test case on ID, who in combination drove the Board to adopt an imprudent and ultimately unconstitutional policy. The breathtaking inanity of the Board's decision is evident when considered against the factual backdrop which has now been fully revealed through this trial. The students, parents, and teachers of the Dover Area School District deserved better than to be dragged into this legal maelstrom, with its resulting utter waste of monetary and personal resources.

Source: https://ncse.com/files/pub/legal/kitzmiller/highlights/2005-12-20_Kitzmiller_decision.pdf

that enters the eye must pass through these structures before hitting the retina. The passage of these nerves through the retina to the optic nerve on the back side of the retina results in a blind spot.

More recently the idea of ID went on trial over an action taken by the Dover, Pennsylvania, School Board. The board passed a rule that a statement describing evolution as "only a theory" had to be read at the start of all ninth-grade science classes. Information about "alternative theories" was made available. Several parents sued, and the ruling in the case of *Kitzmiller v. Dover Area School District* (2005) made the strong case that ID is not science and does not belong in the science classroom. A portion of the judge's ruling is reproduced in Box 1-3. Table 1.1 summarizes the most important court cases involving creationism.

Table 1.1 The Legal Landscape

***The State of Tennessee v. John Thomas Scopes* (1925)**
John Scopes was found guilty of teaching evolution in violation of the Butler Act. The decision was reversed on a technicality by the Tennessee Supreme Court.

***Epperson v. Arkansas* (1968)**
The Supreme Court found that Arkansas's law prohibiting the teaching of evolution was unconstitutional because the motivation was based on a literal reading of Genesis, not science.

***McLean v. Arkansas* (1982)**
A federal judge found that Arkansas's "balanced treatment" law mandating equal treatment of creation-science with evolution was unconstitutional.

***Segraves v. California* (1981)**
A California judge ruled that teaching evolution in public school science classes does not infringe upon the rights of any students or parents to the free exercise of their religion, even if they sincerely believe that evolution is contrary to their religious beliefs.

***Edwards v. Aguillard* (1987)**
The Supreme Court invalidated Louisiana's "Creationism Act" because it violated the Establishment Clause of the Constitution.

***Webster v. New Lenox School District* (1990)**
The Seventh Circuit Court of Appeals ruled that school boards have the right to prohibit teaching creationism because such lessons would constitute religious advocacy and, hence, such restrictions do not constitute an infringement on a teacher's free speech rights.

***Peloza v. Capistrano Unified School District* (1994)**
The Ninth Circuit Court of Appeals decided that a teacher does not have a right to teach creationism in a biology class, that "evolutionism" is not a religion or worldview, and that the government can restrict the speech of employees while they are on the job.

***Freiler v. Tangipahoa Parish Board of Education* (1999)**
The Fifth Circuit Court of Appeals found that a disclaimer to be read before teaching about evolution ultimately had the effect of furthering religious interests and was therefore unconstitutional.

***LeVake v. Independent School District* (2001)**
A federal district court finds that a school may remove a teacher from teaching a biology class when that teacher, a creationist, cannot adequately teach evolution.

***Kitzmiller v. Dover Area School District* (2005)**
The Dover, Pennsylvania, School Board voted to require ninth-grade science teachers to read a statement about intelligent design in class. The judge ruled against the board, stating that intelligent design is not science.

***Hurst v. Newman* (2006)**
Eleven parents at Frazier Mountain High School in Lebec, California, filed suit in federal district court to force cancellation of a high school elective course called "Philosophy of Design." Parents contend that the course, taught by the wife of an Assembly of God pastor, was essentially a religiously motivated course advocating "intelligent design." The school district cancelled the class and the suit was dropped.

Association of Christian Schools International v. Stearns et al.
In 2005, the ACSI and six students at the Calvary Chapel Christian School in Murrieta, California, filed a lawsuit against the University of California (UC). The UC had rejected some of the high school biology classes at the school as fulfilling the college prep requirement for admission to the UC. The courses used a well-known creationist textbook in their biology course which the UC stated was "inconsistent with the viewpoints and knowledge generally accepted in the scientific community." The plaintiffs claimed that this policy violated their rights to "freedom of speech, freedom from viewpoint discrimination, freedom of religion and association. . ." In 2006, a Federal judge ruled in favor of the University. The decision was upheld by the Ninth Circuit Court of Appeals in 2008. The Supreme Court declined to review the case in 2010.

Source: Based on "Ten Significant Court Decisions Regarding Evolution/Creationism," *National Center for Science Education*, www.ncseweb.org.

Summary

Evolutionary theory has been shown to be a valid and reliable explanation of basic questions about life. Modern evolutionary theory grew out of a European intellectual climate. Before the nineteenth century, most Europeans saw humans as the superior center of a world populated by spontaneously created organisms that did not change once created. Each of these ideas fell in the light of new knowledge gathered by hundreds of scholars, including Copernicus, Linnaeus, Buffon, Lamarck, Lyell, Boucher de Crèvecoeur de Perthes, Darwin, Wallace, and Mendel. Central to modern evolutionary theory is the concept of natural selection. Natural selection can be observed and measured by scientists as demonstrated by the peppered moth example described in this chapter. Darwin's concept of natural selection has fused with Mendel's concept of genetics; to this mixture new ingredients continue to be added, including concepts about the genetics of populations. Also, ideas of what embryos, fossils, and animal behavior can tell us about the past have become part of what is called the synthetic theory of evolution. Yet, with all of the scientific facts that have accumulated over the years from numerous fields of study, creationists, to varying degrees, continue to envision the world in a way similar to the way Europeans did before the Age of Exploration.

Key Terms

Study Questions

1. The development of the modern concept of evolutionary theory was part of the general changes that were occurring in Western society from the fifteenth through nineteenth centuries. How were such historical events as the discovery of North America and the American Revolution related to the development of the theory of evolution?
2. What were some of the concepts about human nature and the relationship between humans and nature that had to change before an evolutionary concept could develop?
3. How does the idea of "catastrophism" differ from Darwin's concept of natural selection?
4. Who were some of the scholars who contributed to the development of evolutionary ideas? What did each contribute to that development?
5. Darwin, Wallace, and other naturalists of the nineteenth century did not have an accurate notion of one aspect of modern evolutionary theory. What element of modern theory was missing from their writings? Who began to provide accurate analyses of this missing element?

6. Many anti-evolutionists believe that since science does not have answers for all questions, scientific conclusions are not necessarily correct. This attitude reflects a failure to understand the nature of science. What is the general nature of scientific thinking? In what way is science "self-correcting"?
7. In what way does a scientific statement differ from a doctrine?

Critical Thinking Questions

1. One of the criticisms levied against evolution is that no one has ever seen one kind of animal evolve into another. Although natural selection has been seen to occur in a small-scale situation, such as the case of the dark and light peppered moths, the time frame for the evolution of new species is far greater than the human life span. However, it is possible to infer the evolutionary history of living species by using facts of anatomy, DNA analysis, and the fossil record. We make conclusions as to facts from inference all the time in our normal, everyday activities. Give some examples.
2. The development and acceptance of evolutionary theory in the nineteenth century was very much a product of the political, economic, and intellectual changes of that time. Discuss how the development of the industrial revolution set the stage for the development and acceptance of the concept of evolution.
3. Scientific thinking is based on the application of the scientific method of empirical observation and experimentation to formulate ideas about reality. Religion is generally based on the acceptance of ideas based on faith found in religious writings and the interpretations made by religious practitioners. Do you think that there is any possibility of a philosophical combination of science and religion into one concept of reality?

Suggested Readings

Dawkins, R. *The Greatest Show on Earth: The Evidence for Evolution*. New York: Free Press, 2009. Richard Dawkins presents a very detailed, yet highly understandable, explanation of evolution.

Desmond, A., and J. Moore. *Darwin's Sacred Causes: How a Hatred of Slavery Shaped Darwin's Views on Human Evolution*. Boston: Houghton Mifflin, 2009. This book proposes that a driving force behind many of Darwin's ideas was his opposition to slavery.

Giere, R. N., J. Bickle, and R. F. Mauldin. *Understanding Scientific Reasoning*, 5th ed. Belmont, CA.: Wadsworth, 2006. This book explains scientific thinking by using examples of scientific discoveries and everyday events.

Mayr, E. *What Evolution Is*. New York: Basic Books, 2001. This is an introduction to evolution by one of the most important evolutionary biologists of the twentieth century.

Pennock, Robert T. *Tower of Babel: The Evidence against the New Creationism*. Cambridge, MA: MIT Press, 1999. Philosopher Robert Pennock explores and critiques the ideas of creationism.

Raby, P. *Alfred Russel Wallace: A Life*. Princeton, NJ: Princeton University Press, 2001. A biography of the other naturalist who developed the idea of natural selection.

Rayan, A. S. *A Guide to Careers in Physical Anthropology*. Westport, CT: Bergin & Garvey, 2002. Each chapter, written by someone in the field, discusses various careers pursued by physical anthropologists.

Scott, E. C. *Evolution vs. Creationism*, 2nd ed. Berkeley, CA: University of California Press, 2009. The executive director of the National Center for Science Education surveys the evolution versus creationism controversy.

In addition to books, the following journals and magazines consistently feature materials useful to physical anthropology students. The following are popular magazines:

American Scientist, *Archaeology*, *BioScience*, *Discover*, *National Geographic*, *Natural History*, *Science News*, *Scientific American*, *Smithsonian*, *Wired*

The following are scientific journals:

American Anthropologist, *American Journal of Human Biology*, *American Journal of Physical Anthropology*, *American Journal of Primatology*, *Annals of Human Biology and Human Ecology*, *Current Anthropology*, *Evolutionary Anthropology*, *Human Biology*, *Human Evolution*, *Journal of Animal Behavior*, *Journal of Forensic Science*, *Journal of Human Evolution*, *Nature*, *Science*

Suggested Websites

Many of the magazines and journals listed previously have websites. In addition, there are numerous science websites that are not attached to printed sources. They include:
www.sciencedaily.com
www.livescience.com
https://www.eurekalert.org

You might also find the following websites useful:

About Darwin:
www.aboutdarwin.com

American Anthropological Association:
www.aaanet.org

History of evolutionary theory from the University of California Museum of Paleontology:
www.ucmp.berkeley.edu/history/evolution.html

The TalkOrigins Archive Exploring the Creation/Evolution Controversy:
www.talkorigins.org

The writings of Charles Darwin on the Web:
http://darwin-online.org.uk/

The National Center for Science Education:
http://ncse.com/

Chapter 2

The Study of Heredity

As many more individuals of each species are born than can possibly survive; and as, consequently there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be *naturally selected*. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form. •

—Charles Darwin (1809–1882)[1]

Chapter Outline

The Study of Heredity
The Work of Gregor Mendel
An Overview of Mendelian Genetics
Human Blood-Type Systems
Mendelian Genetics in the Twenty-First Century
Summary

Cytogenetics
The Chromosomes
Cell Division
Reexamining Mendelian Genetics
Summary

The Molecular Basis of Heredity
Proteins
Deoxynucleic Acid
The Genetic Code
Protein Synthesis
Summary

After Reading This Chapter, You Should Be Able to Answer These Questions:

1. In what ways did Gregor Mendel's work disprove the blending theory of inheritance and the concept of pangenesis?
2. What are the principle of segregation and the principle of independent assortment?
3. Are all traits determined completely by inheritance? If not, what other factor might be involved in the expression of a trait?
4. What role do chromosomes play in inheritance?
5. What are the two types of cell division, and what does each one accomplish? How does the process of cell division differ in the two types?
6. In what ways does knowledge of cell division help explain Mendel's findings? In what ways does knowledge of cell division explain why Mendel's principles do not always work in the way he predicted?
7. What is the structure of the genetic material?
8. How does knowledge of the structure of DNA and RNA help us understand the nature of inheritance and the way proteins are manufactured?

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[1] Darwin, C., *On the Origin of Species or the Preservation of Favoured Races in the Struggle for Life*. London: John Murray, 1859, 4–5.

The latter half of the nineteenth and the early twentieth centuries saw the rise of major advances in the understanding of the natural world. One of the most significant ideas was natural selection, proposed by Charles Darwin in his book *On the Origin of Species* published in 1859 (Chapter 1).

Natural selection can be thought of in terms of reproductive success. It's all about the number of offspring an individual produces. In order to maximize reproductive success an individual must survive to reproductive age, maximize the number of matings, and maximize the number of successful births of offspring that will survive to adulthood so that they may reproduce in turn.

In order to achieve these goals an animal must find and process an adequate amount of food and water, stay healthy, avoid predators, find mates, and be lucky. Survival is difficult, and in most animal populations only some of the individuals born actually survive and reproduce. But on the average, individuals who are healthy and best equipped to survive environmental challenges have a better chance of reproducing than other individuals in the group.

Individuals in a population vary in their physical characteristics and behavior. These differences are reflected in which individuals survive and reproduce and which do not. And much of this variability is inherited. Those inherited traits that are found in the more successful individuals will be passed on to the next generation in greater numbers than those inherited traits that are found in less successful individuals. Therefore, the next generation will contain a higher proportion of inherited traits from the more successful individuals.

blending theory An early and incorrect idea that the inherited characteristics of offspring are intermediate between maternal and paternal genetic characteristics.

pangenesis Discredited idea that particles throughout the body that can be influenced by the activities of an organism move to the reproductive organs and modify the sex cells in a way that acquired characteristics can be passed on to the next generation.

THE STUDY OF HEREDITY

Charles Darwin recognized the important role that heredity plays in natural selection. But he and other scientists of his time did not fully understand how heredity actually worked. One early attempt at explaining family resemblances was the simple idea that hereditary units merge as one might mix two colors of paint. This is known as the **blending theory**. If such were the case, traits would be irreversibly changed from generation to generation and would not persist. For example, red paint mixed with white paint yields pink, but both the red and the white colors cease to exist. Neither the red nor the white color can be reconstituted from the pink. However, in living organisms it is quite common for a trait, such as red hair color, for example, to disappear in one generation and reappear again in a future generation.

In 1868, Darwin proposed a mechanism of heredity called **pangenesis**. He believed that particles present in the body were influenced by activities of the organism throughout its life. These particles traveled to the reproductive organs. There they modified the ova and sperm in such a way that the acquired characteristics of the individual organism could now be passed on to the next generation. This hypothesis did not survive.

Much of the nineteenth-century interest in genetics revolved around the study of human characteristics. However, the study of human heredity is many times more difficult to study than the study of heredity in other organisms. This is perhaps the main reason so many early biologists failed to discover the underlying principles of genetics.

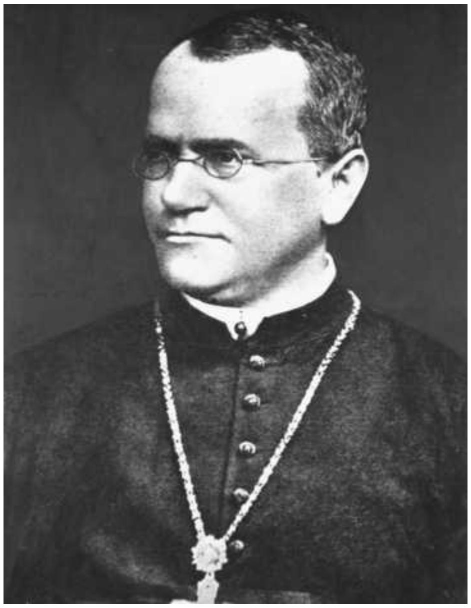


Figure 2.1 Gregor Mendel (1822–1884)
In 1865, Gregor Mendel presented two lectures before the Natural Science Society of Brünn. Those lectures, published in the following year, presented his conclusions from his experiments with pea plants.

The Work of Gregor Mendel

It is not surprising that the breakthrough in the understanding of heredity took place outside the arena of human genetics. In 1865, a monk by the name of Gregor Mendel (1822–1884) wrote about the principles of heredity (Figure 2.1).

Gregor Mendel's insights into how heredity worked were the result of a farmer's son's interest in horticulture and the development of new hybrids for horticultural purposes. Because he was of humble origins, Mendel's only opportunity to get an education was to join the church. He became a monk at a monastery in Brünn, in what is now Brno, Czech Republic. Mendel's order encouraged teaching and research, and when it became apparent after his ordination that his skills as a parish priest were limited, the abbot of the monastery encouraged Mendel to further his education at the university in Vienna. His science education was well rounded and included work in mathematics. Perhaps it was his mathematical view of the world that led Mendel to see in his data things that others of that time failed to see.

Mendel began his work on pea plant hybridization in 1856, a task that lasted eight years. At the conclusion of his experiments, Mendel presented two lectures to the Natural Science Society of Brünn on February 8 and March 8, 1865. They were subsequently published in 1866 in the proceedings of the society. His heavy use of mathematics would have deterred all but the most motivated reader. It wasn't until the start of the twentieth century that his conclusions were rediscovered along with the record of his experiments and conclusions.

An Overview of Mendelian Genetics

Gregor Mendel selected the pea plant because the structure of the flower was such that he could control fertilization easily. Mendel chose seven contrasting pairs of characteristics of the common pea plant: shape of ripe seed (round or wrinkled), color of seed albumen (variation of yellow or green), color of seed coat (white or gray), shape of ripe pod (smooth or wrinkled), color of unripe pod (green or yellow), position of flowers (distributed along the main stem or bunched at the end of the stem), and length of stem (tall or dwarf). The color of the seed coat is associated with the color of the flower: the white seed coat with white color and the gray seed coat with violet color. Using as large a sample as possible to eliminate chance error, he observed each pea plant separately and kept the different generations apart. The results were quantified and expressed as ratios.

In the first series of experiments, Mendel started with **true-breeding** plants. These are plants that have been bred only with plants of the same kind and show the same traits over many generations. For example, Mendel cross-pollinated true-breeding plants that produced only violet flowers with true-breeding plants that produced only white flowers. Those original plants made up the parental, or P_1, generation.

true-breeding Showing the same traits without exception over many generations.

Next, Mendel grew plants from the seeds produced by the parental plants. These were plants of the first filial, or F_1, generation. He observed that plants of the F_1 generation produced only violet flowers; he observed no white flowers or flowers of intermediate color, such as pink. These F_1 plants are termed **hybrids**. The hybrid plant produced violet flowers, as did one of the parental plants, yet it differed from the true-breeding parents in having one parent that produced flowers unlike its own, in this case white.

hybrids Individuals that are the result of a cross or mating between two different kinds of parents.

Mendel then allowed the hybrids to self-pollinate to produce the next generation, called F_2. In this generation, he found that some plants produced violet flowers, while others produced white flowers. When he counted the number of plants showing each trait, he found that approximately three-fourths of the plants bore violet flowers, while one-fourth bore white flowers. As we saw, the F_1 hybrid plants bore violet flowers only, although these plants had parents with white flowers. When the F_1 generation was self-pollinated, some of the offspring had white flowers. The trait that is seen in the hybrid is said to be **dominant**. The trait that is not seen, yet can be passed on in a later cross, is termed **recessive**. Mendel noted that violet flowers, tallness, and smooth seeds were dominant features, while white flowers, dwarfness, and wrinkled seeds were recessive.

dominant The trait that is seen in the hybrid is said to be dominant.

recessive The trait that is not seen in the hybrid is said to be recessive.

The fact that the F_1 generation produced *only* violet flowers and the F_2 generation produced violet *and* white flowers showed that the blending theory was erroneous. No plant with pink flowers appeared in the F_1 generation, and in the F_2 generation white flowers reappeared. This confirmed the fact that the genetic unit for white flower color had not blended but had persisted without having been altered in any way.

A Model of Genetic Events A **model** is a representation of an object or an ideal. It is a simplified representation of a real-world phenomenon. Models help us test hypotheses, make predictions, and see relationships. The model may be a diagrammatic representation of some phenomenon,

model A representation of a phenomenon on which tests can be conducted and from which predictions can be made.

a statistical description, or a mathematical formula. For example, the mathematical formula $A = \pi r^2$ allows us to predict exactly how a change in the radius of a circle will affect the area of that circle.

Models act as summaries of the known characteristics of a phenomenon. They provide a means of testing hypotheses about the phenomenon by measuring the effect of one element (variable) of the model on other elements. Mendel was not aware of the physical or chemical realities of the hereditary mechanism, but he did develop a model to explain what he had observed.

Principle of Segregation Mendel concluded that the hereditary factors exist as discrete pairs, and each factor can exist in several varieties. In the formation of the sex cells of plants—pollen and ova—the paired hereditary factors separate, forming sex cells that contain either one factor or the other. For example, the factor that controls the color of the flower exists in two forms, one responsible for violet flowers and the other responsible for white flowers. These hereditary factors were named **genes** in 1906. There exists a gene that controls flower color. Variants of a particular gene are referred to as **alleles**. If a plant contains one of each allele, one for violet and one for white, the paired alleles will separate during the process of sex cell production, forming sex cells with either one allele for violet or one allele for white, but not both. This is now known as the principle of **segregation**.

gene A sequence of base pairs in the DNA molecule that codes for a specific protein.

alleles Alternative forms of a gene.

segregation In the formation of sex cells, the process in which paired hereditary factors separate, forming sex cells that contain either one or the other factor.

Thus, Mendel reasoned that in the parental generation, the violet-flowered plant produces sex cells that carry the allele for violet flowers only, while the white-flowered plant produces sex cells that carry the allele for white flowers only. The hybrid develops from the union of two sex cells, one carrying the allele for violet color and one carrying the allele for white color. The hybrid therefore contains a pair of alleles—one for violet color and the other for white. Why, then, is the flower on the hybrid plant not pink, a mixture of violet and white? Mendel reasoned that in this case only one of the alleles—that for violet color—is seen in the hybrid, while the other—that for white color—is not. The one that is seen in the hybrid is said to be dominant; the one that is not seen is said to be recessive.

When the hybrid produces sex cells, the two units segregate, producing sex cells of two types. Half the sex cells carry the allele for violet flowers, while the other half carries the allele for white flowers. When fertilization takes place, four different combinations may occur in the new plants. Some F_2 plants may inherit two alleles for violet flowers; others may inherit two alleles for white flowers; and still others may inherit one allele for violet flowers and one allele for white flowers (this last combination can occur in two ways: violet–white or white–violet). Since the violet–violet, violet–white, and white–violet combinations all produce violet flowers, three out of every four plants yield violet flowers. Only the white–white combination (one out of every four plants) produces white flowers. This experiment is illustrated in Figure 2.2.

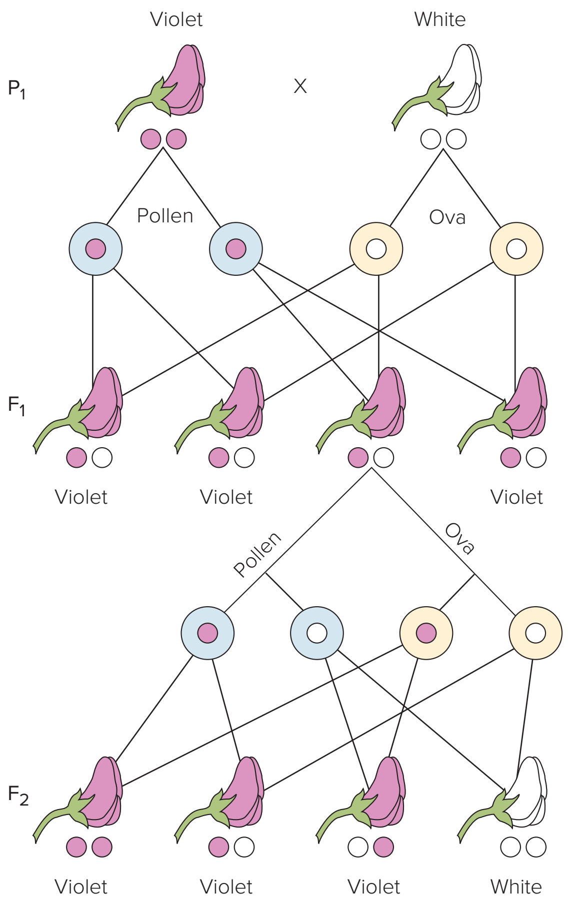


Figure 2.2 Segregation In the formation of sex cells, the hereditary factors separate, forming sex cells that contain either one factor or the other. Individual sex cells combine at fertilization, producing new combinations of hereditary units.

Principle of Independent Assortment Mendel next studied the simultaneous inheritance of more than one trait. For example, he crossed a normal-stature (tall) plant bearing violet flowers with a dwarf plant bearing white flowers. The F_1 hybrid was a tall plant with violet flowers. When the F_1 hybrids were crossed, four distinct types of offspring resulted: tall plants with violet flowers, tall plants with white flowers, dwarf plants with violet flowers, and dwarf plants with white flowers, with the frequencies of $9/16$, $3/16$, $3/16$, and $1/16$, respectively. The explanation for these results is seen in Figure 2.3.

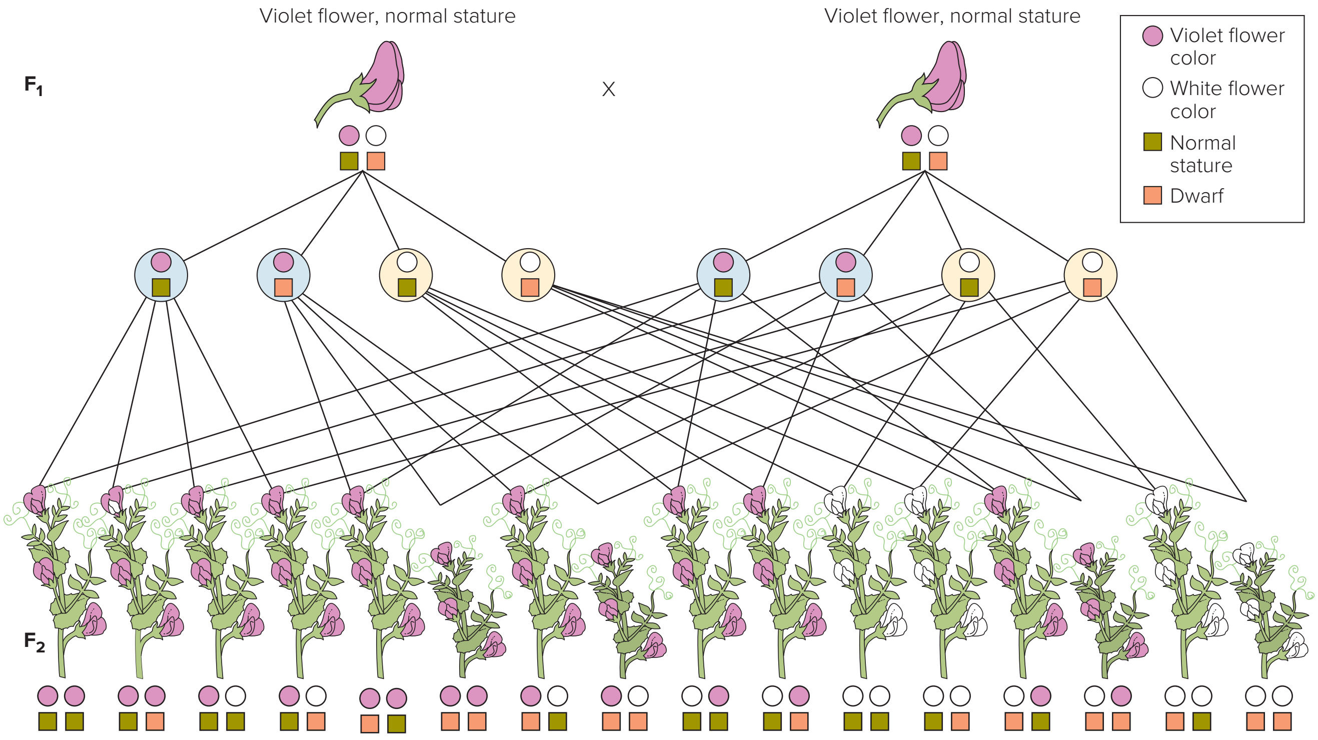


Figure 2.3 Independent Assortment The inheritance of flower color is independent of the inheritance of stature. Since the hereditary factors for flower color segregate independently of those for stature, four different kinds of sex cells are produced. These sex cells will combine at random into 16 different genotypes in the offspring.

From these data, Mendel formulated the principle of **independent assortment**, which states that the inheritance patterns of differing traits are independent of one another. Whether a plant is tall or dwarf is unrelated to whether that plant bears violet or white flowers.

independent assortment A Mendelian principle that states that differing traits are inherited independently of each other.

Human Blood-Type Systems

In 1900, the same year Mendel's experiments were being rediscovered, Karl Landsteiner (1868–1943) at the University of Vienna discovered the existence of important differences among red blood cells. These differences are due to variations found in particular molecules located on the surface of the red blood cells. These variations are the basis of the ABO blood-type system. Many different molecules in many different forms can be found on red blood cells. Such molecules are said to be **polymorphic**, from *poly*, meaning "many," and *morph*, "structure."

polymorphic The presence of several distinct forms of a gene or trait within a population.

Through blood transfusions and occasional mixing of maternal and fetal blood at birth, molecules can be introduced into the blood of a person whose blood naturally lacks them. The body reacts to these foreign molecules by producing or mobilizing **antibodies**, whose role is to destroy or neutralize foreign substances that have entered the body. An entity that triggers the action of antibodies is known as an **antigen**. An antigen can be a toxin, foreign protein, or bacterium. Antigen–antibody reactions are of great medical significance and help define differences in blood proteins that exist in humans.

antibodies Proteins manufactured by the body to neutralize or destroy an antigen.

antigen A substance that stimulates the production or mobilization of antibodies. An antigen can be a foreign protein, toxin, bacterium, or other substance.

The ABO Blood-Type System The best-known set of blood antigens is the **ABO blood-type system**. This system consists of two basic antigens, which are called simply antigens A and B. The antigens are large molecules found on the surface of red blood cells. Other antigens do exist in the system, and the actual situation is more complex than is presented here.

ABO blood-type system A blood-type system that consists of two basic antigens, A and B. Blood type O is the absence of both antigens.

multiple alleles A situation in which a gene has more than two alleles.

codominant When two different alleles of the same gene are present, both alleles are expressed in the phenotype.

genotype The genetic constitution of an individual.

agglutination A clumping together of red blood cells in the presence of an antibody.

Rh blood-type system A blood-type system consisting of two major alleles. A mating between an Rh^- mother and an Rh^+ father may produce the hemolytic disease erythroblastosis fetalis in the infant.

There are four types in the ABO system, depending on which antigens are present. Type A indicates the presence of antigen A, while type B shows the presence of antigen B. Type AB indicates the presence of both antigens; type O indicates the absence of both antigens. In our examples of flower color in pea plants we dealt with two alleles. However, **multiple alleles** frequently occur.

The inheritance of ABO blood types involves three alleles, which we will write as I^A, I^B, and *i*. Two of these alleles are dominant with respect to *i*: I^A results in the production of the A antigen, and I^B in the production of the B antigen. In relationship to each other, alleles I^A and I^B are said to be **codominant** in that an I^AI^B individual produces both antigens. The allele *i* is recessive and does not result in antigen production. These combinations of alleles make up a person's **genotype**.

The ABO system is unusual in that the antibodies are present before exposure to the antigen. Thus, type A individuals have anti-B in their blood and type B individuals have anti-A. Furthermore, an AB individual has neither antibody, while an O individual has both. The various genotypes and phenotypes are summarized in Table 2.1.

Because of the presence of antibodies in the blood, blood transfusions can be risky if the blood is not accurately typed and administered. If, for example, type A blood is given to a type O individual, the anti-A present in the recipient's blood will agglutinate all the donor's type A cells entering the recipient's body. **Agglutination** refers to a clumping together of red cells, forming small clots that may block blood vessels.

Table 2.2 shows the consequences of various types of blood transfusions. Blood type O often is referred to as the universal donor because the entering O cells lack antigens of this system and therefore cannot be agglutinated. However, type O blood does contain anti-A and anti-B, which can cause damage in an A, B, or AB recipient. Although such damage is minimal, since the introduced antibodies become diluted and are rapidly absorbed by the body tissues, the safest transfusions are between people of the same blood type.

Other antigens exist on red blood cells that are determined by separate genes. A well-known example is the **Rh blood-type system**, described in Box 2-1.

Table 2.1 Phenotypes and Genotypes of the ABO Blood-Type System

Type	Antigen	Antibody	Genotype
A	A	Anti-B	I^AI^A, I^Ai
B	B	Anti-A	I^BI^B, I^Bi
O	—	Anti-A, Anti-B	*ii*
AB	A, B	—	I^AI^B

Table 2.2 Results of Blood Transfusions

	Donor			
Recipient	A	B	O	AB
A	−	+	(+)	+
B	+	−	(+)	+
O	+	+	−	+
AB	(+)	(+)	(+)	−

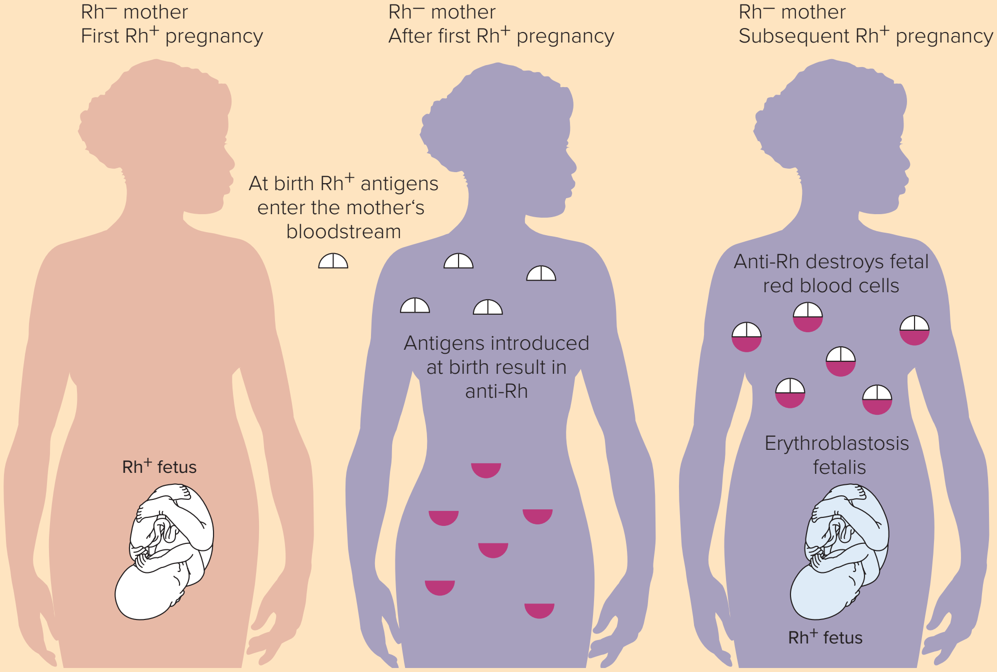
+ indicates heavy agglutination of donor's cells. (+) indicates no agglutination of donor's cells, but antibodies in donor's blood may cause some agglutination of recipient's cells. − indicates no agglutination of donor's or recipient's cells.

Box 2-1 The Rh Blood-Type System

There are many blood-type systems other than the ABO that are inherited independently from one another. A well-known example is the Rh blood-type system that is a great deal more complex than the ABO system. This blood-type system is also polymorphic and has multiple alleles, resulting in many antigens. However, here we will discuss only one of the antigens in this system, Rh_0. The inheritance of Rh blood type and that of ABO blood type are independent of one another, an example of independent assortment.

In the United States and Europe, a problem arises with respect to the antigen, Rh_0. About 15 percent of the population lack this antigen. These individuals, who are homozygous recessive, are said to be Rh-negative (Rh–).

Although Rh compatibility can cause problems in transfusion, it is of greater interest as the cause of **erythroblastosis fetalis**, a hemolytic (blood-cell-destroying) disease affecting 1 out of every 150 to 200 newborns. The problem occurs when an Rh-negative mother carries an Rh-positive fetus. At birth, Rh antigens in the fetal blood can mix with the maternal blood, causing the production of the antibody anti-Rh in the mother's blood. Although the first few pregnancies usually do not present any danger to the fetus, eventually the anti-Rh levels in the mother's blood become fairly high. At this point, if the anti-Rh comes into contact with the fetal bloodstream, it can cause destruction of the fetal blood cells. Today the development of anti-Rh antibodies can be prevented medically.



Mendelian Genetics in the Twenty-First Century

erythroblastosis fetalis A hemolytic disease affecting unborn or newborn infants caused by the destruction of the infant's Rh+ blood by the mother's anti-Rh antibodies.

The modern study of genetics dates from the year 1900. In that year three European scientists independently "rediscovered" Mendel's principles. This led to an explosion of research in genetics using laboratory animals, perhaps the most important being the fruit fly.

Researchers began to search for examples of human traits that behaved as the Mendelian rules predicted. Several were identified and for many generations high school and college students were subjected to checking out their ability to roll their tongue, taste PTC, bend their thumbs, as well as checking off their hair and eye color, and so on. However, it is now apparent that in reality very few human traits, perhaps less than 1 percent, follow the Mendelian rules. This is not because Mendelian genetics is incorrect; it is just that heredity is far more complex than the early geneticists realized.

Imagine a person standing before you. You can describe the physical reality of this individual in many ways. You can describe the physical features that you see before you; you can take a set of measurements of the body; you can analyze the person's blood urine, or body tissues through laboratory tests; you can study x-rays and various scans; and so on. The total physical

phenotype The observable and measurable characteristics of an organism.

trait One aspect of the phenotype.

environment Everything external to the organism.

incomplete penetrance Situation where individuals possess an allele for a particular trait, but the trait is not seen in a proportion of individuals.

reality of an individual is that person's **phenotype**. The phenotype of any organism is everything that you can describe and measure. A particular aspect of the phenotype is called a **trait**.

What determines an individual's phenotype? Actually it's the interaction of a great many factors. To a great extent one's phenotype results from the interaction of the genotype and the **environment**. Environmental factors play a very important role and include food and water, disease factors, parental care, climate, and a person's life experiences.

The problem is that in the past researchers often tended to think in terms of one gene-one trait. They often compile lists of traits and assign a gene for each. However, geneticists now know that this is generally not accurate. The vast majority of traits are the result of the interactions of a great many genes; and any particular gene affects a great many traits. This often results in a range of variation as we see in such traits as stature and skin color. It is actually extremely rare to find a specific trait that is determined by a single gene. The major exceptions are some of the genetic disorder that we will examine in Chapter 3.

People have a tendency to create dichotomies. Mendel did this when he defined flower color as white or violet, peas as smooth or wrinkled, and so on. This way of thinking tends to mask small but very real variation. True dominance is actually an extremely rare state. Most genes exist in a variety of forms or alleles, and the expression of a particular gene, that is how that gene is seen in the phenotype, is usually quite variable. In addition, the expression of one gene is often affected by the action of other genes and environmental factors. And sometimes the presence of a gene completely fails to be expressed at all in the phenotype, a situation called **incomplete penetrance**.

People look for simplicity. In the past geneticists tended to associate very complex traits with simple genetic mechanisms. At one time human traits such as hair color, eye color, and skin color were thought to be explained by simple Mendelian rules.

More consequential to social policies and peoples' actions toward others, behavioral traits such as being "feeble minded," criminality, sexual promiscuity, social class, and even poverty were thought be associated almost exclusively with genetic causes. And many of these so-called behavioral defects were often linked to particular ethnic groups. In the early twentieth century, this faulty thinking led to many laws restricting immigration of people from populations that were labeled "genetically inferior." Laws were also passed permitting the involuntary sterilization of people being judged "feeble minded" and so on.

Today, as the result of the genetic research of the past several decades, we realize that Mendel's work was overly simplistic and somewhat problematical. While his work is historically very important, it doesn't really explain how most traits are passed from parent to offspring and does not take into account the complex interaction between environmental factors and genetics.

Summary

One of the basic pillars of natural selection is that individuals within a population differ from one another and some of these differences found among those individuals who survive and reproduce are inherited by future generations. Charles Darwin realized the importance of heredity both to explain some of this variation and to explain how particular traits are passed on to one's progeny.

The modern study of genetics was founded on the work of Gregor Mendel published in 1866 on pea plants. Mendel developed several important ideas: The hereditary units, that we call genes today, are paired. The genes may exist in different forms called alleles. Genes do not merge or blend with one another. Often only one of the alleles (dominant) is expressed in the phenotype; the other allele (recessive) is not.

Mendel formulated two principles based on a model of genetic events. The principle of segregation states that in the formation of sex cells, the hereditary factors separate, forming sex cells that contain either one or the other of the paired factors. The principle of independent assortment states that the inheritance patterns of differing traits are independent of one another.

Today we realize that although Mendel was generally correct, the true situation is much more complex. Mendel's principles actually apply to less than 1 percent of known genes.

CYTOGENETICS

One of the biological breakthroughs of the late 1800s was the discovery that all living organisms are either a cell or consist of many cells. **Cytology** is the branch of science that specializes in the biology of the cell. This term is derived from *cyto*, meaning "cell." The study of genetics on the cellular level is called **cytogenetics**.

The **cell** is the basic unit of life. In fact, cells are the smallest units that perform all the functions that are collectively labeled "life." These include taking in energy and excreting waste; using and storing energy; combining nutrients into substances for growth, repair, and development; adapting to new situations; and, perhaps the most important of all, reproducing new cells.

The great variety of cells all share several structural features (Figure 2.4). A cell is bounded by a **plasma membrane** that allows for the entry and exit of certain substances and maintains the cell's integrity. A **nucleus** in the cell is contained within its own **nuclear membrane**. The material between the nuclear membrane and the cell membrane is called the **cytoplasm**.

Biologist August Weisman (1834–1914) realized that the fertilized ovum contained hereditary material carried from the father in the **sperm** and from the mother in the **ovum**. If the sperm and ovum contained the same amount of hereditary material found in non-sex cells, the amount of hereditary material in the fertilized ovum would double each generation. He reasoned that there had to be a reduction in the amount of the heredity material in the production of the sperm and ovum so at fertilization the total amount of hereditary material would be restored to the normal amount.

Weisman rejected the idea of the inheritance of acquired characteristics (Chapter 1), although biologists continued to consider such a possibility into the 1930s. Weisman believed that the sperm and ova were not affected by external factors. He also realized that as the fertilized ovum began to divide after fertilization, cells were set aside that became the sex cells that produced the next generation. In other words, sperm and ova were not later produced from "adult" cells.

Weisman wrote that variation, so central to Darwin's theory, was the result of sexual reproduction. When the amount of hereditary material was reduced in the production of sex cells, only half of the hereditary material finds its way into the sperm and ova. But which half? This differs from sex cell to sex cell. Thus each sperm and each ovum has a unique combination of hereditary material that then combines to produce a unique individual.

The Chromosomes

Nineteenth-century biologists concluded that the hereditary material, whatever that might be, resided within small bodies called chromosomes that were located within the nucleus of the cell. When a cell begins to divide, long ropelike structures become visible within the nucleus. Because these structures stain very dark purple, they are called **chromosomes**—*chroma* means "color" and *soma* means "body." Viewed under the microscope, a single chromosome is seen to consist of two strands—the **chromatids**. These chromatids are held together by a structure called the **centromere**.

Figure 2.5 is a photograph of chromosomes prepared from a human blood sample. Much information can be obtained from an image of chromosomes. First, the chromosomes can be counted. Different organisms are characterized by specific chromosome numbers per cell. For example, the Indian fern has the highest number, with 1260 chromosomes; the roundworm has only 2. More typical numbers of chromosomes are found in dogs (78), cats (38), and the fruit fly (8); human body cells have 46.

cytology The study of the biology of the cell.

cytogenetics The study of the heredity mechanisms within the cell.

cell The smallest unit able to perform all those activities collectively called life. All living organisms are either one cell or composed of several cells.

plasma membrane A structure that binds the cell but allows for the entry and exit of certain substances.

nucleus A structure found in the cell that contains the chromosomes.

nuclear membrane A structure that binds the nucleus within the cell.

cytoplasm Material within the cell between the plasma membrane and the nuclear membrane.

sperm Male gamete or sex cell.

ovum A female gamete or sex cell.

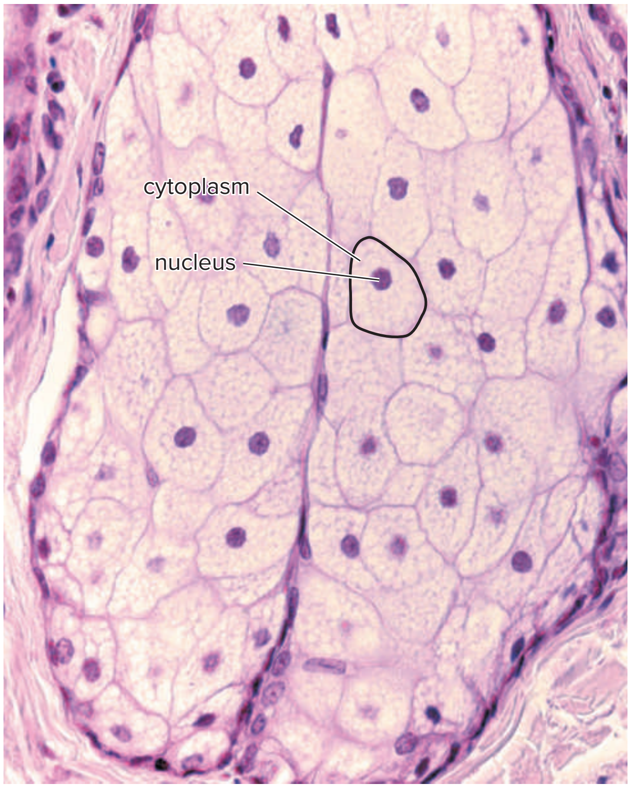


Figure 2.4 Human Cells Most living organisms either are single cells or are made up of cells. Here is a picture of human skin cells as they appear under a microscope. The nuclei appear dark because they have been stained with a purple dye. The chromosomes, which contain the genetic material, are found within the nuclei.

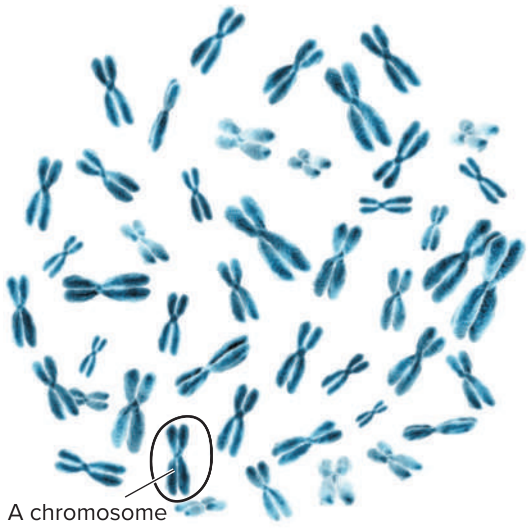


Figure 2.5 Human Chromosomes The genetic material is contained within bodies known as chromosomes. Pictured here is a complete set of 46 chromosomes obtained from a white blood cell from a normal human female.

Second, not all chromosomes are alike; they differ in relative size and in the position of the centromere. In some, the centromere is centered, and so the "arms" of the chromosomes are of equal length; in others, the centromere is off center, and so the arms are of unequal length. Thus, it is possible to identify and classify specific chromosomes. Each chromosome in an image can be isolated and arranged in a standardized representation known as a **karyotype**. The chromosomes in many karyotypes are stained to produce a pattern of bands so that individual chromosomes can be easily identified.

Looking at the karyotypes in Figure 2.6, we can see that all the chromosomes, with one exception, exist as pairs. The chromosomes that make up a pair are called **homologous chromosomes**. Homologous chromosomes have the same shape and are of the same size. They also carry the same genes, but they may carry different alleles for particular genes.

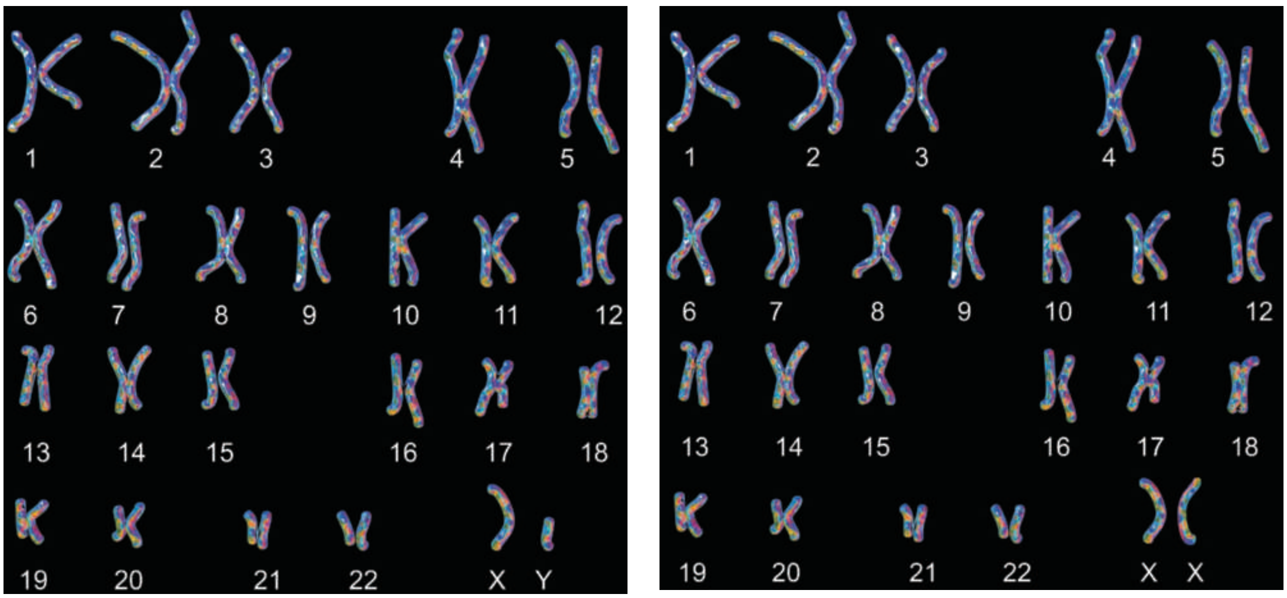
The **sex chromosomes** of the male, however, are not homologous. While the female possesses two homologous sex chromosomes, the **X chromosomes**, the male has only one X chromosome, which pairs with a different type, the **Y chromosome**. In both sexes, there are 22 pairs of non-sex chromosomes, referred to as **autosomes**. These autosomal pairs are numbered from 1 to 22. The 23rd pair consists of the sex chromosomes.

chromosomes Bodies found in the nucleus of the cell that contain the hereditary material.

chromatids Strands of a replicated chromosome. Two chromatids are joined together by a centromere.

Cell Division

The physical basis of Mendelian genetics becomes clear when we observe the movement of chromosomes during cell division. There are two basic forms of cell division: mitosis and meiosis. **Mitosis** is the process by which a one-celled organism divides into two new individuals. In a multicellular organism, mitosis results in the growth and replacement of body cells. **Meiosis**, on the other hand, is specialized cell division that results in the production of sex cells, or **gametes**.



(a) (b)

Figure 2.6 Human Karyotypes Karyotypes of (a) a normal male and (b) a normal female. In both sexes, there are 22 pairs of nonsex chromosomes or autosomes and a pair of sex chromosomes. The autosomal pairs are numbered from 1 to 22.