CUSTOM EDITION FOR THE UNIVERSITY OF OREGON

EVOLUTION OF HUMAN SEXUALITY

COMPILED BY FRANCES J. WHITE, PH.D.

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Taken from

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by Tina S. Miracle, Andrew W. Miracle, and Roy F. Baumeister

Physical Anthropology and Archaeology
by Carol R. Ember, Melvin Ember, and Peter N. Peregrine

Biological Science
by Scott Freeman

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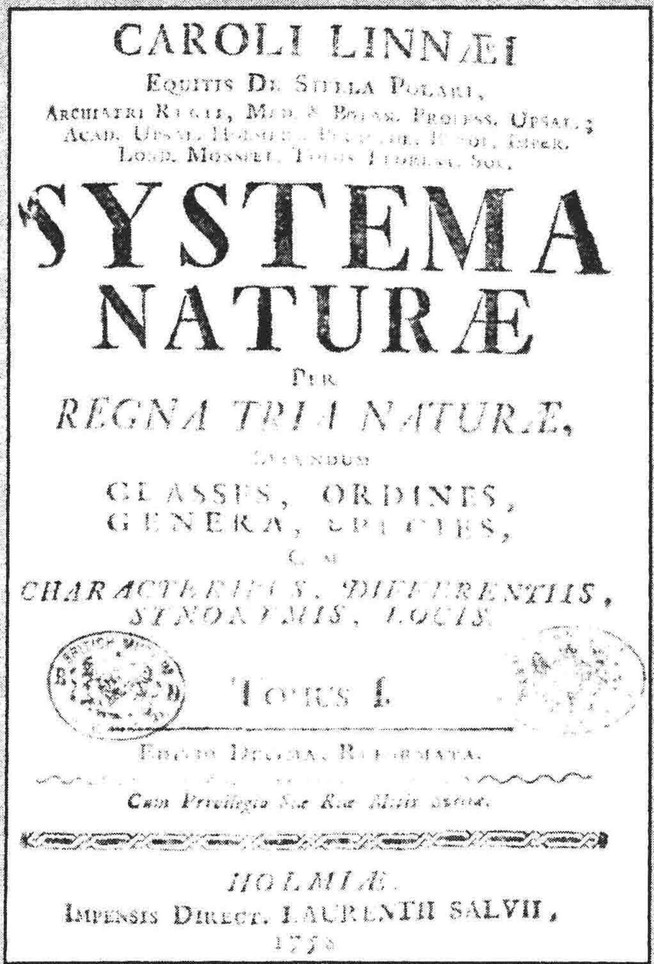
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EDITIO DECIMA, REFORMATA.
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1758.

CHAPTER OUTLINE

The Evolution of Evolution

The Principles of Natural Selection

Heredity

Sources of Variability

The Origin of Species

Natural Selection of Behavioral Traits

Taken from: *Physical Anthropology and Archaeology*
by Carol R. Ember, Melvin Ember, and Peter N. Peregrine

Astronomers estimate that the universe has been in existence for some 15 billion years, plus or minus a few billion. To make this awesome history more understandable, Carl Sagan devised a calendar that condenses this span into a single year.[1] Using as a scale 24 days for every billion years and 1 second for every 475 years, Sagan moves from the "Big Bang," or beginning of the universe, on January 1 to the origin of the Milky Way on May 1. September 9 marks the beginning of our solar system, and September 25 the origin of life on earth. At 10:30 in the evening of December 31, the first humanlike primates appear. Sagan's compression of history provides us with a manageable way to compare the short span of human existence with the total time span of the universe. Humanlike beings have been around for only about 90 minutes out of a 12-month period! In this book we are concerned with what has happened in the last few hours of that year.

Some 55 million to 65 million years ago, the first primates appeared. They were ancestral to all living primates, including monkeys, apes, and humans. The early primates may or may not have lived in trees, but they had flexible digits and could grasp things. Later, about 35 million years ago, the first monkeys and apes appeared. About 15 million years ago, some 20 million years after the appearance of monkeys and apes, the immediate apelike ancestors of humans probably emerged. About 4 million years ago the first humanlike beings appeared. Modern-looking humans evolved only about 100,000 years ago.

How do we account for the biological and cultural evolution of humans? The details of the emergence of primates and the evolution of humans and their cultures are covered in subsequent chapters. In this chapter we focus on how the modern theory of evolution developed and how it accounts for change over time.

The Evolution of Evolution

Traditional Western ideas about nature's creatures were very different from Charles Darwin's theory of *evolution*, which suggested that different species developed, one from another, over long periods of time. In the fifth millennium B.C., the Greek philosophers Plato and Aristotle believed that animals and plants form a single, graded continuum going from more perfection to less perfection. Humans, of course, were at the top of this scale. Later Greek philosophers added the idea that the creator gave life or "radiance" first to humans, but at each subsequent creation some of that essence was lost.[2] Macrobius, summarizing the thinking of Plotinus, used an image that was to persist for centuries, the image of what came to be called the "chain of being": "The attentive observer will discover a connection of parts, from the Supreme God down to the last dregs of things, mutually linked together and without a break. And this is Homer's golden chain, which God, he says, bade hand down from heaven to earth."[3]

Belief in the chain of being was accompanied by the conviction that an animal or plant species could not become extinct. In fact, all things were linked to each other in a chain, and all links were necessary. Moreover, the notion of extinction threatened people's trust in God; it was unthinkable that a whole group of God's creations could simply disappear.

The idea of the chain of being persisted through the years, but it was not discussed extensively by philosophers, scientists, poets, and theologians until the eighteenth century.[4] Those discussions prepared the way for evolutionary theory. It is ironic that, although the chain of being did not allow for evolution, its idea that there was an order of things in nature encouraged studies of natural history and comparative anatomical studies, which stimulated the development of the idea of evolution. People were also now motivated to look for previously unknown creatures. Moreover, humans were not shocked when naturalists suggested that humans were close to apes. This notion was perfectly consistent with the idea of a chain of being; apes were simply thought to have been created with less perfection.

Early in the eighteenth century, an influential scientist, Carolus Linnaeus (1707–1778), classified plants and animals in a *systema naturae*, which placed humans in the same order (Primates) as apes and monkeys. Linnaeus did not suggest an evolutionary relationship between humans and apes; he mostly accepted the notion that all species were created by God and fixed in their form. Not surprisingly, then, Linnaeus is often viewed as an antievolutionist. But Linnaeus's hierarchical classification scheme, in descending order going from kingdom to class, order, genus, and species, provided a framework for the idea that humans, apes, and monkeys had a common ancestor.[5] See Figure 3–1.

Others did not believe that species were fixed in their form. According to Jean Baptiste Lamarck (1744–1829), acquired characteristics could be inherited and therefore species could evolve; individuals who in their lifetime developed characteristics helpful to survival would pass those characteristics on to future generations, thereby changing the physical makeup of the species. For example, Lamarck explained the long neck of the giraffe as the result of successive generations of giraffes stretching their necks to reach the high leaves of trees. The stretched muscles and bones of the necks were somehow transmitted to the offspring of the neck-stretching giraffes, and eventually all giraffes came to have long necks. But because Lamarck and later biologists failed to produce evidence to support the hypothesis that acquired characteristics can be inherited, this explanation of evolution is now generally dismissed.[6]

By the nineteenth century, some thinkers were beginning to accept evolution while others were trying to refute it.[7] For example, Georges Cuvier (1769–1832) was a leading opponent of evolution. Cuvier's theory of *catastrophism* proposed that a quick series of catastrophes accounted for changes in the earth and the fossil record.

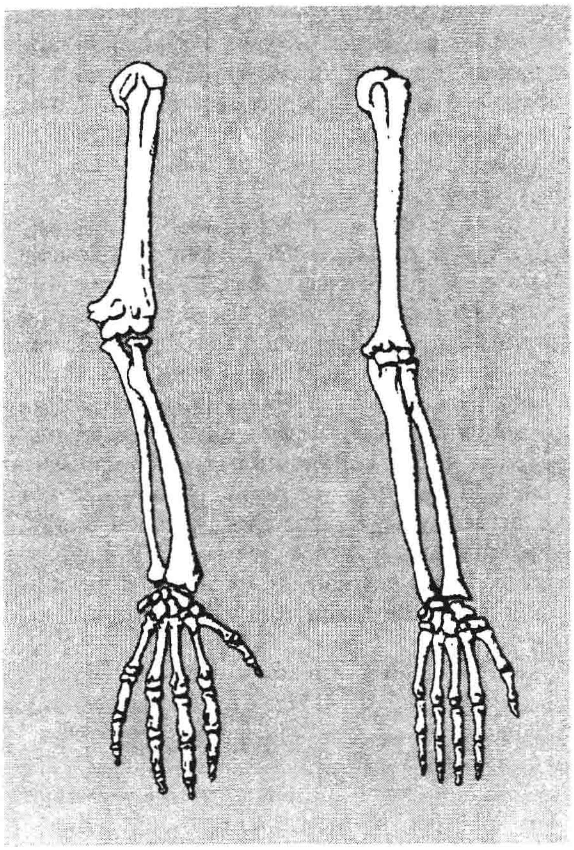


Figure 3–1

The idea that chimpanzees and humans descend from a common ancestor is suggested by anatomical similarities, such as in their forelimbs. Chimpanzee forelimb skeleton (left); human forelimb skeleton (right).

Cataclysms and upheavals such as Noah's flood had killed off previous sets of living creatures, which each time were replaced by new creations.

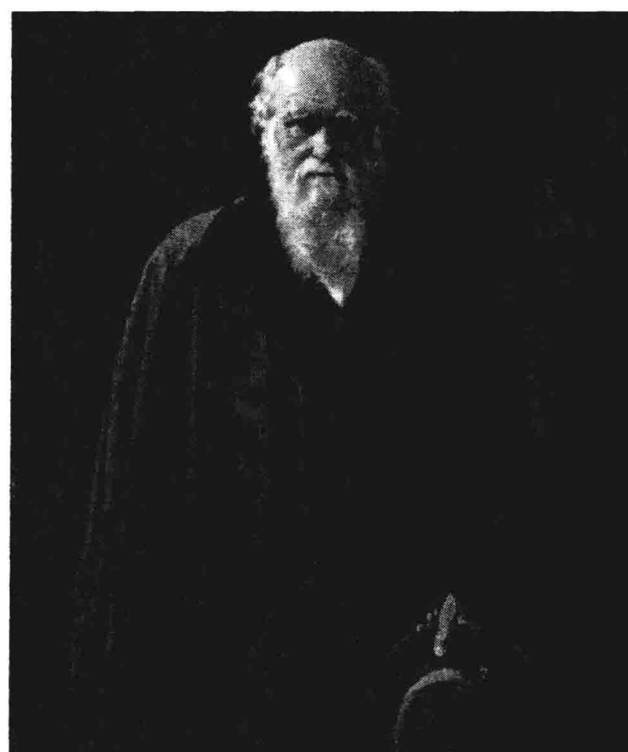
Major changes in geological thinking occurred in the nineteenth century. Earlier, the geologist James Hutton (1726–1797) had questioned catastrophism, but his work was largely ignored. In contrast, Sir Charles Lyell's (1797–1875) volumes of the *Principles of Geology* (1830–1833), which built on Hutton's earlier work, received immediate acclaim. Their concept of *uniformitarianism* suggested that the earth is constantly being shaped and reshaped by natural forces that have operated over a vast stretch of time. Lyell also discussed the formation of geological strata and paleontology. He used fossilized fauna to define different geological epochs. Lyell's works were read avidly by Charles Darwin before and during Darwin's now-famous voyage on the *Beagle*. The two corresponded and subsequently became friends.

After studying changes in plants, fossil animals, and varieties of domestic and wild pigeons, Charles Darwin (1809–1882) rejected the notion that each species was created at one time in a fixed form. The results of his investigations pointed clearly, he thought, to the evolution of species through the mechanism of natural selection. While Darwin was completing his book on the subject, Lyell sent him a manuscript by Alfred Russel Wallace (1823–1913), a naturalist who had independently reached conclusions about the evolution of species that matched Darwin's own.[8] In 1858, the two men presented the astonishing theory of *natural selection* to their colleagues at a meeting of the Linnaean Society of London.[9]

In 1859, when Darwin published *The Origin of Species by Means of Natural Selection*,[10] he wrote, "I am fully convinced that species are not immutable; but that those belonging to what are called the same genera are lineal descendants of some other and generally extinct species, in the same manner as the acknowledged varieties of any one species."[11] His conclusions outraged those who believed in the biblical account of creation, and the result was bitter controversy that continues to this day.[12]

Until 1871, when his *The Descent of Man* was published, Darwin avoided stating categorically that humans were descended from nonhuman forms, but the implications of his theory were clear. People immediately began to take sides. In June 1860, at the annual meeting of the British Association for the Advancement of Science, Bishop Wilberforce saw an opportunity to attack the Darwinists. Concluding his speech, he faced Thomas Huxley, one of the Darwinists' chief advocates, and inquired, "Was

Charles Darwin. (*Source:* Gemalde von John Collier, 1883, "Charles Robert Darwin." Ol auf Leinwand. 125.7 x 96.5 cm. London, National Portrait Gallery/1024. Bildarchiv Preussischer Kulturbesitz. Photo: Jochen Remmer.)



it through his grandfather or his grandmother that he claimed descent from a monkey?" Huxley responded,

> If . . . the question is put to me would I rather have a miserable ape for a grandfather than a man highly endowed by nature and possessing great means and influence and yet who employs those faculties and that influence for the mere purpose of introducing ridicule into a grave scientific discussion—I unhesitatingly affirm my preference for the ape.[13]

The Principles of Natural Selection

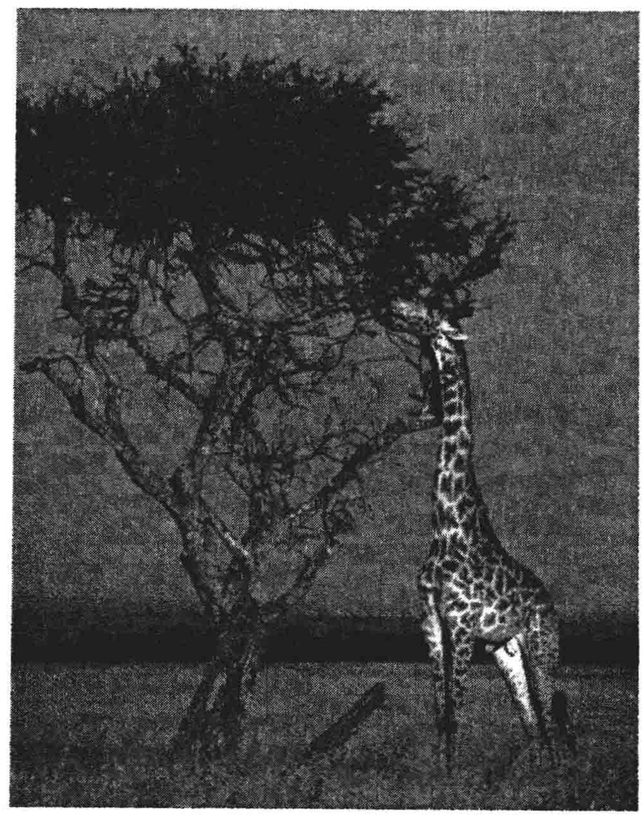
Darwin was not the first person to view the creation of new species in evolutionary terms, but he was the first to provide a comprehensive, well-documented explanation —natural selection—for the way evolution had occurred. **Natural selection is the main process that increases the frequency of adaptive traits through time.** The operation of natural selection involves three conditions or principles.[14] The first is ***variation:*** Every species is composed of a great variety of individuals, some of which are better adapted to their environment than others. The existence of variety is important. Without it, natural selection has nothing on which to operate; without variation, one kind of characteristic could not be favored over another. The second principle of natural selection is ***heritability:*** Offspring inherit traits from their parents, at least to some degree and in some way. The third principle of natural selection is ***differential reproductive success:*** Since better adapted individuals generally produce more offspring over the generations than the poorer adapted, the frequency of adaptive traits gradually increases in subsequent generations. A new species emerges when changes in traits or geographic barriers result in the reproductive isolation of the population.

When we say that certain traits are adaptive or advantageous, we mean that they result in greater reproductive success in a particular environment. The phrase *particular environment* is very important. Even though a species may become more adapted to a particular environment over time, we cannot say that one species adapted to its environment is "better" than another species adapted to a different environment. For example, we may like to think of ourselves as "better" than other animals, but humans are clearly less adapted than fish for living under water, than bats for catching flying insects, than raccoons for living on suburban garbage.

Although the theory of natural selection suggests that disadvantageous or maladaptive traits will generally decline in frequency or even disappear eventually, it does not necessarily follow that all such traits will do so. After all, species derive from prior forms that have certain structures. This means that not all changes are possible; it also means that some traits are linked to others that might have advantages that outweigh the disadvantages. Choking may be very maladaptive for any animal, yet all vertebrates are capable of choking because their digestive and respiratory systems cross in the throat. This trait is a genetic legacy, probably from the time when the respiratory system developed from tissue in the digestive system of some ancestral organism. Apparently, the propensity to choke has not been correctable evolutionarily.[15]

Changes in a species can be expected to occur as the environment changes or as some members of the species move into a new environment. With environmental change, different traits become adaptive. The forms of the species that possess the more adaptive traits will become more frequent, whereas those forms whose characteristics make continued existence more difficult or impossible in the modified environment will eventually become extinct.

Consider how the theory of natural selection would explain why giraffes became long-necked. Originally, the necks of giraffes varied in length, as happens with virtually any physical characteristic in a population. During a period when food was scarce, those giraffes with longer necks, who could reach higher tree leaves, might be better able to survive and suckle their offspring, and thus they would leave more offspring than shorter-necked giraffes. Because of heredity, the offspring of long-necked giraffes are more likely to have long necks. Eventually, the shorter-necked giraffes would diminish in number and the longer-



The giraffe's long neck is adaptive for eating tree leaves high off the ground. When food is scarce, longer-necked giraffes would get more food and reproduce more successfully than shorter-necked giraffes; in this environment, natural selection would favor giraffes with longer necks.

CURRENT ISSUES

Is Evolution Slow and Steady or Fast and Abrupt?

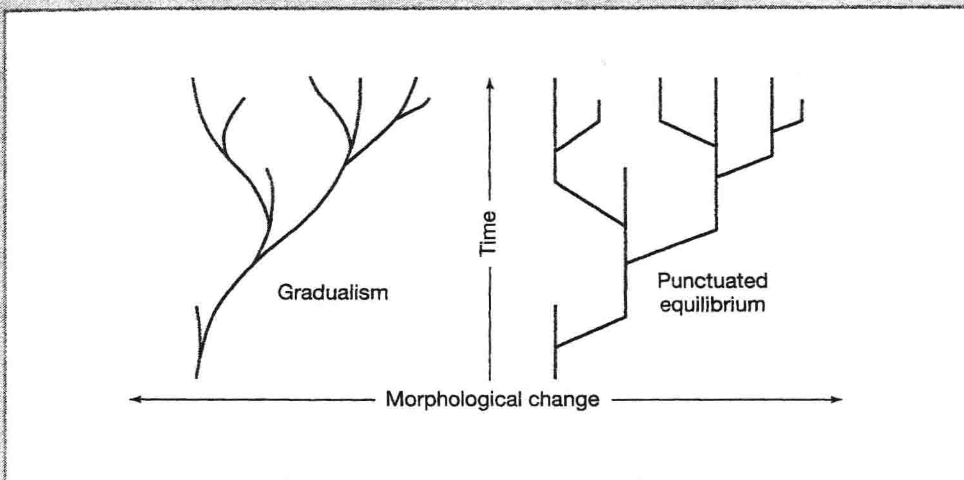
Darwin's evolutionary theory suggested that new species emerge gradually over time. Through the process of natural selection, frequencies of traits would slowly change, and eventually a new species would appear. But Darwin did not explain why so much speciation has occurred. If trait frequencies change only gradually over time, wouldn't descendant populations retain their ability to interbreed and wouldn't they, therefore, continue to belong to the same species?

In the 1930s and 1940s, Theodosius Dobzhansky, Julian Huxley, Ernst Mayr, George Simpson, and others advanced what came to be called the "modern synthesis" in evolutionary theory, adding what was known from genetics about heredity. Mutation and the recombination of genes now provided for genetic variety. The driving force of change was still adaptation to environments through natural selection; gene frequencies of a population presumably changed slowly as adaptive traits (because of existing genes or mutations) increased in prevalence and maladaptive traits decreased. As for speciation, the development and divergence of different species, the modern synthesis postulated that it would occur when subpopulations became isolated by geographic barriers or when different subpopulations encountered different climatic conditions or moved into new ecological niches; those environmental isolating processes would eventually result in the development of reproductive isolation and therefore new species.

This gradualist view of evolution was challenged in 1972 by Niles Eldredge and Stephen Jay Gould. Their alternative model of evolution is referred to as "punctuated equilibrium." They still assume that natural selection is the primary mechanism of evolutionary change, but they see the pace of evolution quite differently. In their view, new species evolve quickly; but once a successful species emerges, its characteristics are likely to change very little over long periods of time. Thus, in contrast to the modern synthesis, Eldredge and Gould do not think it is common for the world's species to change gradually into descendant species. Rather, species are born more or less abruptly, they have lifetimes during which they do not change much, and they become extinct. As examples, Eldredge and Gould cite the history of North American trilobites and Bermudan land snails. In both groups of animals, it looks as if the different species did not change for a long period of time—millions of years for some species—but then certain species seem to have been quickly replaced by related species from nearby areas. In short, Eldredge and Gould believe that the succession of one species after another involves replacement from outside more often than gradual change over time.

Evolution may or may not occur as the model of punctuated equilibrium specifies, but most evolutionists today agree that change could occur relatively quickly. Recent research suggests that some relatively quick climate changes in the earth's history helped bring about massive extinctions of species and families of species and exponential increases in the subsequent number of new families. For example, there is considerable evidence that a large meteorite collided with the earth at the end of the Cretaceous geological period, about 65 million years ago. Louis Alvarez and his colleagues proposed that so much dust was sent into the atmosphere by the collision that the earth was shrouded in darkness for months, if not longer. Some investigators now think that the meteorite impact may have also triggered a great deal of volcanic activity, even on the opposite side of the world, which would also have reduced solar radiation to the earth's surface. Not only the dinosaurs disappeared about 65 million years ago, so also did many sea animals and plants. Afterward, the earth saw the proliferation of many other kinds of animals, such as fish, lizards, birds, and mammals, as well as flowering trees. As we shall see in the chapter on primate evolution, our own biological order, the Primates, is believed to have emerged around that time.

Peter Grant recently studied the same finches on the Galápagos Islands that partially inspired Darwin's theory. But, unlike Darwin, Grant had the chance to see natural selection in action. And it was surprisingly quick. Central



A Graphical Depiction of Gradual versus Punctuated Evolutionary Change

to the project was the attachment of colored bands to each individual bird, which allowed each bird to be identified at a distance. In the midst of the project, in 1977, when half the birds had been banded, there was a serious drought. Of the two main species of finch on one island, the cactus finch and the medium finch, only the cactus finches were able to breed, but they had no surviving offspring. During the next 18 months, 85 percent of the adult medium finches disappeared. Those finches that survived tended to be larger and to have larger beaks than the ones that died. Why larger beaks? Both species of finch eat seeds, but small seeds produced by grasses and herbs are scarce in a drought; bigger seeds are more available. So it seems that natural selection under conditions of drought favored finches with bigger beaks, which are better at cracking the husks of large seeds.

If it were not for the fact that wet years, which favor smaller finches, occur between years of drought, we might see the quick evolution of new finch species. It is estimated that 20 drought episodes would be sufficient to produce a new species of finch. Darwin's (and Grant's) finches do not really provide an example of punctuated equilibrium (no replacement from outside occurred), but they do suggest that evolutionary change could be a lot quicker than Darwin imagined.

Controversy continues over whether evolution is slow and steady or fast and abrupt. But many scholars, including Gould, point out that there is no need to pit one model against the other. Both may be correct in different instances. In any case much more investigation of evolutionary sequences is needed to help us evaluate the competing theoretical models.

Sources: Ian Tattersall, "Paleoanthropology and Evolutionary Theory," in Peter N. Peregrine, Carol R. Ember, and Melvin Ember, eds., *Physical Anthropology: Original Readings in Method and Practice* (Upper Saddle River, NJ: Prentice Hall, 2002); Charles Devillers and Jean Chaline, *Evolution: An Evolving Theory* (New York: Springer-Verlag, 1993); Peter R. Grant, "Natural Selection and Darwin's Finches," *Scientific American*, October 1991, 82–87; Jonathan Weiner, *Beak of the Finch* (New York: Vintage, 1994).

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necked giraffes would increase. The resultant population of giraffes would still have variation in neck length but on the average would be longer-necked than earlier forms.

Natural selection does not account for all variation in the frequencies of traits. In particular, it does not account for variation in the frequencies of neutral traits—that is, those traits that do not seem to confer any advantages or disadvantages on their carriers. Changes in the frequencies of neutral traits may result rather from random processes that affect gene frequencies in isolated populations—*genetic drift*—or from matings between populations—*gene flow.* We discuss these other processes later in the chapter.

Observed Examples of Evolution

Because the process of evolution may involve nearly imperceptible gradations over generations, it is usually difficult to observe directly. Nevertheless, because some life forms reproduce rapidly, some examples of natural selection have been observed over relatively short periods in changing environments.

For example, scientists think they have observed natural selection in action in British moths. In 1850, an almost black moth was spotted for the first time in Manchester. That was quite unusual, for most of the moths were speckled gray. A century later, 95 percent of the moths in industrial parts of Britain were black; only in the rural areas were the moths mostly gray. How is this to be explained? It seems that in the rural areas, the gray-speckled moth is hard to spot by bird predators against the lichen growing on the bark of trees. But in industrial areas, lichen is killed by pollution. The gray-speckled moths, formerly well adapted to blend into their environment, became clearly visible against the darker background of the lichen-free trees and were easier prey for birds. In contrast, the black moths, which previously would have had a disadvantage against the lighter bark, were now better adapted for survival. Their dark color was an advantage, and subsequently the darker moths became the predominant variety in industrial regions.

How can we be sure that natural selection was the mechanism accounting for the change? Consistent evidence comes from a series of experiments performed by H.B.D. Kettlewell. He deliberately released specially marked moths, black and gray, into two areas of England—one urban industrial and one rural—and then set light traps to recapture them subsequently. The proportions of the two kinds of moths recovered tell us about differential survival. Kettlewell found that proportionately more black moths compared with gray moths were recovered in the urban industrial area. Just the reverse happened in the rural area; proportionately more gray-speckled moths were recovered.[16] The same transformation—the switch to darker color—occurred in 70 other species of moth, as well as in a beetle and a millipede. It did not occur just in Britain; it also happened in other highly polluted areas, the Ruhr area of Germany and in the Pittsburgh area of the United States. Moreover, in the Pittsburgh area, antipollution measures in the last 40 years have apparently caused the black moth to dwindle in number once again.[17]

The type of natural selection in the moth example is called **directional selection** because a particular trait seems to be positively favored and the average value shifts over time toward the adaptive trait. But there can also be **normalizing selection.** In this type of selection the average value does not change, but natural selection removes the extremes.[18] An example is the birthweight of babies. Both very low birthweights and very high birthweights are disadvantageous and would be selected against. Directional and normalizing selection both assume that natural selection will either favor or disfavor genes, but there is a third possibility—balancing selection.[19] **Balancing selection** occurs when a *heterozygous* (varied) combination of *alleles* (genes) is positively favored even though a *homozygous* (genes in the pairs are the same) combination is disfavored. In the chapter on human variation, we discuss a trait that apparently involves balancing selection—sickle-cell anemia—which is found in persons of West African ancestry, among other populations.

Another well-known example of observed natural selection is the acquired resistance of houseflies to the insecticide DDT. When DDT was first used to kill insects, beginning in the 1940s, several new, DDT-resistant strains of housefly evolved. In the early DDT environment, many houseflies were killed, but the few that survived were the ones that reproduced, and their resistant characteristics became common to the housefly populations. To the cha-

The changes that occurred in the moth population in different areas of England show natural selection in action. Before industrialization, tree trunks were lighter and light-colored moths predominated. (Rural areas today, with little or no industrial air pollution, show that natural selection in unpolluted areas still favors light-colored moths.) But with industrial pollution and the darkening of tree trunks, light-colored moths became more visible to predators. Darker-colored moths quickly increased in number in the new industrial environment.

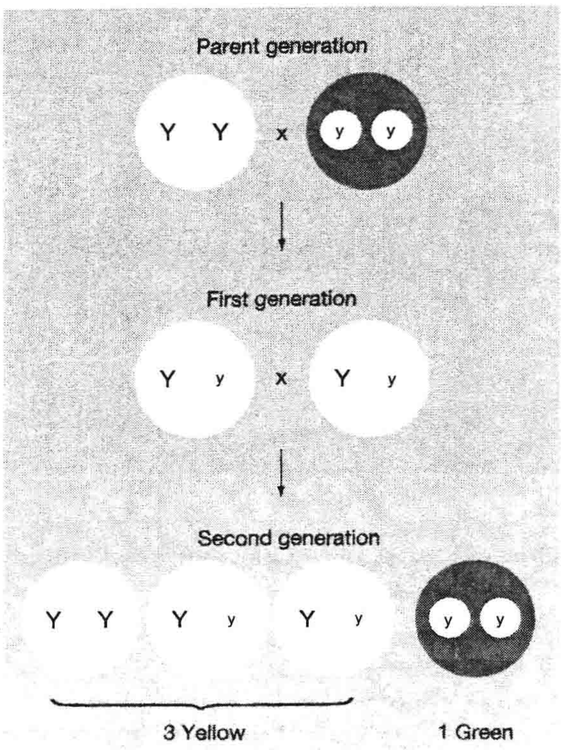


Figure 3–2

When Mendel crossed a plant having two genes for yellow peas (YY) with a plant having two genes for green peas (yy), each offspring pea was yellow but carried one gene for yellow and one gene for green (Yy). The peas were yellow because the gene for yellow is dominant over the recessive gene for green. Crossing the first generation yielded three yellow pea plants for each green pea plant.

grin of medical practitioners, similar resistances develop in bacteria. A particular antibiotic may lose its effectiveness after it comes into wide use because new, resistant bacterial strains emerge. These new strains will become more frequent than the original ones because of natural selection. In the United States now, a few strains are resistant to *all* antibiotics on the market, a fact that worries medical practitioners. One possible way to deal with the problem is to stop using antibiotics for a few years, so resistance to those antibiotics might not develop or develop only slowly.

The theory of natural selection answered many questions, but it also raised at least one whose answer eluded Darwin and others. The appearance of a beneficial trait may assist the survival of an organism, but what happens when the organism reproduces by mating with members that do not possess this new variation? Will not the new adaptive trait eventually disappear if subsequent generations mate with individuals that lack this trait? Darwin knew variations were transmitted through heredity, but he did not have a clear model of the mode of inheritance. Gregor Mendel's pioneering studies in the science of genetics provided the foundation for such a model, but his discoveries did not become widely known until 1900.

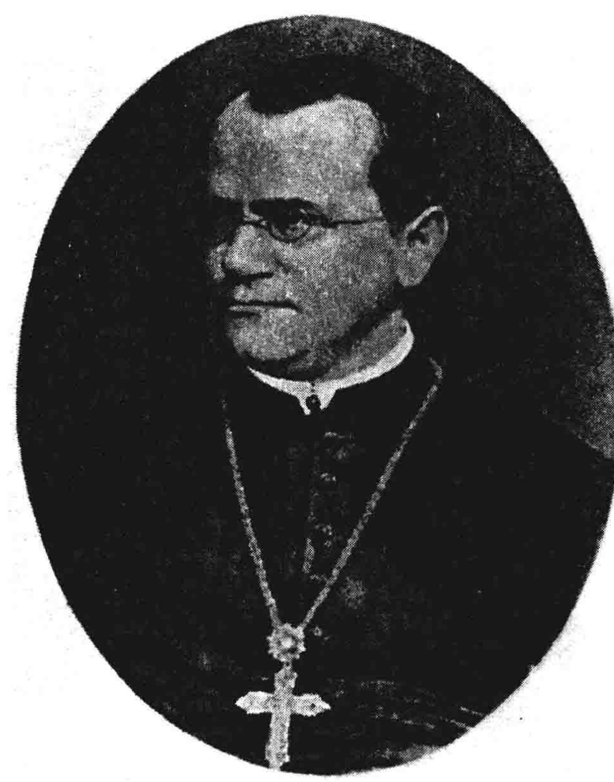
Heredity

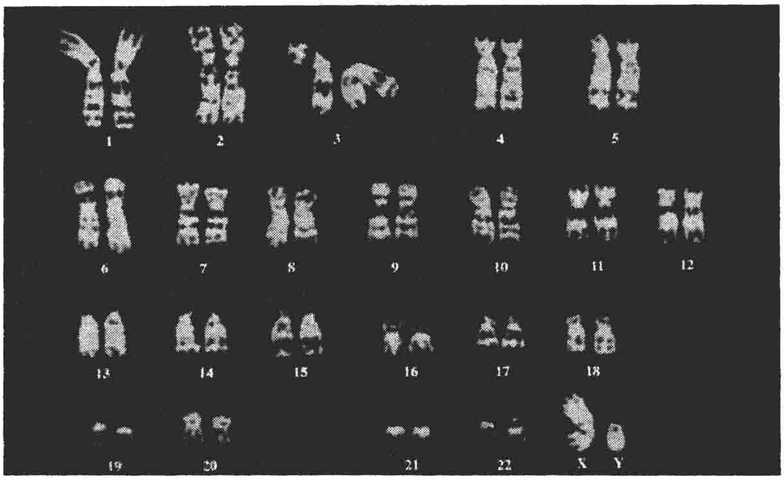
Gregor Mendel's Experiments

Mendel (1822–1884), a monk and amateur botanist who lived in what is now the Czech Republic, bred several varieties of pea plants and made detailed observations of their offspring. He chose as breeding partners plants that differed by only one observable trait. Tall plants were crossed with short ones, and yellow ones with green, for example.

When the pollen from a yellow pea plant was transferred to a green pea plant, Mendel observed a curious phenomenon: All of the first-generation offspring bore yellow peas. It seemed that the green trait had disappeared. But when seeds from this first generation were crossed, they produced both yellow and green pea plants in a ratio of three yellow to one green pea plant (see Figure 3–2). Apparently, Mendel reasoned, the green trait had not been lost or altered; the yellow trait was simply **dominant** and the green trait was **recessive**. Mendel observed similar results with other traits. Tallness dominated shortness, and the factor for smooth-skinned peas dominated the factor for wrinkled ones. In each cross, the 3-to-1

Gregor Mendel.





This karyotype shows the 23 paired chromosomes in a normal human male. Note the small Y chromosome at the bottom right that makes this individual male.

ratio appeared in the second generation. Self-fertilization, however, produced different results. Green pea plants always yielded green pea plants, and short plants always produced short plants.

From his numerical results, Mendel concluded that some yellow pea plants were pure (homozygous) for that trait, whereas others also possessed a green factor (the plants were heterozygous). That is, although two plants might both have yellow peas, one of them might produce offspring with green peas. In such cases, the genetic makeup, the **genotype,** differed from the observable appearance, or **phenotype.**

Genes: The Conveyors of Inherited Traits

Mendel's units of heredity were what we now call **genes.** He concluded that these units occurred in pairs for each trait and that offspring inherited one unit of the pair from each parent. Each member of a gene pair or group is called **an allele.** If the two genes, or alleles, for a trait are the same, the organism is **homozygous** for that trait; if the two genes for a characteristic differ, the organism is **heterozygous for that trait.** A pea plant that contains a pair of genes for yellow is homozygous for the trait. A yellow pea plant with a dominant gene for yellow and a recessive gene for green, although phenotypically yellow, has a heterozygous genotype. As Mendel demonstrated, the recessive green gene can reappear in subsequent generations. But Mendel knew nothing of the composition of genes or the processes that transmit them from parent to offspring. Many years of scientific research have yielded much of the missing information.

The genes of higher organisms (not including bacteria and primitive plants such as green-blue algae) are located on ropelike bodies called **chromosomes** within the nucleus of every one of the organism's cells. Chromosomes, like genes, usually occur in pairs. Each allele for a given trait is carried in the identical position on corresponding chromosomes. The two genes that determined the color of Mendel's peas, for example, were opposite each other on a pair of chromosomes.

MITOSIS AND MEIOSIS The body cells of every plant or animal carry chromosome pairs in a number appropriate for its species. Humans have 23 pairs, or a total of 46 chromosomes, each carrying many times that number of genes. Each new body cell receives this number of chromosomes during cellular reproduction, or **mitosis,** as each pair of chromosomes duplicates itself.

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But what happens when a sperm cell and an egg cell unite to form a new organism? What prevents the human baby from receiving twice the number of chromosomes characteristic of its species—23 pairs from the sperm and 23 pairs from the egg? The process by which the reproductive cells are formed, **meiosis,** ensures that this will not happen (see Figure 3–3). Each reproductive cell contains *half* the number of chromosomes appropriate for the species. Only one member of each chromosome pair is carried in every egg or sperm. At fertilization, the human embryo normally receives 23 *separate* chromosomes from its mother and the same number from its father, which add up to the 23 pairs.

DNA As we have said, genes are located on chromosomes. Each gene carries a set of instructions encoded in its chemical structure. It is from this coded information carried in genes that a cell makes all the rest of its structural parts and chemical machinery. It appears that in most living organisms, heredity is controlled by the same chemical substance, **DNA—deoxyribonucleic acid.** An enormous amount of research has been directed toward understanding DNA—what its structure is, how it duplicates itself in reproduction, and how it conveys or instructs the formation of a complete organism.

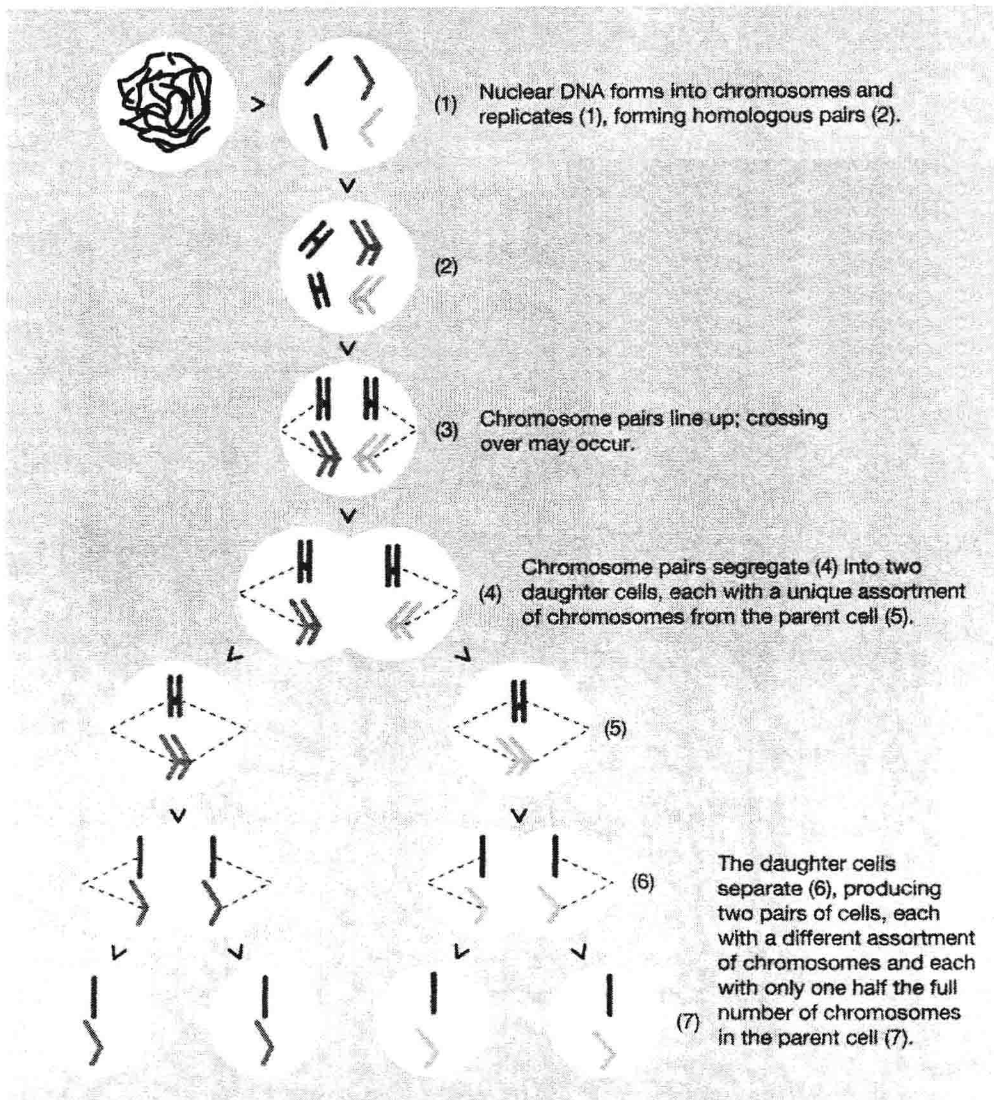

Figure 3–3 ***Meiosis (sex cells)***

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One of the most important keys to understanding human development and genetics is the structure and function of DNA. In 1953, the American biologist James Watson, with the British molecular biologist Francis Crick, proposed that DNA is a long, two-stranded molecule shaped like a double helix[20] (see Figure 3–4). Genetic information is stored in the linear sequences of the bases; different species have different sequences, and every individual is slightly different from every other individual. Notice that in the DNA molecule each base always has the same opposite base; adenine and thymine are paired, as are cytosine and guanine. The importance of this pattern is that the two strands carry the same information, so that when the double helix unwinds each strand can form a template for a new strand of complementary bases.[21] Because DNA stores the information required to make up the cells of an organism, it has been called the language of life. As George and Muriel Beadle put it,

> the deciphering of the DNA code has revealed our possession of a language much older than hieroglyphics, a language as old as life itself, a language that is the most living language of all—even if its letters are invisible and its words are buried deep in the cells of our bodies.[22]

Once it was understood that genes are made of DNA, concerted efforts were begun to map DNA sequences and their locations on the chromosomes of different organisms. A project known as the human genome project set out to assemble a complete genetic map for humans. In July 2000, the initial mapping of the human genome was

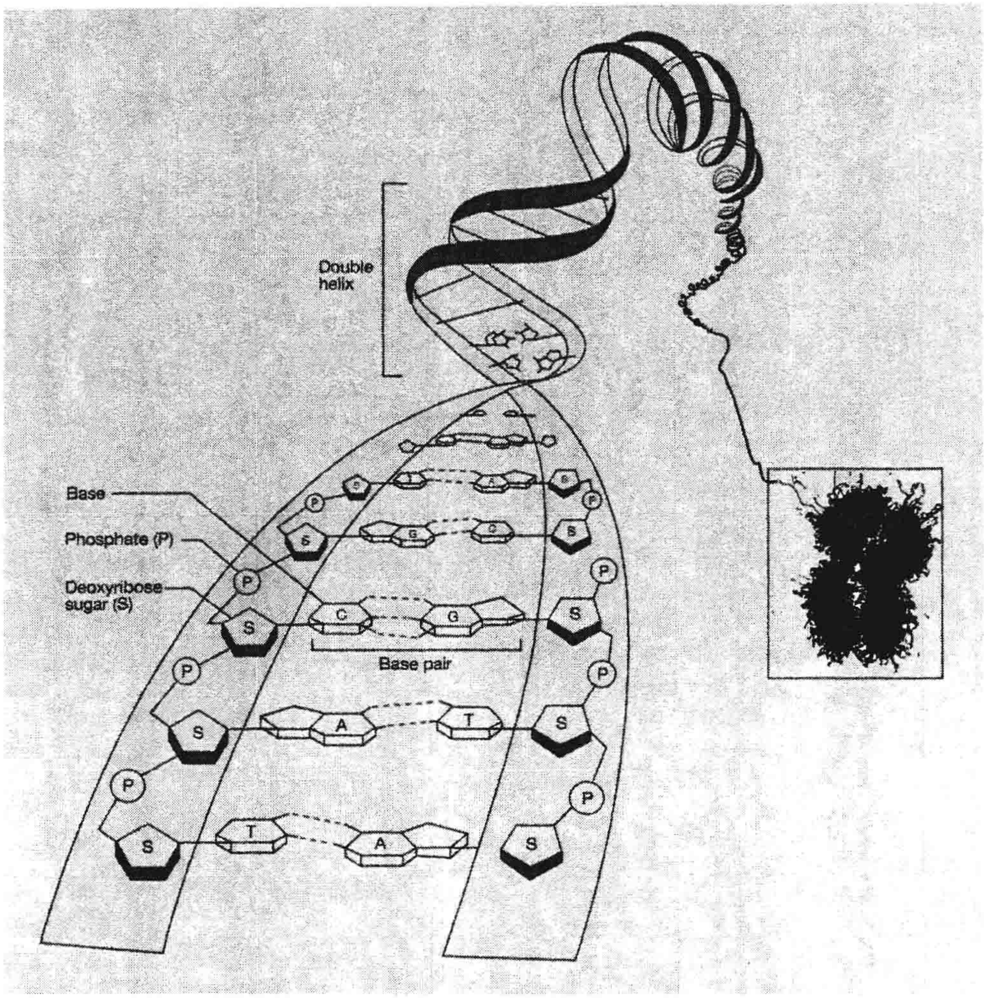

Figure 3–4 *The DNA molecule consists of two spiral sugar-phosphate strands. The strands are linked by the nitrogenous bases adenine (A), guanine (G), thymine (T), and cytosine (C). When the DNA molecule reproduces, the bases separate and the spiral strands unwind. Each original strand serves as a mold along which a new complementary chain is formed. Source:* From *The Language of Heredity* by Paul Berg and Maxine Singer. Reprinted by permission of University Science Books, 55D Gate Five Road, Sausalito, Ca 94965.

completed. While much work remains, this is a significant achievement and will certainly lead to breakthroughs in our understanding of how the genetic code functions.[23]

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MESSENGER RNA DNA stores the information to make cells, but it does not directly affect the formation of cells. One type of ribonucleic acid (RNA), **messenger RNA (mRNA)**, is copied from a portion of DNA and moves outside the cell nucleus to direct the formation of proteins.[24] Proteins have so many functions that they are considered to be responsible for most of the characteristics of an organism. They act as catalysts for synthesizing DNA and RNA and for the activities of cells; they also contribute many structural elements that determine the shape and movement of cells.[25] Messenger RNA is like DNA in that it has a linear sequence of bases attached to a sugar-phosphate backbone, but it is slightly different chemically. One difference is that messenger RNA has the base uracil instead of the base thymine. Messenger RNA also has a different sugar-phosphate backbone and is single- rather than double-stranded. Messenger RNA is formed when a double-stranded DNA molecule unwinds and forms a template for the mRNA. After a section of DNA is copied, the mRNA releases from the DNA and leaves the nucleus, and the double helix of the DNA is re-formed.[26]

PROTEIN SYNTHESIS Once the mRNA is released from the DNA, it travels out of the cell nucleus and into the body of the cell. There it attaches to a structure in the cell called a **ribosome**, which uses the information on the mRNA to make proteins. The ribosome essentially "reads" the chemical bases on the mRNA in commands that tell the ribosome the specific amino acids to join together to form a protein (see Figure 3–5). For example, the mRNA sequence adenine, adenine, guanine (AAG) tells the ribosome to place the amino acid lysine in that location, whereas the sequence adenine, adenine, cytosine (AAC) calls for the amino acid histidine. There are also mRNA commands that tell the ribosome when to begin and when to stop constructing a protein. Thus, the DNA code copied onto mRNA provides all the information necessary for ribosomes to build the proteins that make up the structures of organisms and drive the processes of life.

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Sources of Variability

Natural selection proceeds only when individuals within a population vary. There are two genetic sources of variation: genetic recombination and mutation.

Genetic Recombination

The distribution of traits from parents to children varies from one offspring to another. Brothers and sisters, after all, do not look exactly alike, nor does each child resemble 50 percent of the mother and 50 percent of the father. This variation occurs because when a sperm cell or an egg is formed, the single member of each chromosome pair it receives is a matter of chance. Each reproductive cell, then, carries a random assortment of chromosomes and their respective genes. At fertilization, the egg and sperm that unite are different from every other egg carried by the mother and every other sperm carried by the father. A unique offspring is thus produced by a shuffling of the parents' genes. One cause of this shuffling is the random **segregation**, or sorting, of chromosomes in meiosis. Conceivably, an individual could get any of the possible assortments of the paternal and maternal chromosomes. Another cause of the shuffling of parental genes is **crossing-over**, the exchange of sections of chromosomes between one chromosome and another (Figure 3–6).[27] Thus, after meiosis, the egg and sperm do not receive just a random mixture of complete paternal and maternal chromosomes; because of crossing-over they also receive chromosomes in which some of the sections may have been replaced.

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The traits displayed by each organism are not simply the result of combinations of dominant and recessive genes, as Mendel had hypothesized. In humans, most traits are influenced by the activity of many genes. Skin color, for example, is the result of several inherited characteristics. A brownish shade results from the presence of a pigment known as *melanin;* the degree of darkness in the hue depends largely on the amount of melanin present and how it is distributed in the layers of the skin. Another factor contributing to the color of all human skin is the blood that flows in blood vessels located in the outer layers of the skin. Humans carry at least five different genes for the manufacture of melanin and many other genes for the other components of skin hue. In fact, almost all physical characteristics in humans are the result of the concerted action of many genes. Some traits are sex-linked. The X chromosome, which together with the presence or absence of a Y chromosome determines sex, may also carry the gene for hemophilia or the gene for color blindness. The expression of these two characteristics depends on the sex of the organism.

Genetic recombination produces variety, which is essential for the operation of natural selection. Ultimately, however, the major source of variability is mutation. This is because mutation replenishes the supply of variability, which is constantly being reduced by the selective elimination of less fit variants. Mutation also produces variety in organisms that reproduce asexually.

Mutation

A **mutation** is a change in the DNA sequence. Such a change produces an altered gene. The majority of mutations are thought to occur because of occasional mismating of the chemical bases that make up DNA. Just as a typist will make errors in copying a manuscript, so will DNA, in duplicating itself, occasionally change its code.[28] A mutation will result from such an error. Some mutations have more drastic consequences than others. Suppose the error is in one base on a DNA strand. The effect depends on what that portion of the DNA controls. The effect may be minimal if the product hardly affects the organism. On the other hand, if the change occurs at a place where the DNA regulates the production of many proteins, the effect on the organism can be serious.[29]

Although it is very difficult to estimate the proportions of mutations that are harmful, neutral, or beneficial, there is no doubt that some mutations have lethal consequences. We can discuss the relative merits or disadvantages of a mutant gene only in terms of the physical, cultural, and genetic environment of that gene.[30] Galactosemia, for example, is caused by a recessive mutant gene and usually results in mental retardation and blindness. But it can be prevented by dietary restrictions begun at an early age. In this instance, the intervention of human culture counteracts the mutant gene and allows the afflicted individual to lead a normal life. Thus, some cultural factors can modify the effects of natural selection by helping

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