CHAPTER 12

Genetic Engineering



In mythology, the chimera is a fire-breathing monster that is part lion, part goat, and part serpent. In genetics, the word chimera refers to a piece of DNA (or even an entire organism) that is made up of DNA from different sources.

In Greek mythology, the chimera was a frightening beast with the head of a lion, the body of a goat, and the tail of a serpent. The idea of combining the characteristics of many animals into one, however, did not originate with the Greeks. The Sphinx of Egypt and the winged lions of Assyria are just two examples of composite monsters that predate the Greek myths. Although we do not take these stories seriously today, it is ironic to note that biology has progressed to the point where these old myths have been dusted off. Today the word chimera has a different meaning: It refers to fragments of DNA from two organisms that have been joined to make a single DNA molecule. Although these DNA chimeras have not yet merged the serpent, the goat, and the lion, they have carried human genes into mice, produced plants that glow in the dark, and made it possible to design new organisms to suit human needs.

CHAPTER OUTLINE

12–1 Modifying the Living World
- Breeding Strategies
- Mutations: Producing New Kinds of Organisms

12–2 Genetic Engineering: Technology and Heredity
- The Techniques of Genetic Engineering
- Engineering New Organisms

12–3 The New Human Genetics
- Analyzing Human DNA
- DNA Fingerprinting
- Sequencing the Human Genome
- Genetic Engineering of Humans
- Ethical Issues

12–1 Modifying the Living World

Section Objectives

- Describe breeding strategies that have been used to modify living things.
- Explain how mutations in organisms can be useful to humans.

We humans are rarely, if ever, satisfied with the world around us. We are always trying to improve it. Humans are not content with merely altering the course of a river, building cities, or sailing the seas. For thousands of years we've been trying to do something equally remarkable: to make "better" living things.

Breeding Strategies

Farmers and ranchers throughout the world have long tried to improve the organisms with which they work. **By selecting the most productive plants or animals to produce the next generation, people have found that the productivity of a domesticated species can gradually be increased.** Such an increase in productivity results from using breeding strategies such as selective breeding and two special forms of selective breeding: inbreeding and hybridization.

SELECTIVE BREEDING The oldest and most obvious way of improving a species is by **selective breeding**, or selecting a few individuals to serve as parents for the next generation. By crossing only those individual plants or animals that have a



Figure 12–1 *The small horse is a full-grown miniature horse. Miniature horses, which are 86 centimeters high at the shoulder (or less), are the product of selective breeding. First produced in the mid-1700s, they were originally intended to pull ore carts in the low, narrow passages of mines. However, they were soon adopted as exotic pets by wealthy families.*



Figure 12–2 Selective breeding has produced domestic animals such as pigs (top) that are very different from their wild ancestors (bottom).

desired characteristic, the breeder can improve the yield of a crop plant, increase the milk production of cattle, or develop flowers of a particular color. Most present-day crop plants were first developed by selective breeding.

Luther Burbank of California (1849–1926) was perhaps the world's foremost selective breeder. Burbank produced more than 250 new varieties of fruit by selective breeding, but his work also extended to other plants, including the daisy and the famous Burbank Potato.

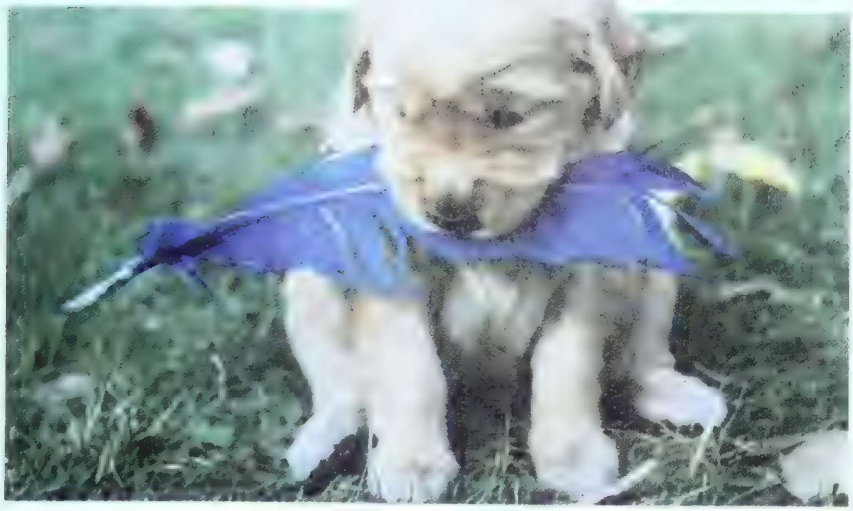
INBREEDING Once a breeder has successfully produced an organism with a useful set of characteristics, the next concern is to maintain a stock of similar organisms. The most direct method is **inbreeding**, or crossing individuals with similar characteristics so that those characteristics will appear in their offspring. Often the individuals crossed in inbreeding are closely related. The many varieties of purebred dogs—including German shepherds, toy poodles, and Great Danes—are maintained by inbreeding. Puppies are considered purebreds only if both their parents are registered members of the same breed.

Although inbreeding is useful in retaining a certain set of characteristics, it does have its risks. Because most of the members of an inbred line are genetically similar, the chances that recessive genetic defects will show up after repeated inbreeding become much greater. Problems in many dog breeds, including deformities in the joints and progressive blindness in German shepherds and golden retrievers, have resulted from repeated inbreeding.

HYBRIDIZATION One of the most useful of the breeder's techniques is **hybridization**, a cross between dissimilar individuals. Hybridization often involves crossing members of different (but related) species. Hybrids, the individuals produced by such crosses, are often hardier than either of the parents. This phenomenon is known as hybrid vigor. All breeds of corn that are grown commercially are hybrids, and every year corn breeders produce new hybrids that combine such basic characteristics as disease resistance, yield per acre, and nutritional value. Modern hybrid corn produces as much as ten times the crop per acre of older varieties of corn.

Mutations: Producing New Kinds of Organisms

As useful as selective breeding is, it is confined to characteristics that already exist in the population. But as you may recall from earlier chapters, mutations, which are inheritable changes in DNA, can sometimes produce organisms with new characteristics. If the new characteristics are desirable, breeders can use selective breeding to produce an entire population possessing these characteristics.



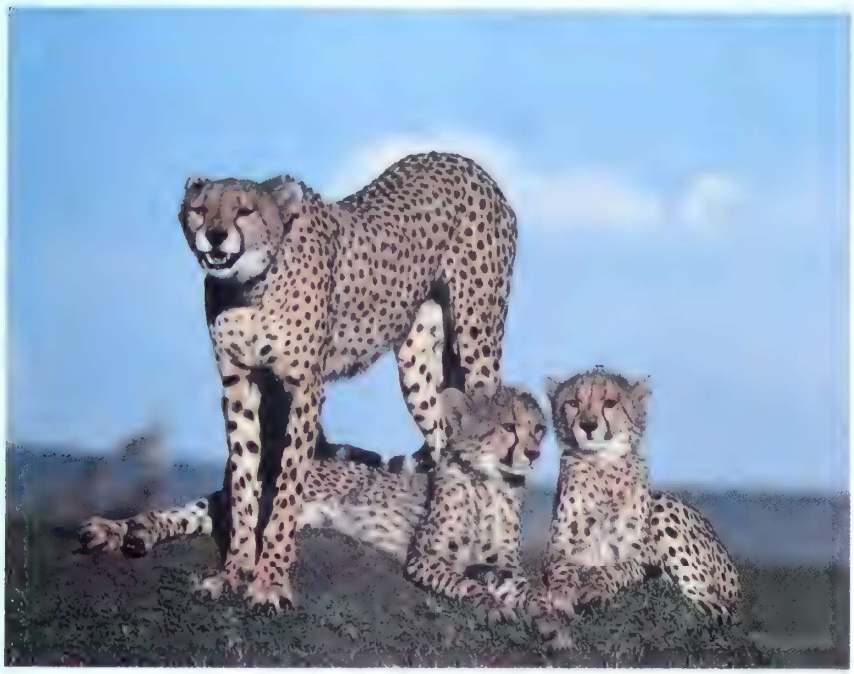


Figure 12–3 *Inbreeding has resulted in an increased susceptibility to diseases and deformities in cheetahs (bottom), dogs, and other organisms. Fortunately for this golden retriever puppy (top), which was bred by Ken Miller, its ancestors have been certified to be free of certain inherited defects. The puppy can be expected to lead a happy—and healthy—life.*

Of course, a breeder may not want to wait for a beneficial mutation to appear naturally. In such a case, a breeder may decide to artificially increase the chances of mutations occurring in a group of organisms. This can be done with agents or substances known as **mutagens**. Mutagens, which include radiation and chemicals, cause mutations. Many mutations are harmful; but with luck and perseverance, a few mutants (individuals with mutations) with desirable characteristics not found in the original population may be produced.

Mutagenesis, or using mutagens to increase the mutation rate, is particularly useful with bacteria. Their small size enables millions of organisms to undergo mutagenesis at the same time, thereby increasing the chances of producing a useful mutant. Using this technique, scientists have been able to develop hundreds of useful bacterial strains. It has even been possible to produce bacteria that can digest oil and are thus useful in cleaning up oil spills.

Figure 12–4 *Seedless oranges and hairless mice are the result of mutations.*



Uniformity or Diversity?

Why would any sensible person want to raise a breed of cows that produces less milk than other breeds? Or a breed of sheep that has coarser wool than other breeds?

At one time, the goals of livestock breeders were plain: to produce animals that yielded high-quality products, were highly productive, and completely predictable. Uniformity was particularly important. It is easier and less expensive to raise large numbers of animals if all the individuals have the same needs and growing times.



Although belted Galloway cattle are not as productive as modern breeds, they contain a wealth of potentially useful genes, such as those for the ability to thrive on poor-quality food.

However there is a problem associated with the improvements that result from uniformity in domestic animals. Modern breeds are homogeneous; that is, the genes of individuals are almost identical. Although genetic similarity is good in terms of raising livestock and producing animal products of uniformly high quality, it is potentially disastrous in the long run. Similar animals are similarly vulnerable to changes in their environment. For example, a single disease could wipe out an entire herd or flock of genetically similar animals. (In a group of genetically diverse animals, the same disease might kill only susceptible individuals. The resistant individuals could go on to produce resistant offspring.)

This is where the old-fashioned breeds come in. Although the productivity of old-fashioned breeds is lower than that of modern breeds, they have greater genetic diversity. They are vital to modern agriculture because they serve as banks of genes that may be useful in livestock at a future date.

So here's the dilemma for breeders: The breeding strategies for preserving genetic diversity are opposite those for producing commercially feasible livestock. To preserve genetic diversity, breeders must ensure that as many individuals as possible breed and pass on their genes to the next generation. Selective breeding—allowing only the best individuals to produce the next generation—automatically breeds out many genes. And these may be precisely the genes that are needed in the future.

12-1 SECTION REVIEW

1. What is selective breeding? Inbreeding? Hybridization?
2. What are some advantages of breeding strategies?
3. Why might breeders want to cause mutations in plants?
4. Many human societies have laws preventing close blood relatives from marrying. How are these restrictions related to the practice of inbreeding?

12–2 Genetic Engineering: Technology and Heredity

Section Objectives

- Describe how DNA is isolated, cut, spliced, and handled.
- Explain how DNA is used to transform cells and organisms.

Ultimately, the selection techniques that humans use to generate new breeds of plants and animals affect DNA, the molecule that carries genetic information. Hybridization, inbreeding, and mutagenesis are, after all, indirect techniques designed to alter the DNA of a particular organism.

In the last two decades molecular biologists have developed a powerful new set of techniques that affect DNA directly. For the first time biologists can engineer a set of genetic changes directly into an organism's DNA. Appropriately enough, this new form of manipulation is called **genetic engineering.**

The Techniques of Genetic Engineering

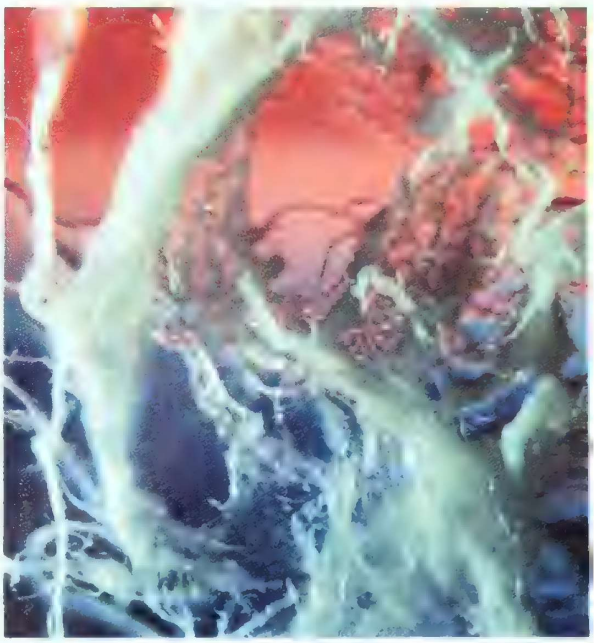
Genetic engineering could not have come about without the development of a technology to support the process. The Wright Brothers could not have built an airplane without the existence of a small gasoline engine and lightweight metal tubing. Such equipment was actually developed for the automobile and the bicycle; but once available, it was adapted to the needs of a flying machine. The story of genetic engineering is much the same.

Imagine for a moment the tools you would need to take a gene from one organism and place it into another. First, you would need a way to carefully cut the DNA containing the gene away from the genes surrounding it. Second, you would have to find a way to combine that gene with a piece of DNA from the recipient organism; that is, the organism that will receive the DNA. Third, you would have to insert the combined DNA into the new organism. Finally, it would be useful to have a way to read the sequences of nucleotide bases in the gene in order to analyze the genes that you are manipulating. Each of these tools is now available, making it possible to insert a gene from one organism into another.

RESTRICTION ENZYMES Genes can be cut at specific DNA sequences by proteins known as **restriction enzymes**. More than 75 different kinds of restriction enzymes are known, and each one "recognizes" and cuts DNA at a particular sequence. The cutting sites of three typical restriction enzymes are shown in Figure 12–6 on page 252. Each one of the restriction enzymes shown "recognizes" a site of four to six nucleotide pairs and then makes a cut across both strands of DNA.

The accuracy of these enzymes is breathtaking. They will not cut any sequence other than the one they recognize, even if five out of six bases are identical to their recognition site. Restriction enzymes make it possible to cut DNA into fragments that can be isolated, separated, and analyzed.

Figure 12–5 *These strands of artificial DNA were synthesized from DNA extracted from animal cells. The techniques of genetic engineering allow scientists to manipulate and change DNA directly.*



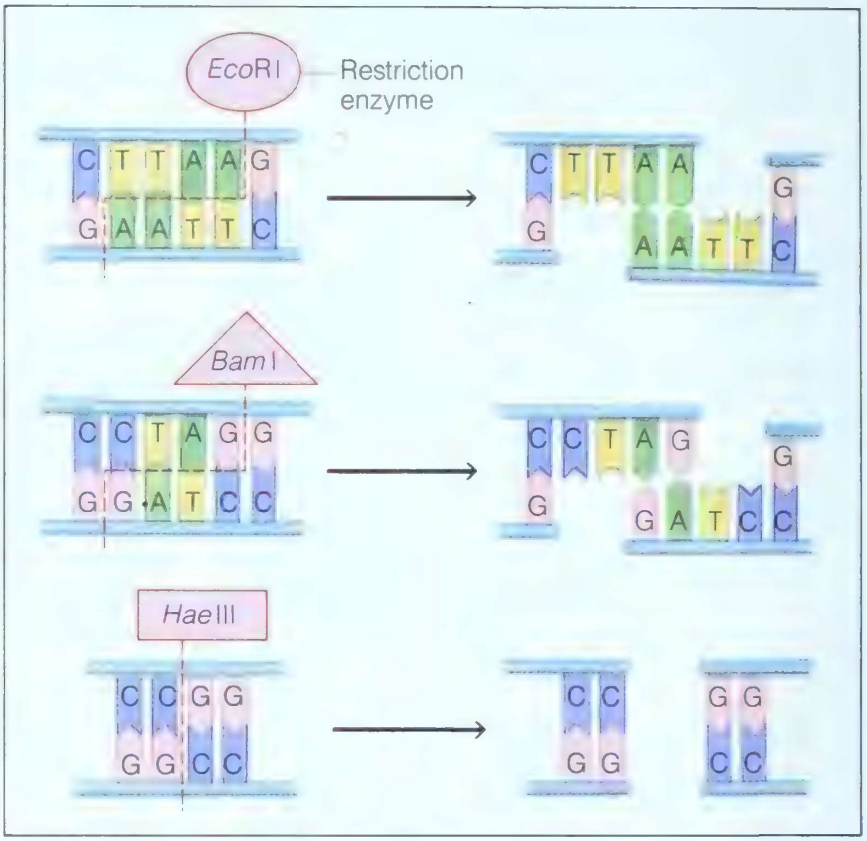
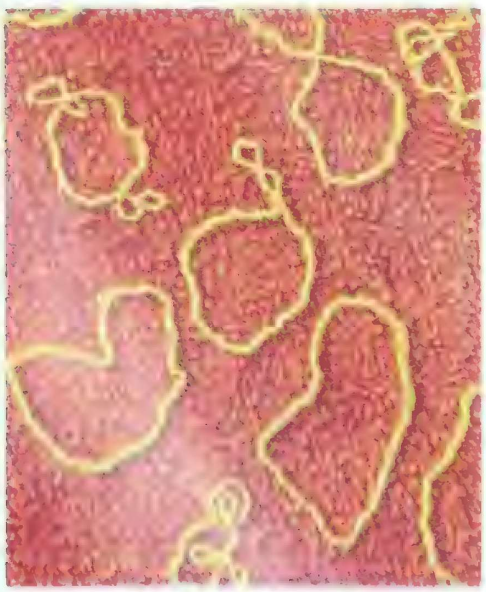


Figure 12–6 *Different restriction enzymes "recognize" different sequences of bases on DNA molecules. Each restriction enzyme cuts DNA at the sites at which its recognition sequence occurs.*

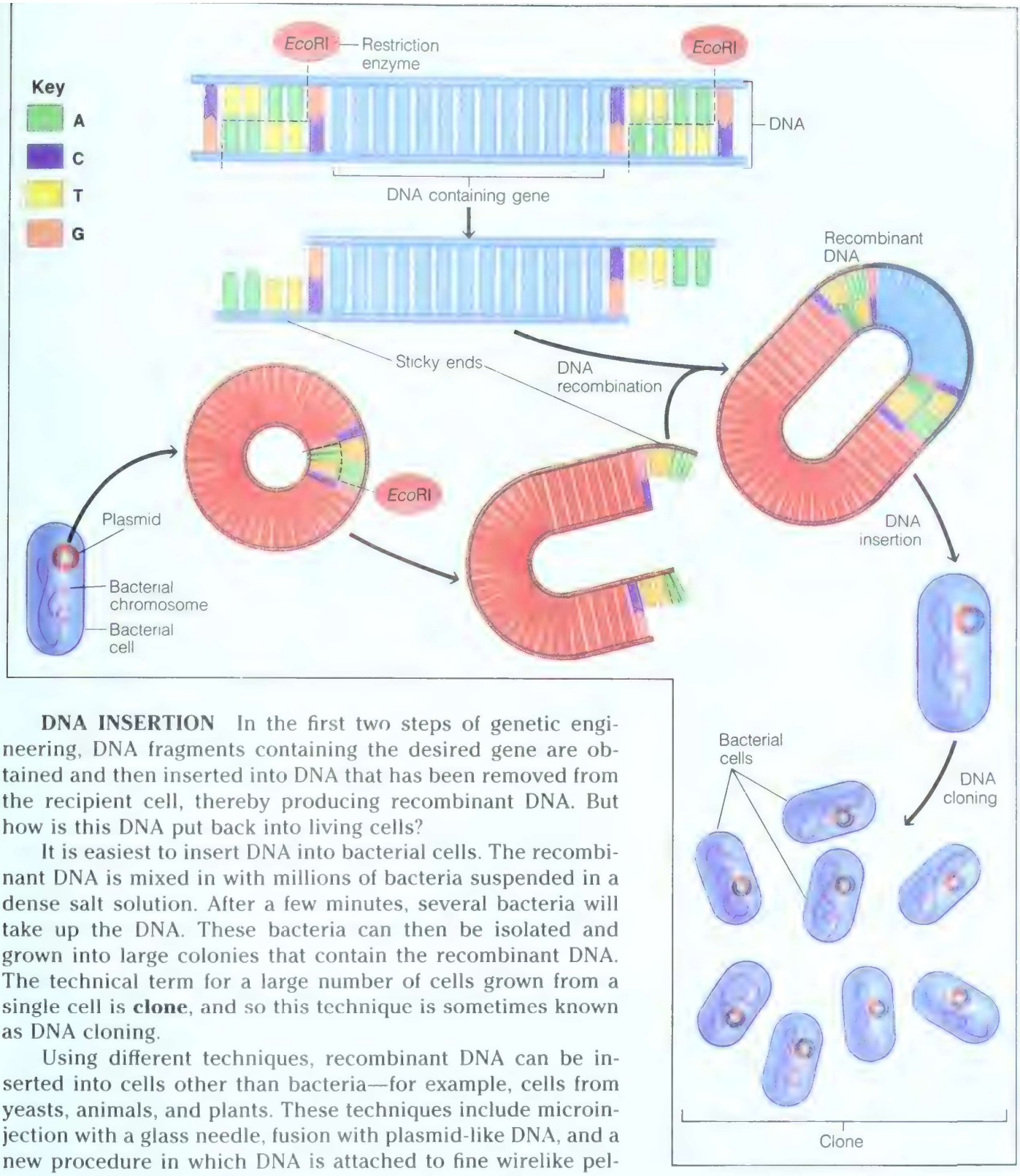
DNA RECOMBINATION DNA fragments cannot function all by themselves. They must become part of the genetic material of living cells before the gene they contain can be activated. In the second step of genetic engineering, DNA fragments are made into part of the recipient cell's genetic material. This is done by combining DNA fragments with DNA from the recipient cell.

For example, DNA fragments may be combined with bacterial DNA so that they can later be inserted into a bacterial cell. Bacteria often contain small circular DNA molecules known as **plasmids** in addition to their chromosomes. These plasmids can be removed from bacterial cells and cut with the same restriction enzyme used to produce the DNA fragments. The cuts made by the restriction enzyme produce matching "sticky ends" on the DNA fragments and the cut plasmids. These sticky ends are the sites at which a DNA fragment and a plasmid can be joined end to end, thereby forming a new plasmid that contains a piece of foreign DNA. See Figure 12–7.

Figure 12–7 *Plasmids are small circular pieces of bacterial DNA.*



Like the mythical chimera (kigh-MIHR-ah), which you read about in the chapter opener, the combined DNA formed by fusing a DNA fragment and a plasmid consists of parts from different kinds of organisms. In genetic engineering, molecules of combined DNA are known as chimeras because they are produced by combining DNA from different species. Combined DNA is also known as **recombinant DNA**, since DNA from two sources has been recombined to produce it.



DNA INSERTION In the first two steps of genetic engineering, DNA fragments containing the desired gene are obtained and then inserted into DNA that has been removed from the recipient cell, thereby producing recombinant DNA. But how is this DNA put back into living cells?

It is easiest to insert DNA into bacterial cells. The recombinant DNA is mixed in with millions of bacteria suspended in a dense salt solution. After a few minutes, several bacteria will take up the DNA. These bacteria can then be isolated and grown into large colonies that contain the recombinant DNA. The technical term for a large number of cells grown from a single cell is **clone**, and so this technique is sometimes known as DNA cloning.

Using different techniques, recombinant DNA can be inserted into cells other than bacteria—for example, cells from yeasts, animals, and plants. These techniques include microinjection with a glass needle, fusion with plasmid-like DNA, and a new procedure in which DNA is attached to fine wirelike pellets that are then shot into cells with a microscopic gun.

Figure 12–8 *In genetic engineering, foreign genes are inserted into plasmids. The altered plasmids are then used to carry the foreign genes into a bacterial cell.*

DNA SEQUENCING Sequencing a piece of DNA, or reading the sequence of DNA bases along its length, can now be accomplished. Only one of the two strands of the DNA double helix is used in the process of DNA sequencing. However, many copies of this one strand are needed. These multiple copies can be produced through the process of DNA cloning.

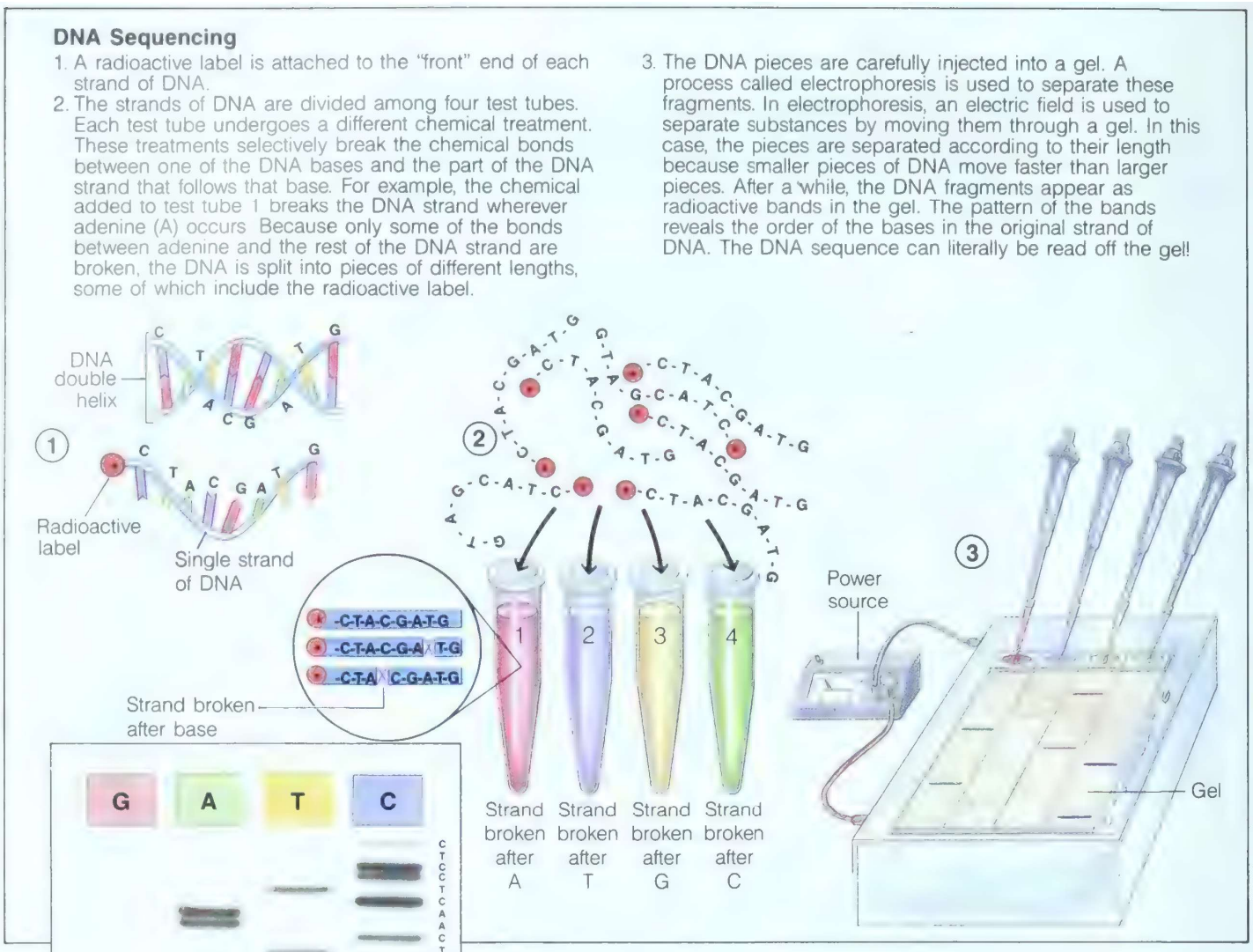


Figure 12–9 In DNA sequencing, DNA is treated to produce pieces that are then separated by electrophoresis. The bands on the gel that result from this process reveal the sequence of the bases in DNA (inset).

In DNA sequencing, a radioactive label (in the form of a radioactive phosphorus atom) is added to single-stranded DNA. The DNA is divided into four groups that undergo different chemical treatments. The chemical treatments break the DNA into pieces that when separated reveal the positions of the bases on the original strand. The DNA pieces are separated by an electrical field in a process called electrophoresis (ee-lehk-troh-fuh-REE-sihs). Refer to Figure 12–9 for a more detailed explanation of DNA sequencing.

Engineering New Organisms

Recombinant DNA technology has advanced rapidly in the past few years. Techniques now exist for cutting and splicing DNA molecules, for ensuring that the foreign gene becomes part of the chromosome of the recipient cell, and for controlling the gene once it has been inserted. Organisms that contain such foreign genes are said to be **transgenic**.

GENETIC ENGINEERING IN BACTERIA When a gene coding for a human protein is properly inserted into bacteria, the recombinant cells can be used to produce large amounts of

the protein quickly and inexpensively. As recently as ten years ago, human growth hormone, a protein needed for normal growth and development, was rare and extremely costly. (It could only be obtained in small amounts from cadavers, or dead bodies used for scientific purposes.) Thus people who do not produce normal amounts of this hormone themselves could not always be guaranteed a supply. Genetically engineered bacteria that contain the human growth hormone gene now produce large quantities of this protein, making it plentiful enough to treat everyone who needs it. Other genetically engineered bacteria produce human insulin (another hormone) and interferon, a protein that blocks the growth of viruses and may be useful in cancer treatment.

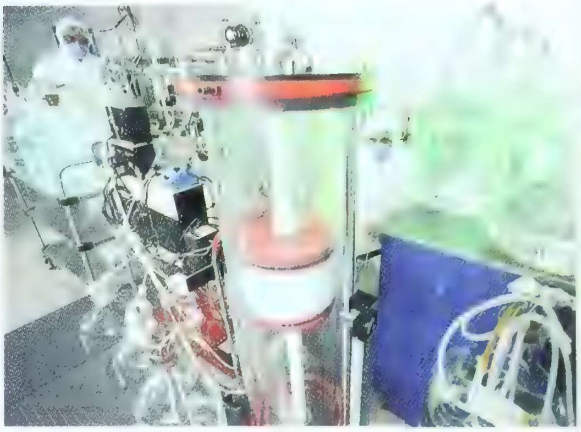


Figure 12–10 *The hepatitis B vaccine being tested here for purity was produced by genetically engineered bacteria.*

GENETIC ENGINEERING IN PLANTS DNA can be injected into plant cells directly or attached to plasmids of certain species of bacteria that infect plant cells. Plant cell biologists have developed techniques that enable a complete transgenic plant to be grown from the cells containing recombinant DNA. The goals of genetic engineering in plants include the production of plants that manufacture natural insecticides and the production of plants that contain genes that enable them to produce their own nitrogen nutrients, thus eliminating the need for fertilizers. Australian researchers have successfully transferred into alfalfa the gene for an enzyme that aids in the synthesis of amino acids and thereby increases the protein content of the plants. These engineered plants will be a new source of protein-rich feed for Australian sheep.

Can genes from animals be made to work in plants? Steven Howell and his associates at the University of California at San Diego provided the answer to that question in 1986. They isolated the gene for luciferase, the enzyme that makes fireflies glow, and inserted it into tobacco cells. When whole plants were grown from the recombinant cells and the gene was activated, the plants glowed in the dark!

Figure 12–11 *Transgenic bacteria are used to make important chemicals such as human insulin (left). This transgenic tobacco plant contains firefly genes (right). When the firefly genes are activated, the plant glows!*

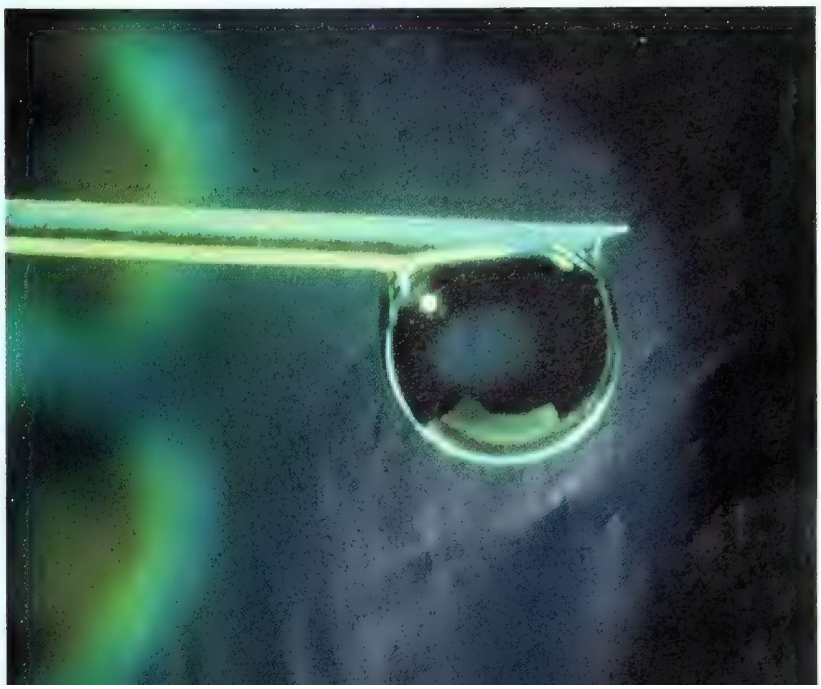






Figure 12–12 This giant mouse, shown next to a normal mouse, is one of the first types of transgenic mammals. The giant mouse developed from a mouse egg that was injected with recombinant DNA containing the gene for rat growth hormone.

GENETIC ENGINEERING IN ANIMALS Genetic engineering has successfully produced a variety of transgenic insects, roundworms, and vertebrates. In one experiment, a group of researchers introduced the growth hormone gene from rainbow trout into carp and produced a bigger, faster-growing fish. The genes of the AIDS virus have been introduced into mice to help develop a strain of mice that can be used for research on the AIDS disease. A number of research groups are now experimenting with transgenic farm animals in hopes of producing meat and milk more quickly.

12–2 SECTION REVIEW

1. What are restriction enzymes? How are they used in genetic engineering?
2. Define recombinant DNA, plasmid, and clone. How do these terms apply to genetic engineering?
3. What is a transgenic plant? How does it differ from a hybrid?
4. What are some of the advantages of genetically engineered proteins such as human growth hormone?

Section Objectives

- Describe some possible applications of analyzing and sequencing human DNA.
- Discuss ethical issues involving new genetic techniques.

12–3 The New Human Genetics

The rapid development of molecular biology has produced a number of other developments. For the first time it has become possible to think about curing genetic diseases. We have also begun to wonder about the practicality of decoding the entire human **genome**, which is all of the genes possessed by humans. And we have started to apply molecular biology to personal identification and the diagnosis of disease.

Analyzing Human DNA

As we saw in Chapter 11, researchers have already developed tests for genetic disorders, which compare human DNA to DNA sequences known to produce the disorders—Huntington disease and sickle cell anemia, for example. In the near future, DNA obtained from prenatal sampling may be tested for the presence of a great many other disorders, enabling physicians to treat some disorders before birth and to be prepared to treat others shortly after birth.

Researchers have also begun to look for genes that might predispose individuals to other medical problems, such as

heart disease, diabetes, and cancer. If tests that identify individuals at risk can be developed, early medical attention would be able to prolong many lives.

DNA Fingerprinting

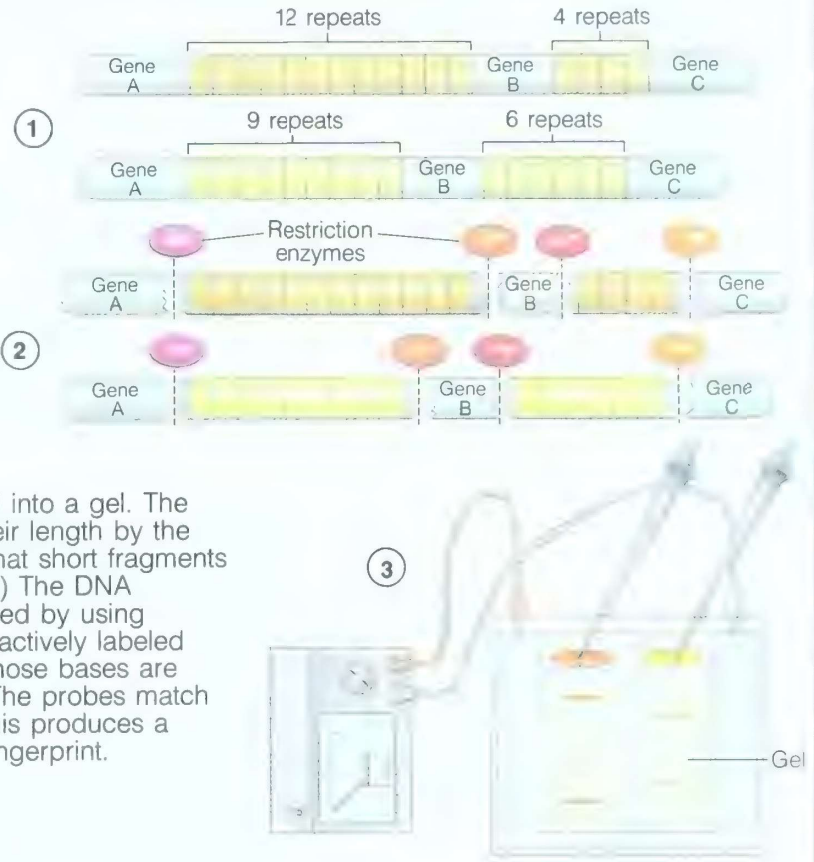
The great complexity of the human genome ensures that no individual is exactly like any other. In the last three years, medical researchers have used this biological fact to add a powerful new tool to criminal investigations. The tool is known as **DNA fingerprinting**. DNA fingerprinting takes advantage of the fact that large portions of the human genome are made up of repeated sequences of varying lengths that do not code for proteins. It has turned out that individuals may have completely different numbers of these repeated units between actual working genes. You may have 15 repeats between two genes; the person sitting next to you in class might have 6 repeats between the same two genes; and someone else may have 33.

Here's how DNA fingerprinting works: A small sample of human DNA is cut with a restriction enzyme. The resulting fragments are separated by size through the process of electrophoresis. Fragments that contain the repeats are then labeled

Figure 12–13 *DNA fingerprinting can be used to match up a suspect with blood, sperm, or other bits of DNA-containing material left at the scene of a crime.*

DNA Fingerprinting

1. There is a large amount of "junk DNA"—DNA that does not code for protein—in the human genome. Junk DNA is made up of repeated sequences that are called repeats. Although individuals may have identical genes, there may be different numbers of repeats between these genes. The more repeats, the longer the junk DNA between genes.
2. Restriction enzymes are used to cut DNA into fragments.
3. The DNA fragments are carefully injected into a gel. The fragments are separated according to their length by the process of electrophoresis. (Remember that short fragments of DNA move faster than long fragments.) The DNA fragments that contain repeats are detected by using radioactive probes. The probes are radioactively labeled pieces of nucleic acids (DNA or RNA) whose bases are complementary to those of the repeats. The probes match up with the repeats and stick to them. This produces a pattern of radioactive bands—the DNA fingerprint.



with DNA "probe," which binds to the DNA sequence of the repeats. This produces a series of bands that by their position show the lengths of the fragments containing the repeats. If enough combinations of restriction enzymes and DNA probes are used, a pattern of bands is produced that can be distinguished from the pattern of any other individual in the world.

DNA samples can be obtained from blood, sperm, and even hair strands with small pieces of tissue at the base. It is clear that DNA fingerprinting will be useful in solving crimes. Several rape suspects have already been convicted in the United States and Great Britain because DNA fingerprinting showed that their DNA patterns matched blood or sperm samples recovered from their victims. And in at least one case, a wrongly accused person has been set free.

Sequencing the Human Genome

Because molecular techniques can help us read the DNA sequence, several prominent scientists have suggested that a large project to sequence the entire human genome should be undertaken. This would be no small task. Working with today's technology, a very productive scientist might be able to sequence about 1000 bases in a week—50,000 bases in a year (allowing for two weeks' vacation)! At that rate, it would take a single scientist more than 100,000 years to sequence the complete genome. However, many scientists are optimistic that automated sequencing methods can be developed so the process could be speeded up dramatically.

A crash program to sequence the human genome would be a vast project. The amount of information gathered would be so enormous that only complex computer systems would be able to manipulate all the data. Nonetheless, there is little doubt that sooner or later, crash program or not, the complete DNA sequence of the human genome will be determined. When that day comes, we will be closer than ever to achieving the poet Alexander Pope's directive: "Know then thyself . . . the glory, jest, and riddle of the world."

Genetic Engineering of Humans

Because humans are animals, too, there is no *technical* barrier to the insertion of foreign genes into human cells. Many transgenic mammals have been produced by injecting DNA into fertilized ova (eggs) and then transplanting the ova back into a female reproductive tract. This strategy could work with humans as well.

A review of a few of the genetic diseases found in our own species indicates that there is plenty of room for genetic engineering of human cells. Cystic fibrosis, Tay-Sachs disease, and a host of other genetic disorders might be treated by replacing defective genes. The genes for a polypeptide in human hemo-

globin have already been inserted into bone marrow cells of mice, suggesting that it might be possible to treat human diseases like sickle cell anemia in the same way.

Ethical Issues

Despite these possibilities, there are problems, risks, and doubts that have persuaded many scientists that the time is not yet right to carry out these procedures on human beings. Of course it would be marvelous to be able to cure hemophilia or other genetic diseases. But could we be sure that experimentation on humans would involve only diseases? If human cells can be manipulated in this way, should we try to engineer taller people or change their eye color, hair texture, sex, blood type, ear shape? What will happen to the human species and to our conception of ourselves if we gain the opportunity to design our bodies? What will be the consequences if we develop the ability to "clone" ourselves by making identical genetic copies of our own cells? These are questions that science will rapidly force us to come to grips with.

If we acquire the ability to alter ourselves, we shall also acquire awesome responsibilities. How shall we decide which genes should be transplanted, altered, or redesigned? Who shall determine whether experiments with genetic engineering should be done? Scientists? A government agency? The local community?

As we said in Chapter 1, the purpose of science is to gain a better understanding of the nature of life. The more we understand life, the more we shall be able to manipulate it. As our power over nature increases, our society shall have to learn to use wisely the tools that science has given us. And we shall have to develop a thoughtful and ethical consensus of what should and should not be done with the human genome. Scientists alone should not be expected to assume all of the responsibility for these decisions. Society in its entirety should have to deal with these questions. To do anything less would be to lose control of our most precious gifts: our intellect and our humanity.

12-3 SECTION REVIEW

1. What are some potential benefits of genetic analysis?
2. What is DNA fingerprinting? How does it work?
3. What are some of the principal ethical issues involved in human genetic engineering?
4. If human bone marrow cells were removed, altered genetically, and reimplanted, would the change be passed on to a patient's children?

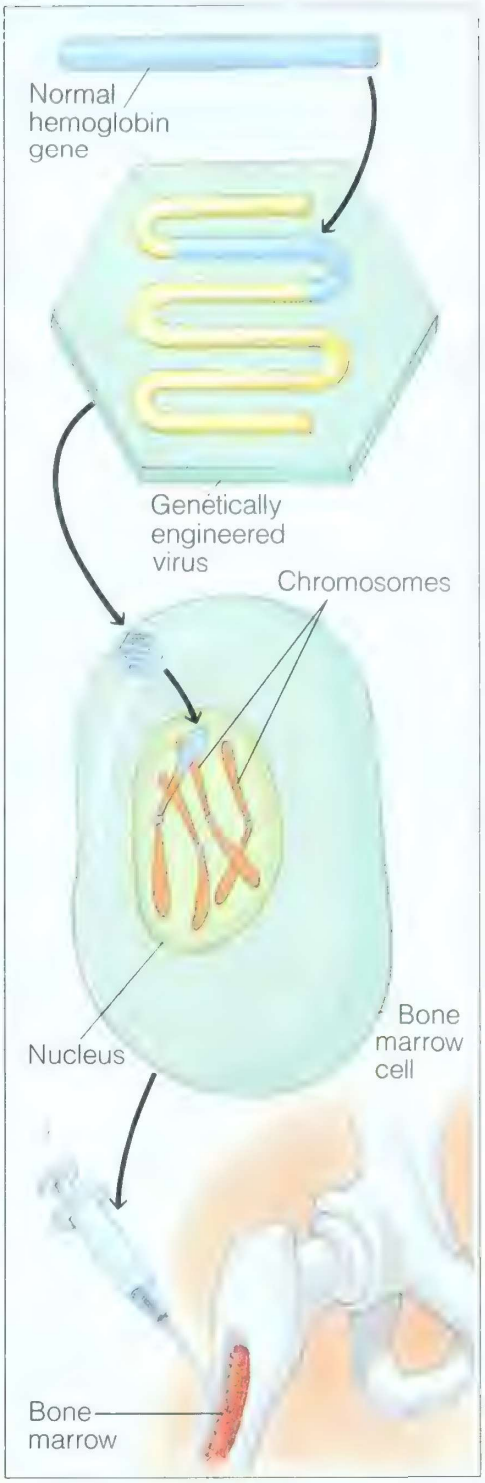


Figure 12-14 *Gene therapy may someday make it possible to "correct" cells that contain defective genes and thus cure genetic diseases.*

LABORATORY INVESTIGATION

SIMULATING DNA FINGERPRINTS

PROBLEM

How can DNA be used for the identification of criminals?

MATERIALS *(per student)*

scissors graph paper

PROCEDURE

1. The accompanying table describes the pattern of genes and repeats of a particular segment of DNA for five individuals. This information will be used to construct models of the DNA segment for each of the five individuals.

Individual	DNA Sequence
1	*G1 G2* **10R** *G3* **4R** *G4 G5* **7R** *G6* **6R** *G7*
2	*G1 G2* **1R** *G3* **15R** *G4 G5* **3R** *G6* **2R** *G7*
3	*G1 G2* **11R** *G3* **8R** *G4 G5* **5R** *G6* **3R** *G7*
4	*G1 G2* **6R** *G3* **2R** *G4 G5* **9R** *G6* **7R** *G7*
5	*G1 G2* **4R** *G3* **5R** *G4 G5* **12R** *G6* **4R** *G7*

Key: G = gene R = repeats

2. Cut a lengthwise strip of graph paper two boxes wide. Starting at the top, label the first box *G1* and the second box *G2*.
3. For each repeat, label a box *R*. For example, for individual 1, the ten boxes following G2 would be labeled *R*.
4. Continue labeling the boxes through to *G7*, remembering to put the proper number of *R*'s (repeats) in the correct locations. Write the number of the individual on the back of the strip.
5. Fold a clean sheet of graph paper into sixths lengthwise. Unfold the paper and number the boxes up the left-hand edge, starting at the bottom, from 1 through 25. This sheet will be used to record the DNA fingerprints of individuals 1 through 5 and of an unknown criminal. Label the first of the six columns *1* for individual 1; the second, *2* for individual 2; and so on. Label the sixth column *CRIMINAL*.
6. Select one of the five individuals to be a criminal. *Note: Do not tell your classmates which individual you have selected.* Make a duplicate strip of DNA for that individual following the procedure outlined in steps 3 through 5.
7. Cut the strip representing the criminal's DNA between genes 4 and 5. This represents the cutting of DNA by restriction enzymes.
8. Arrange the two pieces of the DNA strip in order of size, with the largest first. This represents the separation of DNA pieces through electrophoresis.
9. Count the number of boxes in the longest piece of DNA. Color in a box in the column of your data table marked *CRIMINAL* directly across from this number. Repeat this procedure using the shorter fragment. You should have two marks in the column. These represent the marks that DNA tagged with a radioactive probe would leave on a photographic plate—a DNA fingerprint.
10. Exchange the DNA fingerprint of your criminal with one of your classmates.
11. Prepare DNA fingerprints for individuals 1 through 5.

OBSERVATIONS

1. Did any of the five individuals have the same DNA fingerprints?
2. Which individual was the criminal?

ANALYSIS AND CONCLUSIONS

1. If the possible number of repeats between two genes varies between 1 and 20, what is the probability of having exactly 3 repeats?
2. Why is it unlikely that two individuals would have the same DNA fingerprint?
3. If blood or hair samples are recovered at the scene of a crime, how could they be used to make a positive identification of a criminal?

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

12–1 Modifying the Living World

- By using carefully selected individuals as parents for the next generation, people can improve and change domesticated plants and animals.
- Inbreeding involves crosses between similar individuals.
- Hybridization involves crossing dissimilar individuals.
- Random mutations, which can be caused artificially, can produce useful variations in organisms.

12–2 Genetic Engineering: Technology and Heredity

- Genetic engineering changes DNA through direct manipulation.
- Restriction enzymes are used to cut DNA. The cut DNA can be combined with other DNA molecules and inserted into organisms in various ways.
- There are techniques for reading the sequence of bases in DNA.
- Genetic engineering uses DNA to transform cells and organisms.

12–3 The New Human Genetics

- Human DNA can be analyzed to detect genetic diseases.
- DNA fingerprinting can be used to solve crimes and identify people.
- The technology exists to determine the sequence of the entire human genome.
- There are many ethical considerations that must be taken into account before new genetic techniques are applied to humans.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

12–1 Modifying the Living World

selective breeding
inbreeding
hybridization
mutagen

12–2 Genetic Engineering: Technology and Heredity

genetic engineering
restriction enzyme
plasmid
recombinant DNA
clone
transgenic

12–3 The New Human Genetics

genome
DNA fingerprinting

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. Crossing individuals that have similar characteristics and are often closely related is called
   a. hybridization. c. mutagenesis.
   b. inbreeding. d. genetic engineering.
2. A piece of DNA that is produced by combining DNA fragments from different sources is called
   a. hybrid DNA. c. plasmid DNA.
   b. cloned DNA. d. recombinant DNA.
3. A large number of cells grown from a single cell is called a
   a. clone. c. chimera.
   b. hybrid. d. plasmid.
4. A cross between dissimilar individuals is
   a. cloning. c. hybridization.
   b. mutagenesis. d. genetic engineering.
5. Organisms that contain foreign genes are
   a. mutagenized. c. hybridized.
   b. transgenic. d. inbred.
6. What is the name of the process of engineering changes directly into an organism's DNA?
   a. mutagenesis c. selective breeding
   b. hybridizing d. genetic engineering
7. Which technique takes advantage of repeated DNA sequences that do not code for protein?
   a. DNA fingerprinting
   b. DNA sequencing
   c. genetic engineering
   d. cloning
8. The process that uses electricity to separate DNA fragments according to their length is
   a. electrophoresis.
   b. DNA sequencing.
   c. genetic engineering.
   d. mutagenesis.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. Offspring resulting from a cross between <u>similar</u> individuals often show hybrid vigor.
2. A <u>plasmid</u> is a cell or organism whose DNA comes from different species.
3. Crossing similar individuals is called <u>selective breeding</u>.
4. Increasing the mutation rate is called <u>genetic engineering</u>.
5. <u>Transgenic</u> organisms contain foreign genes.
6. A <u>chimera</u> is a large number of cells grown from a single cell.
7. A circular piece of bacterial DNA is called a <u>clone</u>.
8. <u>DNA fingerprinting</u> produces a pattern of bands that is unique for each person.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

1. hybridization, genetic engineering, selective breeding, inbreeding
2. restriction enzymes, recombinant DNA, DNA cloning, mutagenesis
3. clone, chimera, transgenic, recombinant DNA

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Explain why inbreeding and hybridization are sometimes considered to be forms of selective breeding.
2. Describe the processes involved in creating bacteria that produce human proteins.
3. How is mutagenesis useful to humans?
4. The nuclei from certain cells in an adult frog can be placed into frog eggs from which the nuclei have been removed. This produces genetically identical frog embryos. Explain why these embryos are considered to be a clone.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** Suppose a plant breeder has thornless rose bushes that have pink flowers, thorny rose bushes that have sweet-smelling yellow flowers, and thorny rose bushes that have purple flowers. How might the plant breeder develop a purebred variety of thornless sweet-smelling purple roses?
2. **Problem solving** The following fragments are obtained when a gene that consists of 10 codons is cut by restriction enzymes. What is the sequence of bases in the gene? (*Hint:* Look for overlapping sequences on the fragments.)
3. **Making comparisons** Compare the advantages and disadvantages of breeding techniques and genetic engineering.
4. **Applying technology** Describe the processes involved in isolating, cloning, and sequencing a gene.
5. **Expressing an opinion** Should genetic engineering ever be done on humans? If so, under what circumstances? Explain your answer.
6. **Using the writing process** If you could create the "ideal organism" by combining the traits of two organisms, what two organisms would you select and why?

