CHAPTER 13

Genetic Engineering

Excessive inbreeding of cheetahs has resulted in a lack of genetic diversity and a higher rate of mortality.

Inquiry Activity

Can you improve plant breeding?

Procedure

1. Examine 5 apples of different varieties. Record the color, shape, and size of each apple.
2. Record your choices of the varieties that you consider best in color, shape, and size.

Think About It

1. **Formulating Hypotheses** How could you produce an apple that has the best traits of all 5 varieties?
2. **Formulating Hypotheses** Most apple trees do not produce fruit until they are about 15 years old. How could you use your knowledge of DNA to produce a new variety of apple more quickly?

13–1 Changing the Living World

BI 5.c. Students know how genetic engineering (biotechnology) is used to produce novel biomedical and agricultural products.

Visit a dog show, and what do you see? You can compare dogs of every breed imaginable, distinguished from one another by an enormous range of characteristics that are the result of genetic variation. Striking contrasts are everywhere—the size of a tiny Chihuahua and that of a massive great Dane, the short coat of a Labrador retriever and the curly fur of a poodle, the long muzzle of the wolfhound and the pug nose of a bulldog. The differences among breeds of dogs are so great that someone who had never seen such animals before might think that many of these breeds are different species. They're not, of course, but where did such differences come from? What forces gave rise to the speed of a greyhound, the courage of a German shepherd, and the herding instincts of a border collie?

Guide for Reading

Key Concepts
- What is the purpose of selective breeding?
- Why might breeders try to induce mutations?

Vocabulary
selective breeding
hybridization
inbreeding

Reading Strategy: Outlining Before you read, write down the blue headings of the section. As you read, list the important information under each heading.

Selective Breeding

The answer, of course, is that *we* did it. Humans have kept and bred dogs for thousands of years, always looking to produce animals that might be better hunters, better retrievers, or better companions. By **selective breeding,** allowing only those animals with desired characteristics to produce the next generation, humans have produced many different breeds of dogs.

Humans use selective breeding, which takes advantage of naturally occurring genetic variation in plants, animals, and other organisms, to pass desired traits on to the next generation of organisms. Nearly all domestic animals—including horses, cats, and farm animals—and most crop plants have been produced by selective breeding. American botanist Luther Burbank (1849–1926) may have been the greatest selective plant breeder of all time. He developed the disease-resistant Burbank potato, which was later exported to Ireland to help fight potato blight and other diseases. During his lifetime, Burbank developed more than 800 varieties of plants.

Figure 13–1 **Humans use selective breeding to pass desired traits on to the next generation of organisms.** Luther Burbank used selective breeding to develop these Shasta daisies, a popular variety.

Hybridization As one of his tools, Burbank used **hybridization,** crossing dissimilar individuals to bring together the best of both organisms. Hybrids, the individuals produced by such crosses, are often hardier than either of the parents. In many cases, Burbank's hybrid crosses combined the disease resistance of one plant with the food-producing capacity of another. The result was a new line of plants that had the characteristics farmers needed to increase food production. **Figure 13–1** shows hybrid daisies developed using Burbank's techniques.

➤ **Figure 13–2** Inbreeding is required to maintain the characteristics of pedigreed dogs, such as these golden retrievers. However, inbreeding has also increased the breed's susceptibility to diseases and deformities. **Applying Concepts** *What other animals are likely to be inbred?*

Inbreeding To maintain the desired characteristics of a line of organisms, breeders often use a technique known as inbreeding. **Inbreeding** is the continued breeding of individuals with similar characteristics. The many breeds of dogs—from beagles to poodles—are maintained by inbreeding. Inbreeding helps to ensure that the characteristics that make each breed unique will be preserved. The golden retrievers shown in **Figure 13–2** are an example of inbred animals.

Although inbreeding is useful in retaining a certain set of characteristics, it does have its risks. Most of the members of a breed are genetically similar. Because of this, there is always a chance that a cross between two individuals will bring together two recessive alleles for a genetic defect. Serious problems in many breeds of dogs, including blindness and joint deformities in German shepherds and golden retrievers, have resulted from excessive inbreeding.

CHECKPOINT *What is inbreeding?*

▼ **Figure 13–3** **Breeders can increase genetic variation by inducing mutations.** This process was used to produce the oil-eating bacteria shown here. This image was made using a scanning electron microscope and has been artificially colored.

(magnification: 6200×)

Increasing Variation

Selective breeding would be nearly impossible without the wide variation that is found in natural populations. This is one of the reasons biologists are interested in preserving the diversity of plants and animals in the wild. However, sometimes breeders want more variation than exists in nature. **Breeders can increase the genetic variation in a population by inducing mutations, which are the ultimate source of genetic variability.**

As you may recall, mutations are inheritable changes in DNA. Mutations occur spontaneously, but breeders can increase the mutation rate by using radiation and chemicals. Many mutations are harmful to the organism. With luck and perseverance, however, breeders can often produce a few mutants—individuals with mutations—with desirable characteristics that are not found in the original population.

Producing New Kinds of Bacteria This technique has been particularly useful with bacteria. Their small size enables millions of organisms to be treated with radiation or chemicals at the same time. This increases 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, as shown in **Figure 13–3,** and that were once used to clean up oil spills. (Today, naturally occurring strains of oil-digesting bacteria are used to clean up oil spills.)

Producing New Kinds of Plants Drugs that prevent chromosomal separation during meiosis have been particularly useful in plant breeding. Sometimes these drugs produce cells that have double or triple the normal number of chromosomes. Plants grown from such cells are called polyploid because they have many sets of chromosomes. Polyploidy is usually fatal in animals. However, for reasons that are not clear, plants are much better at tolerating extra sets of chromosomes. Polyploidy may instantly produce new species of plants that are often larger and stronger than their diploid relatives. **Figure 13–4** shows some polyploid day lilies. Many important crop plants have been produced in this way, including bananas and many varieties of citrus fruits.

Word Origins

Polyploid comes from the Greek words *polus,* meaning "many," and *-ploos,* meaning "fold." So *polyploid* means "many-fold" or "many times." **How many sets of chromosomes do you think a triploid plant has?**

➤ **Figure 13–4** The day lilies at the right are examples of polyploid plants. New species of plants are produced when the chromosome number is doubled or tripled. Applying Concepts *What are some other examples of polyploid plants?*

13–1 Section Assessment

1. **Key Concept** Give one example of selective breeding.
2. **Key Concept** Relate genetic variation and mutations to each other.
3. How might a breeder induce mutations?
4. What is polyploidy?
5. **Critical Thinking** Comparing and Contrasting You are a geneticist trying to develop a sunflower with red flowers and a short stem. As you compare the sunflowers you have, what genetic variations would you look for? What kinds of plants would you select for crossing?

Focus on the BIG Idea

Science, Technology, and Society Write a paragraph in which you suggest ways that plants could be genetically altered to improve the world's food supply. *Hint:* The first sentence in your paragraph should express the paragraph's main idea.

13–2 Manipulating DNA

BI 5.c. Students know how genetic engineering (biotechnology) is used to produce novel biomedical and agricultural products. ***BI 5.d.** Students know how basic DNA technology (restriction digestion by endonucleases, gel electrophoresis, ligation, and transformation) is used to construct recombinant DNA molecules.

Guide for Reading

Key Concept
- How do scientists make changes to DNA?

Vocabulary
genetic engineering
restriction enzyme
gel electrophoresis
recombinant DNA
polymerase chain reaction (PCR)

Reading Strategy: Previewing Graphics
Before you read this section, examine the figures. Read the captions, and identify questions about or predict relationships among the techniques illustrated.

Until very recently, animal and plant breeders could not modify the genetic code of living things. They were limited by the need to work with the variation that already exists in nature. Even when they tried to add to that variation by introducing mutations, the changes they produced in the DNA were random and unpredictable. Imagine, however, that one day biologists were able to go right to the genetic code and rewrite an organism's DNA. Imagine that biologists could transfer genes at will from one organism to another, designing new living things to meet specific needs. That day, as you may know from scientific stories in the news, is already here.

How are changes made to DNA? **Scientists use their knowledge of the structure of DNA and its chemical properties to study and change DNA molecules. Different techniques are used to extract DNA from cells, to cut DNA into smaller pieces, to identify the sequence of bases in a DNA molecule, and to make unlimited copies of DNA.** Understanding how these techniques work will help you develop an appreciation for what is involved in genetic engineering.

The Tools of Molecular Biology

Suppose you had a computer game you wanted to change. Knowing that the characteristics of that game are determined by a coded computer program, how would you set about rewriting parts of the program? To make such changes, a software engineer would need a way to get the program out of the computer, read it, make changes in it, and then put the modified code back into the game. **Genetic engineering,** making changes in the DNA code of a living organism, works almost the same way.

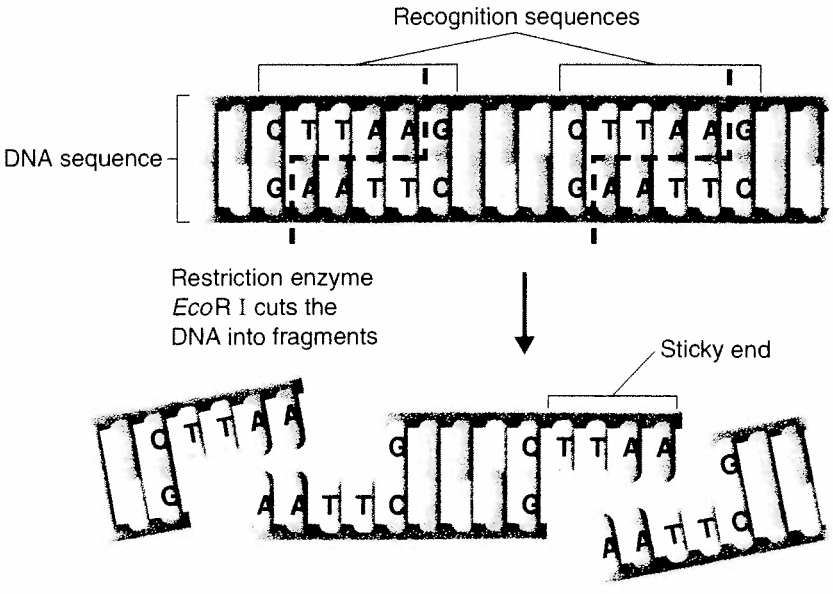


Figure 13–5 Molecular biologists have developed different techniques that allow them to study and change DNA molecules. Endonucleases—enzymes that cut DNA molecules into fragments—are one of their most important tools. The most useful endonucleases are restriction enzymes, which cut DNA at specific sequences. This drawing shows how restriction enzymes are used to edit DNA. The restriction enzyme *Eco*R I, for example, finds the sequence CTTAAG on DNA. Then, the enzyme cuts the molecule at each occurrence of CTTAAG. The cut ends are called sticky ends because they may "stick" to complementary base sequences by means of hydrogen bonds.

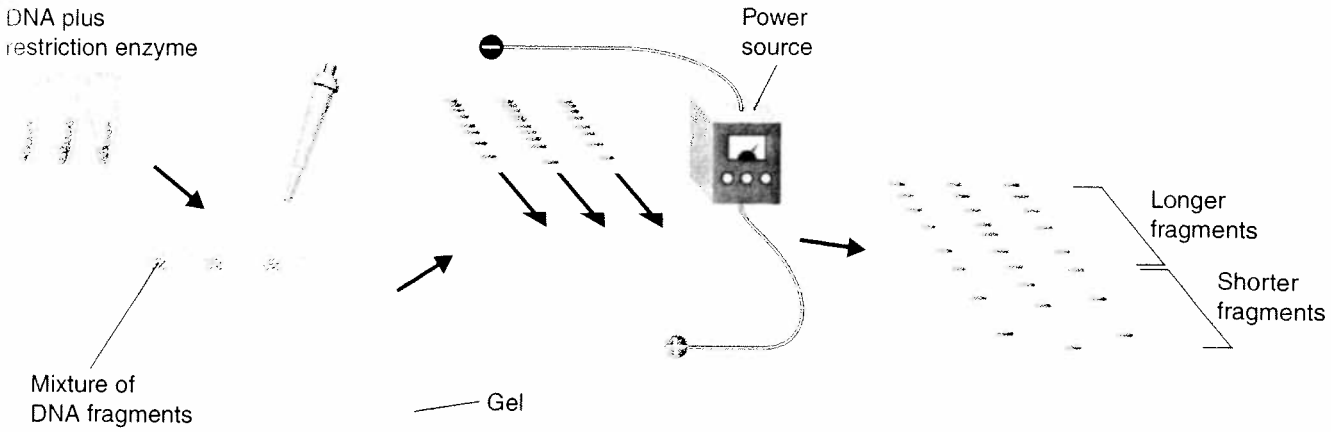


Figure 13–6 Gel electrophoresis is used to separate DNA fragments. First, restriction enzymes cut DNA into fragments. The DNA fragments are then poured into wells on a gel, which is similar to a thick piece of gelatin. An electric voltage moves the DNA fragments across the gel. Because longer fragments of DNA move through the gel more slowly, they do not migrate as far across the gel as shorter fragments of DNA. Based on size, the DNA fragments make a pattern of bands on the gel. These bands can then be compared with other samples of DNA. **Inferring** *What kinds of information might the bands from two different DNA sources provide?*

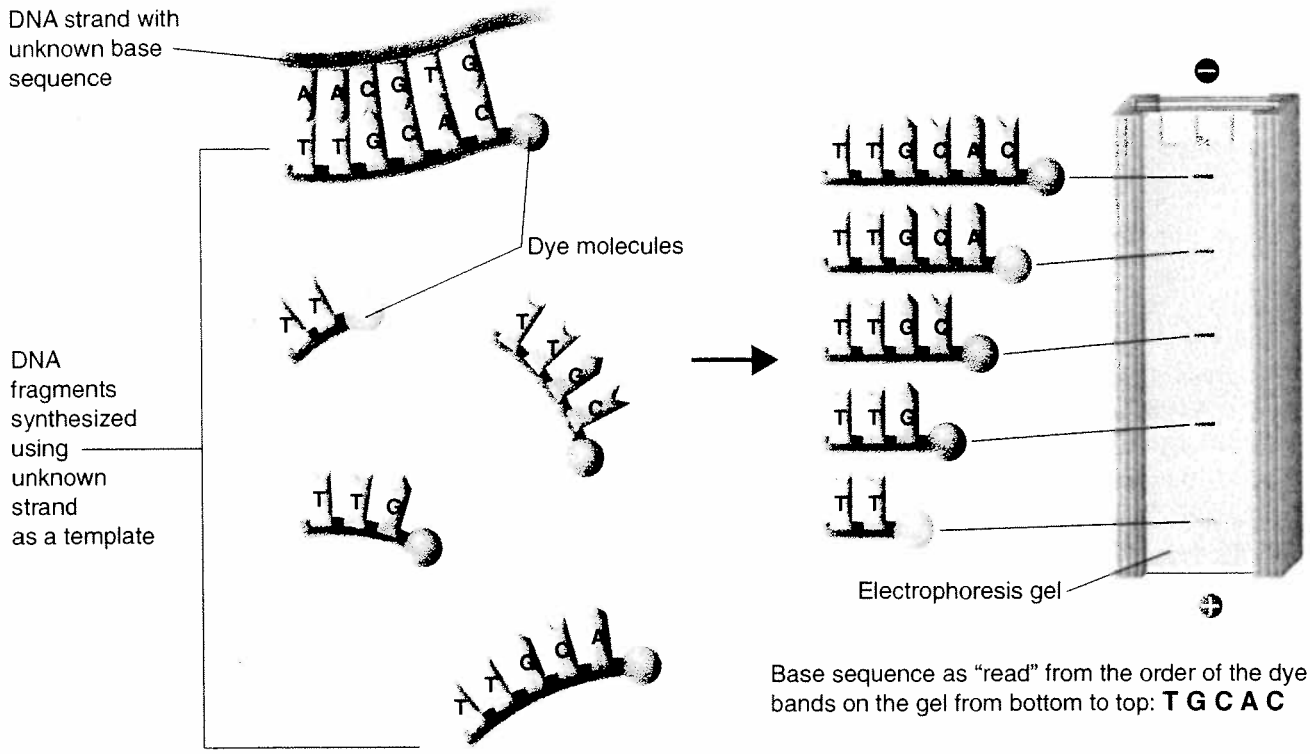
DNA Extraction How do biologists get DNA out of a cell? DNA can be extracted from most cells by a simple chemical procedure: The cells are opened and the DNA is separated from the other cell parts.

Cutting DNA DNA molecules from most organisms are much too large to be analyzed, so biologists cut them precisely into smaller fragments using restriction enzymes. Hundreds of **restriction enzymes** are known, and each one cuts DNA at a specific sequence of nucleotides. As shown in **Figure 13–5**, restriction enzymes are amazingly precise. Like a key that fits only one lock, a restriction enzyme will cut a DNA sequence only if it matches the sequence precisely.

Separating DNA How can DNA fragments be separated and analyzed? One way, a procedure known as gel electrophoresis (ee-lek-troh-fuh-REE-sis), is shown in **Figure 13–6.** In **gel electrophoresis,** a mixture of DNA fragments is placed at one end of a porous gel, and an electric voltage is applied to the gel. When the power is turned on, DNA molecules, which are negatively charged, move toward the positive end of the gel. The smaller the DNA fragment, the faster and farther it moves. Gel electrophoresis can be used to compare the genomes, or gene composition, of different organisms or different individuals. It can also be used to locate and identify one particular gene out of the tens of thousands of genes in an individual's genome.

Using the DNA Sequence

Once DNA is in a manageable form, its sequence can be read, studied, and even changed. Knowing the sequence of an organism's DNA allows researchers to study specific genes, to compare them with the genes of other organisms, and to try to discover the functions of different genes and gene combinations. The following are some techniques scientists use to read and change the sequence of DNA molecules.



▲ **Figure 13–7** **Knowing the sequence of an organism's DNA allows researchers to study specific genes.** In DNA sequencing, a complementary DNA strand is made using a small proportion of fluorescently labeled nucleotides. Each time a labeled nucleotide is added, it stops the process of replication, producing a short color-coded DNA fragment. When the mixture of fragments is separated on a gel, the DNA sequence can be read directly from the gel.

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Reading the Sequence Researchers use a clever chemical trick to "read" DNA by determining the order of its bases. A single strand of DNA whose sequence of bases is not known is placed in a test tube. DNA polymerase, the enzyme that copies DNA, and the four nucleotide bases, A, T, G, and C, are added to the test tube. As the enzyme goes to work, it uses the unknown strand as a template to make one new DNA strand after another. The tricky part is that researchers also add a small number of bases that have a chemical dye attached.

Each time a dye-labeled base is added to a new DNA strand, the synthesis of that strand is terminated. When DNA synthesis is completed, the new DNA strands are different lengths, depending on how far synthesis had progressed when the dye-tagged base was added. Since each base is labeled with a different color, the result is a series of dye-tagged DNA fragments of different lengths. These fragments are then separated according to length, often by gel electrophoresis, as shown in **Figure 13–7.** The order of colored bands on the gel tells the exact sequence of bases in the DNA.

Cutting and Pasting DNA sequences can be changed in a number of ways. Short sequences can be assembled using laboratory machines known as DNA synthesizers. "Synthetic" sequences can then be joined to "natural" ones using enzymes that splice DNA together. The same enzymes make it possible to take a gene from one organism and attach it to the DNA of another organism. Such DNA molecules are sometimes called **recombinant DNA** because they are produced by combining DNA from different sources.

Making Copies In order to study genes, biologists often need to make many copies of a particular gene. Like a photocopy machine stuck on "print," a technique known as **polymerase chain reaction (PCR)** allows biologists to do exactly that. **Figure 13–8** shows how PCR works.

The idea behind PCR is surprisingly simple. At one end of a piece of DNA a biologist wants to copy, he or she adds a short piece of DNA that is complementary to a portion of the sequence. At the other end, the biologist adds another short piece of complementary DNA. These short pieces are known as "primers" because they provide a place for the DNA polymerase to start working.

The DNA is heated to separate its two strands, then cooled to allow the primers to bind to single-stranded DNA. DNA polymerase starts making copies of the region between the primers. Because the copies themselves can serve as templates to make still more copies, just a few dozen cycles of replication can produce millions of copies of the DNA between those primers.

Where did Kary Mullis, the American inventor of PCR, find a DNA polymerase enzyme that could stand repeated cycles of heating and cooling? Mullis found it in bacteria living in the hot springs of Yellowstone National Park—a perfect example of the importance of biodiversity to biotechnology.

CHECKPOINT *What is a polymerase chain reaction?*

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For: Links on recombinant DNA
Visit: www.SciLinks.org
Web Code: cbn-4132

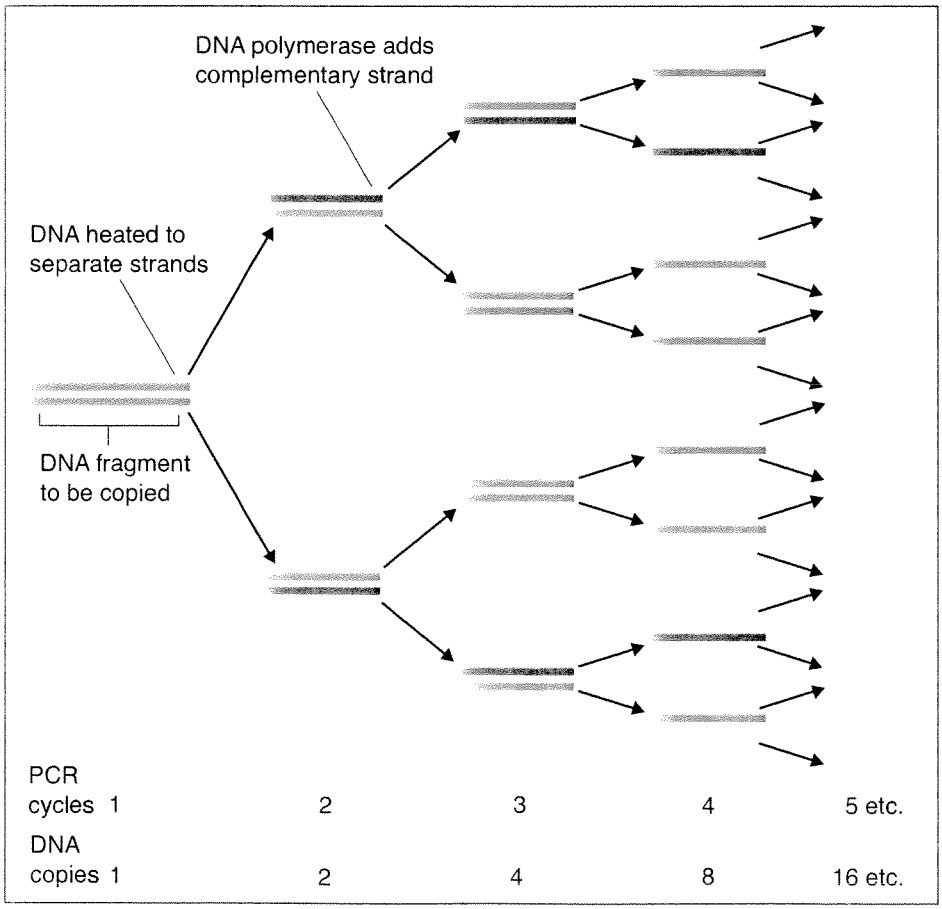
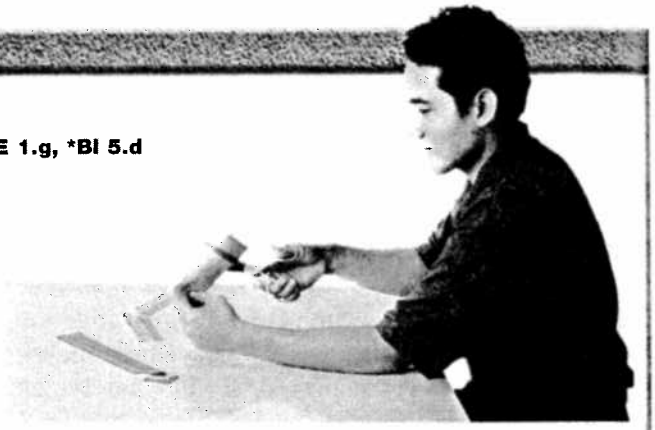


Figure 13–8 Polymerase chain reaction (PCR) is used to make multiple copies of genes. **Calculating** *How many copies of the DNA will there be after six cycles?*

Quick Lab

BIIE 1.g, *BI 5.d

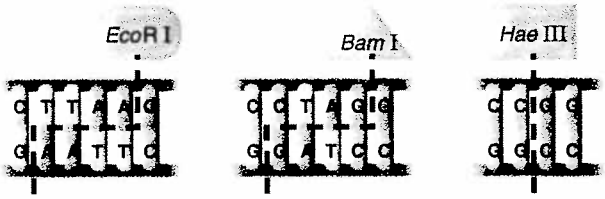


How can restriction enzymes be modeled?

Materials construction paper, scissors, transparent tape

Procedure

1. Write a 50-base double-stranded DNA sequence using the letters A, C, G, and T in random order. Include each of the base sequences shown below at least once in your 50 base-pair sequences.
2. Make three copies of your double-stranded sequence on three different-colored strips of paper.
3. Use the drawings below to see how the restriction enzyme *Eco*R I would cut your double-stranded sequence. Use scissors to cut one copy of the sequence as *Eco*R I would.



4. Use the procedure in step 3 to cut apart another copy of your sequence as the restriction enzyme *Bam* I would. Cut apart the third copy as the restriction enzyme *Hae* III would.
5. To model the building of recombinant DNA, tape the single-stranded end of one of your pieces of DNA sequences to a complementary, single-stranded end of one of a classmate's pieces. This will form a single, long DNA molecule.

Analyze and Conclude

1. **Observing** Which restriction enzyme produced the most pieces? The fewest pieces?
2. **Evaluating** Evaluate your model of restriction-enzyme function according to how well it represents the actual process. (*Hint:* Contrast the length of your model DNA sequence to the actual length of a DNA molecule.)

13–2 Section Assessment

1. **Key Concept** Describe the process scientists use to manipulate DNA.
2. Why might a scientist want to know the sequence of a DNA molecule?
3. How does gel electrophoresis work?
4. Which technique can be used to make multiple copies of a gene? What are the basic steps in this procedure?
5. **Critical Thinking Using Analogies** How is genetic engineering like computer programming?

Writing in Science

Explaining a Process

Write a paragraph that explains, in your own words, how molecular biologists determine the order of bases in a segment of a DNA molecule. *Hint:* Before you write, use a flowchart to organize the steps in the process.

13–3 Cell Transformation

BI 5.c. Students know how genetic engineering (biotechnology) is used to produce novel biomedical and agricultural products. ***BI 5.e.** Students know how exogenous DNA can be inserted into bacterial cells to alter their genetic makeup and support expression of new protein products.

It would do little good to modify a DNA molecule in the test tube if it were not possible to put that DNA back into a living cell and make it work. This sounds tricky, and it is, but you have already seen an example of how this can be done. Remember Griffith's experiments on bacterial transformation? **During transformation, a cell takes in DNA from outside the cell. This external DNA becomes a component of the cell's DNA.**

Today, biologists understand that Griffith's extract of heat-killed bacteria must have contained DNA fragments. When he mixed those fragments with live bacteria, a few of them actually took up the DNA molecules. This suggests that bacteria can be transformed simply by placing them in a solution containing DNA molecules—and indeed they can.

Guide for Reading

Key Concepts
- What happens during cell transformation?
- How can you tell if a transformation experiment has been successful?

Vocabulary
plasmid
genetic marker

Reading Strategy: Summarizing As you read, take notes on how each kind of cell can be transformed. After you read, go back to your notes and compare the different techniques.

Transforming Bacteria

Figure 13–9 shows how bacteria can be transformed using recombinant DNA. The foreign DNA is first joined to a small, circular DNA molecule known as a **plasmid.** Plasmids are found naturally in some bacteria and have been very useful for DNA transfer. Why? The plasmid DNA has two essential features. First, it has a DNA sequence that helps promote plasmid replication. If the plasmid containing the foreign DNA manages to get inside a bacterial cell, this sequence ensures that it will be replicated.

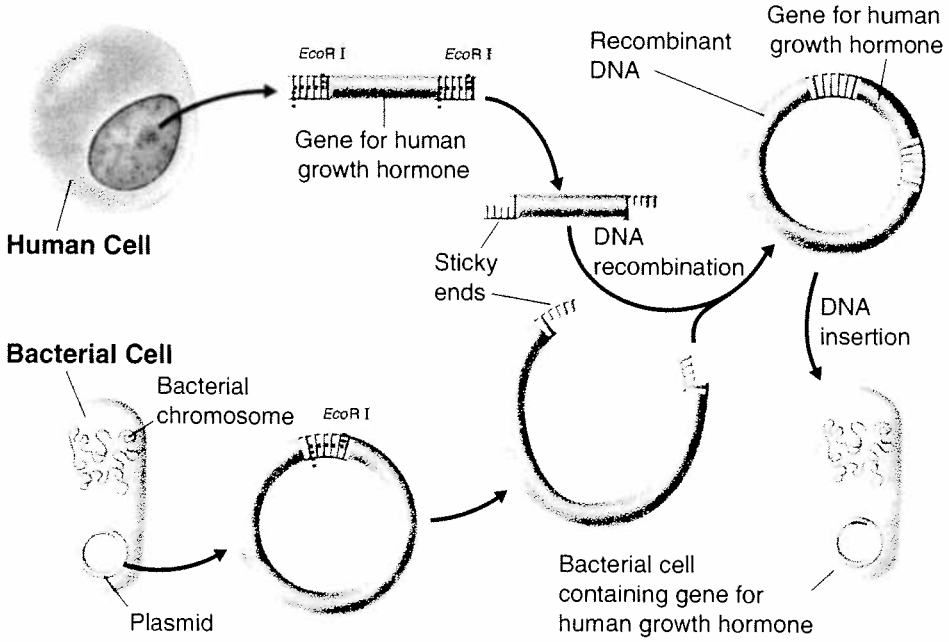


Figure 13–9 During transformation, a cell incorporates DNA from outside the cell into its own DNA. One way to use bacteria to produce human growth hormone is to insert a human gene into bacterial DNA. The new combination of genes is then returned to a bacterial cell. The bacterial cell containing the gene replicates over and over.

Second, the plasmid has a **genetic marker**—a gene that makes it possible to distinguish bacteria that carry the plasmid (and the foreign DNA) from those that don't. Genes for resistance to antibiotics, compounds that can kill bacteria, are commonly used as markers. A marker makes it possible for researchers to mix recombinant plasmids with a culture of bacteria, add enough DNA to transform one cell in a million, and still be able to "find" that cell. After transformation, the culture is treated with an antibiotic. Only those rare cells that have been transformed survive—because only they carry a resistance gene.

CHECKPOINT *What is a genetic marker?*

Transforming Plant Cells

Many plant cells can be transformed by using a process that takes advantage of a bacterium. In nature, this bacterium inserts a small DNA plasmid that produces tumors into a plant's cells. Researchers have discovered that they can inactivate the tumor-producing gene and insert a piece of foreign DNA into the plasmid. The recombinant plasmid can then be used to infect plant cells, as shown in **Figure 13–10.**

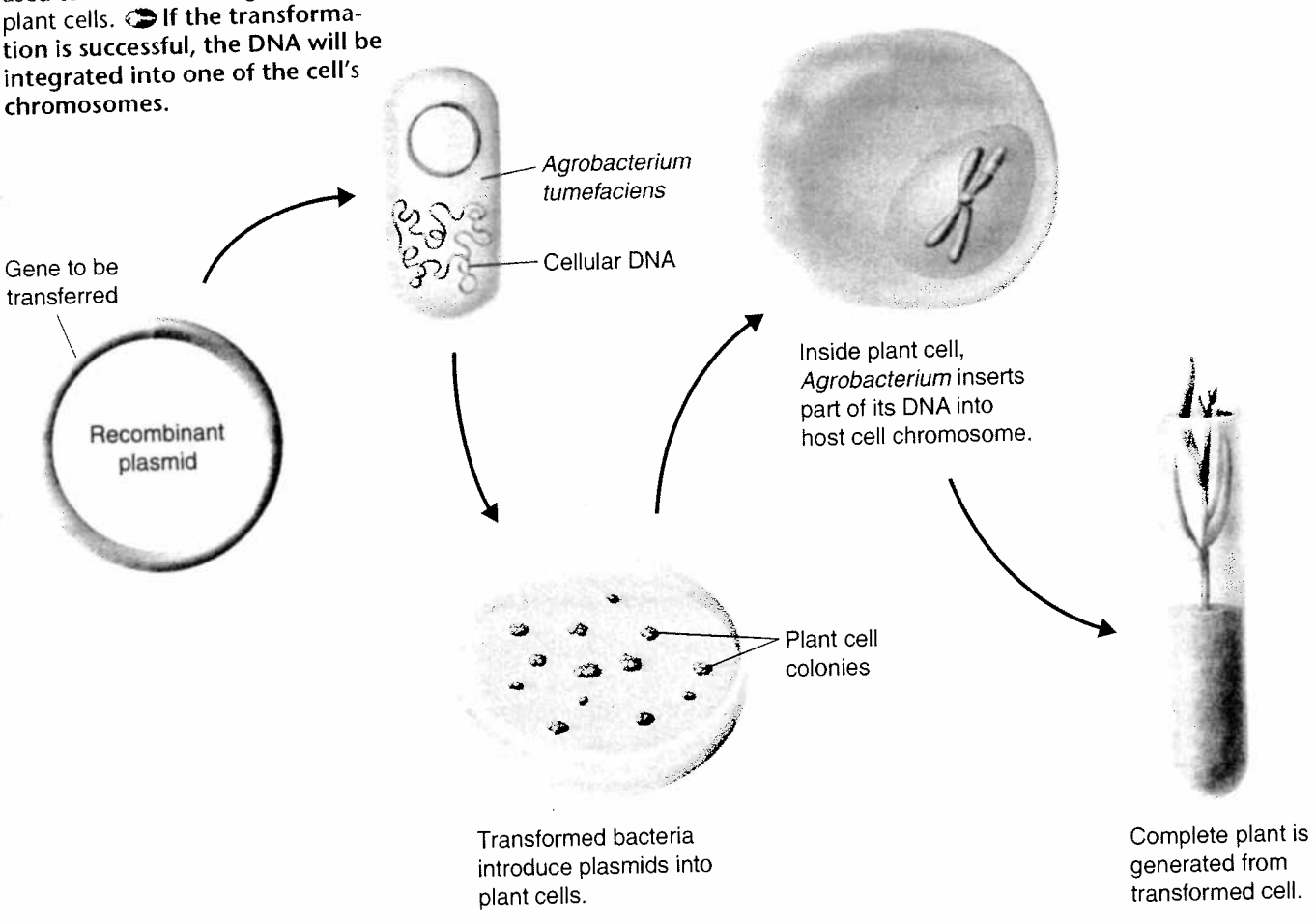


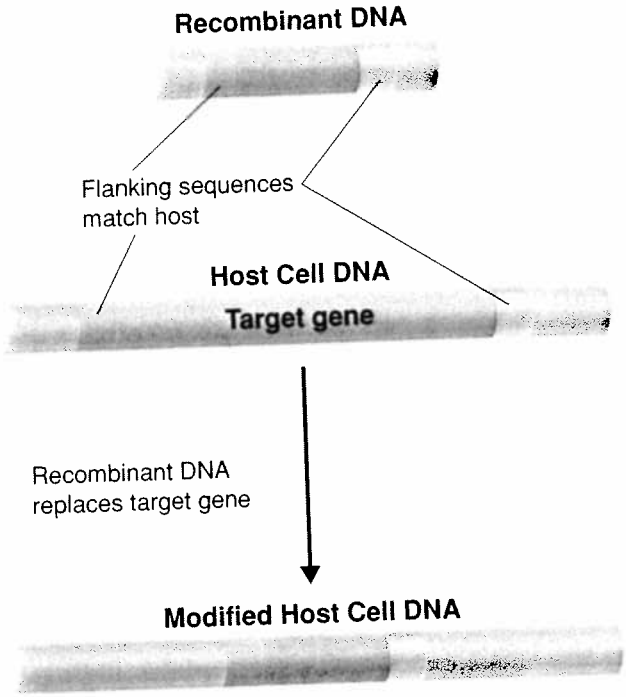
Figure 13–10 The bacterium *Agrobacterium tumefaciens* can be used to introduce foreign DNA into plant cells. **If the transformation is successful, the DNA will be integrated into one of the cell's chromosomes.**

When their cell walls are removed, plant cells in culture will sometimes take up DNA on their own. DNA can also be injected directly into some cells. Cells transformed by either procedure can be cultured to produce adult plants. **If transformation is successful, the recombinant DNA is integrated into one of the chromosomes of the cell.**

Transforming Animal Cells

Animal cells can be transformed in some of the same ways as plant cells. Many egg cells are large enough that DNA can be directly injected into the nucleus. Once inside the nucleus, enzymes normally responsible for DNA repair and recombination may help to insert the foreign DNA into the chromosomes of the injected cell. Like bacterial plasmids, the DNA molecules used for transformation of animal and plant cells contain marker genes that enable biologists to identify which cells have been transformed.

Recently, it has become possible to eliminate particular genes by careful design of the DNA molecules that are used for transformation. As **Figure 13–11** shows, DNA molecules can be constructed with two ends that will sometimes recombine with specific sequences in the host chromosome. Once they do, the host gene normally found between those two sequences may be lost or specifically replaced with a new gene. This kind of gene replacement has made it possible to pinpoint the specific functions of genes in many organisms, including mice.



▲ **Figure 13–11** Recombinant DNA can replace a gene in an animal's genome. The ends of the recombinant DNA recombine with sequences in the host cell DNA. When the recombinant DNA is inserted into the target location, the host cell's original gene is lost or knocked out of its place. **Applying Concepts** *How might this technique be used to treat disorders caused by a single gene? What might be some risks?*

13–3 Section Assessment

1. **Key Concept** What is transformation?
2. **Key Concept** How can you tell if a transformation experiment has been successful?
3. How are genetic markers related to transformation?
4. What are two features that make plasmids useful for transforming cells?
5. **Critical Thinking Comparing and Contrasting** Compare the transformation of a bacterium cell with the transformation of a plant cell.

Writing in Science

Writing a Plan for an Experiment

Imagine that you are a genetic engineer. Determine what your next experiment will be. Then, write up the steps you will follow and what your intended result will be.

ISSUES in Biology

BI 5.c, BIIE 1.m

Do Genetically Modified Foods Need Stricter Controls?

Since they were first introduced in 1994, bioengineered, or genetically modified (GM), crops have become common in the American supermarket and diet. Most GM plants are engineered to produce pest-killing chemicals or to resist weed-killing chemicals. For example, in 1998, 20 percent of U.S. corn crops contained a gene for *Bt-toxin,* a natural insecticide that protects corn plants from the European corn borer, a major insect pest. *Bt*-corn, as this GM corn is called, enables farmers to produce more food on fewer acres, increasing food production and profits.

Many consumers, however, are concerned about the long-term impact of these crops. The European Union, for example, has effectively stopped the import of many GM food crops and required that others be prominently labeled as genetically modified. Should GM foods be more tightly controlled?

The Viewpoints

GM Foods Need Tighter Controls

Some people are concerned that GM foods might have unexpected effects on people. For example, one type of GM corn approved only for animal feed has appeared accidentally in tortillas. The corn contains a protein that could cause allergic reactions in people. The contaminated tortillas show that GM crops can get mixed in with crops that have not been genetically modified.

Genetically modified crops also could pose a hazard to the environment. Antibiotic-resistant genes used as markers could spread into the environment, resulting in antibiotic-resistant bacteria. Pollen from GM plants might transfer genes to wild plants, resulting in "super weeds" that are impossible to control with weed killers. Plants engineered to produce insecticides can kill beneficial insects as well as pests. The spread of these pesticide genes from crop plants into wild plants might harm beneficial insects, such as bees and butterflies.

GM Foods Do Not Need Tighter Controls

Recently developed GM food crops contain essential vitamins that are lacking in the diets of many people. For example, golden rice contains genes that greatly increase its content of beta-carotene, which the body uses to make vitamin A. The high productivity and nutritional benefits of GM crops are especially important in developing countries, where their use may prevent famine and ease suffering.

Because they increase production and reduce the need for chemical pesticides, GM crops can be beneficial to the environment. Someday, GM plants could be sources of medicines, fuels, and plastics. If GM products are more strictly controlled, companies might not research new applications.

Research and Decide

1. **Analyzing the Viewpoints** To make an informed decision, learn more about this issue by consulting library or Internet resources. Then, list the risks and benefits of GM plants.
2. **Forming Your Opinion** Are stricter regulations needed? Give reasons for your opinion.

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BI 5.c. Students know how genetic engineering (biotechnology) is used to produce novel biomedical and agricultural products.

Genetic engineering makes it possible to transfer DNA sequences, including whole genes, from one organism to another. Does this mean that genes from organisms as different as animals and plants can be made to work in each other? American researcher Steven Howell and his associates provided the answer in 1986. They isolated the gene for luciferase, an enzyme that allows fireflies to 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, as you can see in **Figure 13–12.** The gene for luciferase, which comes from an animal, can specify a trait in a plant. This shows that the basic mechanisms of gene expression are shared by plants and animals.

Guide for Reading

Key Concept
- How are transgenic organisms useful to human beings?

Vocabulary
transgenic
clone

Reading Strategy: Monitoring Your Understanding Make a table with three columns. Before you read, write what you already know about cloning in the first column. Under the next heading, write down what you want to learn about cloning. After you read, write down what you learned about cloning in the last column.

Transgenic Organisms

The universal nature of genetic mechanisms makes it possible to construct organisms that are **transgenic,** meaning that they contain genes from other species. Using the basic techniques of genetic engineering, a gene from one organism can be inserted into cells from another organism. These transformed cells can then be used to grow new organisms. **Genetic engineering has spurred the growth of biotechnology, which is a new industry that is changing the way we interact with the living world.**

Transgenic Microorganisms Because they reproduce rapidly and are easy to grow, transgenic bacteria now produce a host of important substances useful for health and industry. The human forms of proteins such as insulin, growth hormone, and clotting factor, which are used to treat serious human diseases and conditions, were once rare and expensive. Bacteria transformed with the genes for human proteins now produce these important compounds cheaply and in great abundance. People with insulin-dependent diabetes are now treated with pure human insulin produced by human genes inserted into bacteria. In the future, transgenic microorganisms may produce substances designed to fight cancer, as well as the raw materials for plastics and synthetic fibers.

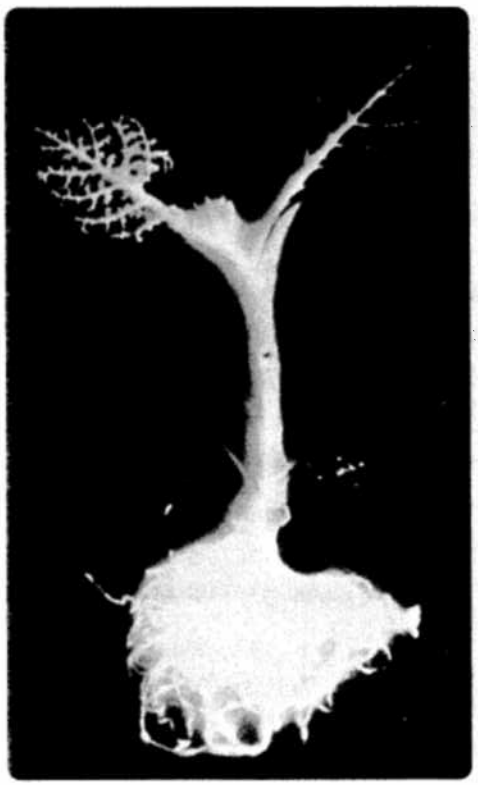

Figure 13–12 **Genetic engineering has changed the way we interact with living things.** This transgenic tobacco plant, which glows in the dark, was grown from a tobacco cell transformed with the firefly luciferase gene. The plant illustrates how DNA from one organism contains information that can specify traits in another organism.

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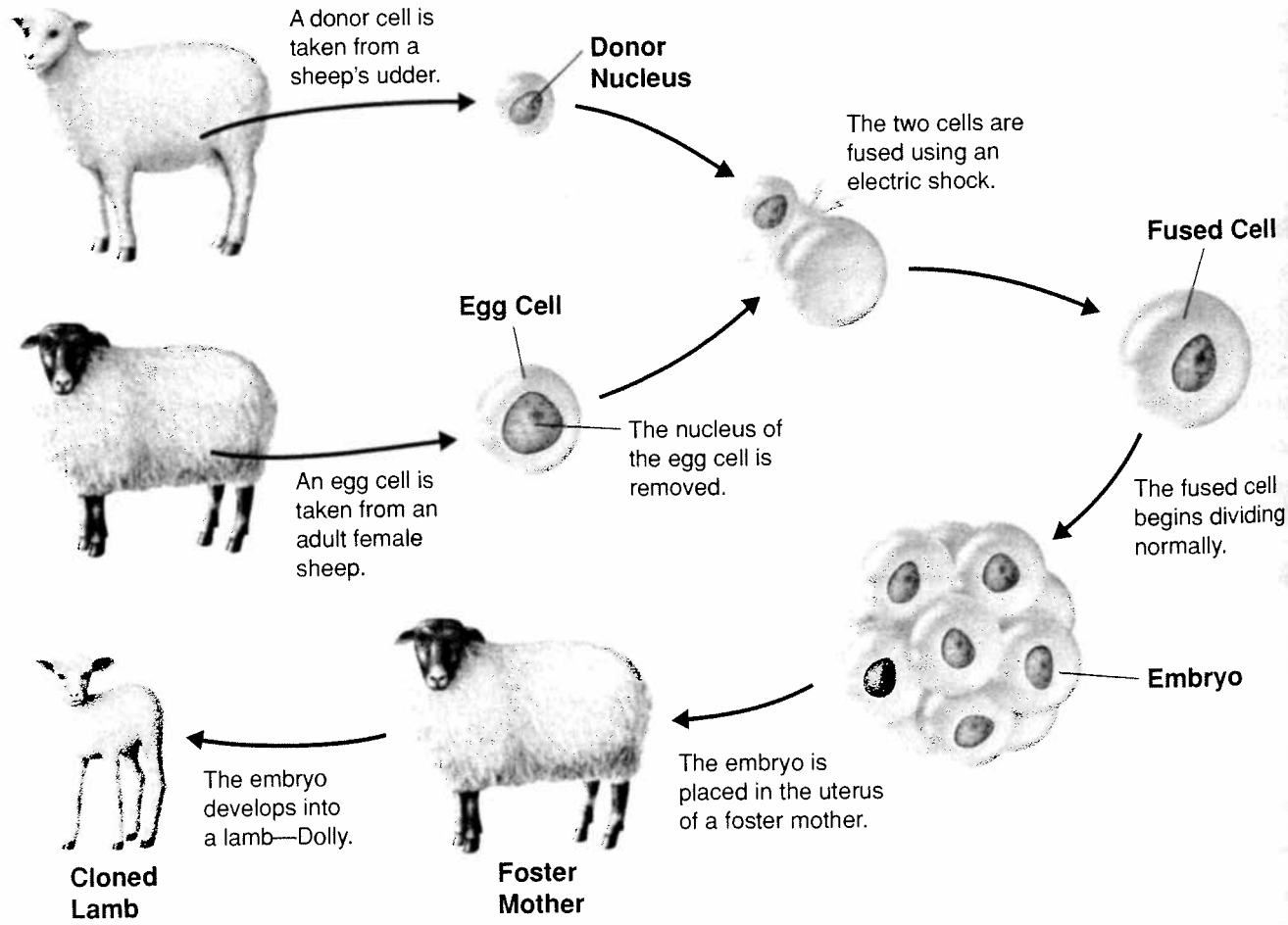
For: Links on genetic engineering
Visit: www.SciLinks.org
Web Code: cbn-4134

Transgenic Animals Transgenic animals have been used to study genes and to improve the food supply. Mice have been produced with human genes that make their immune systems act similarly to those of humans. This allows scientists to study the effects of diseases on the human immune system. Some transgenic livestock now have extra copies of growth hormone genes. Such animals grow faster and produce leaner meat than ordinary animals. Researchers are trying to produce transgenic chickens that will be resistant to the bacterial infections that can cause food poisoning.

In the future, transgenic animals might also provide us with an ample supply of our own proteins. Several labs have engineered transgenic sheep and pigs that produce human proteins in their milk, making it easy to collect and refine the proteins.

Transgenic Plants Transgenic plants are now an important part of our food supply. In the year 2000, 52 percent of the soybeans and 25 percent of the corn grown in the United States were transgenic, or genetically modified (GM). Many of these plants contain genes that produce a natural insecticide, so the crops do not have to be sprayed with synthetic pesticides. Other crop plants have genes that enable them to resist weed-killing chemicals. These genes allow crop plants to survive while weeds are still controlled.



▼ **Figure 13–13** In early 1997, Dolly made headlines as the first clone of an adult mammal.
Applying Concepts *Why did Dolly not look like her foster mother?*

Transgenic plants may soon produce human antibodies that can be used to fight disease, plastics that can now be produced only from petroleum, and foods that are resistant to rot and spoilage. One of the most important new developments in GM foods is a rice plant that contains vitamin A, a nutrient that is essential for human health. Since rice is the major food for billions of the world's people, this rice may improve the diets and health of many people by supplying an important nutrient.

Cloning

A **clone** is a member of a population of genetically identical cells produced from a single cell. Cloned colonies of bacteria and other microorganisms are easy to grow, but this is not always true of multicellular organisms, especially animals. For many years, biologists wondered if it might be possible to clone a mammal—to use a single cell from an adult to grow an entirely new individual that is genetically identical to the organism from which the cell was taken. After years of research, many scientists had concluded that this was impossible.

In 1997, Scottish scientist Ian Wilmut stunned biologists by announcing that he had cloned a sheep. How did he do it? **Figure 13–13** shows the basic steps. In Wilmut's technique, the nucleus of an egg cell is removed. The cell is fused with a cell taken from another adult. The fused cell begins to divide and the embryo is then placed in the reproductive system of a foster mother, where it develops normally. The sheep, which Wilmut named Dolly, is shown in **Figure 13–14.** Cloned cows, pigs, mice, and other mammals have been produced by similar techniques. Researchers hope that cloning will enable them to make copies of transgenic animals and even help save endangered species. On the other hand, the technology is controversial for many reasons, including studies suggesting that cloned animals may suffer from a number of genetic defects and health problems.

The use of cloning technology on humans, while scientifically possible, raises serious ethical and moral issues that have caused many people to oppose such work. As techniques improve, these important issues will become even more pressing.

▲ **Figure 13–14** The adult sheep is Dolly, the first mammal cloned from an adult cell. The lamb is Dolly's first offspring, called Bonnie. The fact that Dolly was cloned did not affect her ability to produce a live offspring. **Inferring** *Why might it be important for cloned animals to be able to reproduce?*

13–4 Section Assessment

1. **Key Concept** List one practical application for each of the following: transgenic bacteria, transgenic animals, transgenic plants.
2. **Key Concept** What is a transgenic organism?
3. What basic steps were followed to produce Dolly?
4. **Critical Thinking Making Judgments** List reasons you would or would not be concerned about eating genetically modified food.

You & Your Community

Conducting a Survey

Survey at least ten people about their viewpoints on cloning animals. To help the people you survey understand the topic, prepare an illustrated explanation of the process of cloning.

7IIE 7.c, 8IIE 9.c, **BIIE 1.a, BIIE 1.b**

Investigating the Effects of Radiation on Seeds

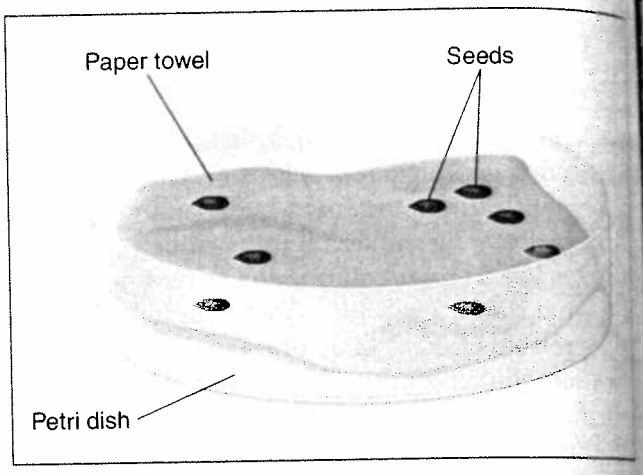
Mutations occur naturally in all organisms. However, an organism's mutation rate increases when it is exposed to certain chemicals or types of radiation. In this investigation, you will design an experiment to test the effects of X-ray exposure on seeds.

Problem **Do plants grown from irradiated seeds show evidence of increased mutation?**

Materials

- irradiated seeds and nonirradiated seeds of the same species
- petri dishes
- paper towels
- plant pots with commercial potting soil
- glass-marking pencil

Skills Forming Operational Definitions



Design Your Experiment

Part A: Plan the Experiment

1. **Designing Experiments** Working with two of your classmates, design an experiment to test the hypothesis that radiation increases the rate of mutation in seeds.
2. As you plan your investigative procedures, refer to the Lab Tips box on page 55 for information on demonstrating safe practices, making wise choices in the use of materials, and selecting equipment and technology.
3. Discuss your experimental plan with your group. Make certain that you have identified and controlled all important variables and included both irradiated and control seeds in your experimental plan.
4. You will not be able to observe mutations in DNA directly. What observations or measurements can you make that will provide evidence of the number of mutations that have occurred in a seed? With your group, plan what observations you will use to estimate the number of mutations that have occurred in a seed.
5. Design a data table in which to record your observations.
6. Show your experimental plan to your teacher. Once your teacher approves your plan, begin your experiment.

Part B: Carry Out Your Experiment

7. To grow the seeds, follow any instructions that are on the seed packages. If there are no instructions, line a petri dish with a paper towel for each experimental group of seeds. Place the seeds in the petri dishes, as shown in the diagram above. Cover the seeds with water. **CAUTION:** *Wash your hands well with warm water and plenty of soap after handling seeds, plants, or soil and before leaving the laboratory.*
8. Place the covers on the petri dishes to protect the seeds from mold and bacteria. Record everything you do to the seeds.
9. Use a glass-marking pencil to label each petri dish. Every petri dish that you use in this experiment should be identified by a different label that includes your name. Store the petri dishes in the location that your teacher designates.
10. Record your observations of each group of seeds every day for 2 weeks. Add water to the petri dishes as necessary to keep the seeds moist.
11. After 2 weeks, count the seeds that failed to germinate. Carefully transfer the young plants from the petri dishes to pots of soil. Water each plant. Label each pot with your name and the kind of plants it contains.

12. Place the potted plants in sunlight or under a fluorescent lamp as your teacher directs. Water the plants regularly. Continue to observe the plants daily, according to your experimental plans, for the next 2 weeks. Record your observations each day.

Analyze and Conclude

1. **Comparing and Contrasting** What differences did you observe between the irradiated seeds and the nonirradiated seeds?
2. **Designing Experiments** How could you best determine whether a seed contains mutant DNA?
3. **Forming Operational Definitions** What kinds of observations did you decide to use as evidence of mutations? Explain why you think that these observations are reliable evidence.
4. **Analyzing Data** Did the irradiated seeds show evidence of more mutations than the nonirradiated seeds?
5. **Formulating Hypotheses** Mutations sometimes cause part of an otherwise healthy-looking leaf or other plant part to appear abnormal. Did you see abnormal-looking areas on any plants? Would you expect this kind of abnormality to be inherited? Explain.
6. **Evaluating** What explanations, other than mutation, can you think of for the differences you observed between the irradiated seeds and the nonirradiated seeds?
7. **SAFETY:** Explain how you demonstrated safe practices during this investigation.

Go Further

Communicating Valid Conclusions
Compare your data to those of other students in your class. Work with the rest of the students in your class to reach a conclusion about the effect of radiation on seeds. Your conclusion should be based on class data. Then, write a short report about your experiment that would be suitable to submit to a scientific journal. Your report should communicate your conclusion and explain why it is valid.

Chapter 13 Study Guide

13-1 Changing the Living World

Key Concepts — **BI 5.c**

- Humans use selective breeding, which takes advantage of naturally occurring genetic variation in plants, animals, and other organisms, to pass desired traits on to the next generation of organisms.
- Breeders can increase the genetic variation in a population by inducing mutations, which are the ultimate source of genetic variability.

Vocabulary
selective breeding, p. 319
hybridization, p. 319
inbreeding, p. 320

13-2 Manipulating DNA

Key Concept — **BI 5.c, *BI 5.d**

- Scientists use their knowledge of the structure of DNA and its chemical properties to study and change DNA molecules. Different techniques are used to extract DNA from cells, to cut DNA into smaller pieces, to identify the sequence of bases in a DNA molecule, and to make unlimited copies of DNA.

Vocabulary
genetic engineering, p. 322
restriction enzyme, p. 323
gel electrophoresis, p. 323
recombinant DNA, p. 324
polymerase chain reaction (PCR), p. 325

13-3 Cell Transformation

Key Concepts — **BI 5.c, *BI 5.e**

- During transformation, a cell takes in DNA from outside the cell. This external DNA becomes a component of the cell's DNA.
- If transformation is successful, the recombinant DNA is integrated into one of the chromosomes of the cell.

Vocabulary
plasmid, p. 327
genetic marker, p. 328

13-4 Applications of Genetic Engineering

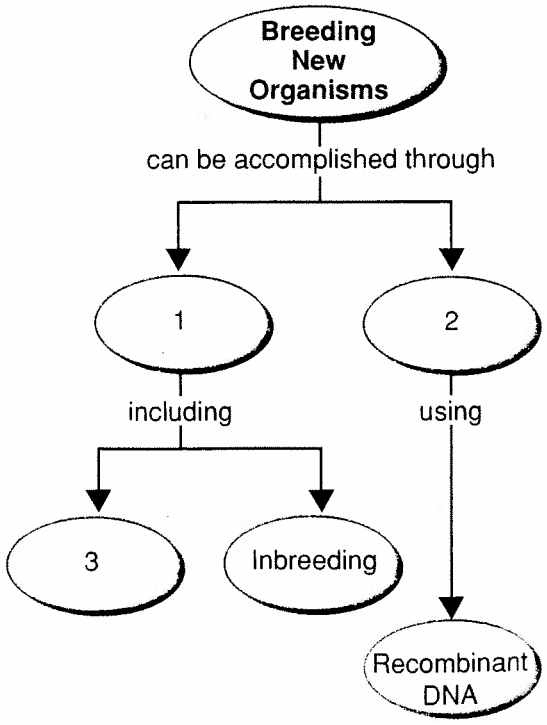
Key Concept — **BI 5.c**

- Genetic engineering has spurred the growth of biotechnology, which is a new industry that is changing the way we interact with the living world.

Vocabulary
transgenic, p. 331
clone, p. 333

Thinking Visually

Using the information in this chapter, complete the following concept map:



Chapter 13 Assessment

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. A cross between dissimilar individuals to bring together their best characteristics is called
   a. genetic engineering. c. hybridization.
   b. inbreeding. d. sequencing.

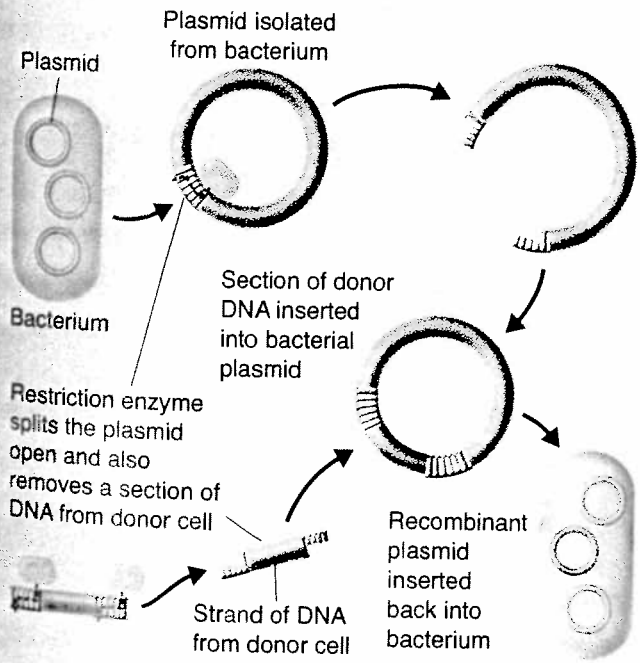
2. Crossing individuals with similar characteristics so that those characteristics will appear in the offspring is called
   a. inbreeding. c. hybridization.
   b. electrophoresis. d. genetic engineering.

3. Varieties of purebred dogs are maintained by
   a. selective breeding. c. inbreeding.
   b. hybridization. d. genetic engineering.

4. Changing the DNA of an organism is called
   a. genetic engineering.
   b. hybridization.
   c. selective breeding.
   d. inbreeding.

5. DNA can be cut into shorter sequences by proteins known as
   a. restriction enzymes.
   b. plasmids.
   c. mutagens.
   d. clones.

6. What has been produced in the drawing below?



   a. a clone c. a genome
   b. recombinant DNA d. a species

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7. When cell transformation is successful, the recombinant DNA
   a. undergoes mutation.
   b. is treated with antibiotics.
   c. becomes part of the transformed cell's genome.
   d. becomes a nucleus.

8. Bacteria often contain small circular molecules of DNA known as
   a. clones. c. plasmids.
   b. restriction enzymes. d. hybrids.

9. Organisms that contain genes from other organisms are called
   a. transgenic. c. donor organisms.
   b. mutagenic. d. cloned organisms.

10. A member of a population of genetically identical cells produced from a single cell is a
    a. clone. c. mutant.
    b. plasmid. d. sequence.

Understanding Concepts

11. Compare hybridization and inbreeding. Why are they considered forms of selective breeding?

12. How do breeders produce new genetic variations not found in nature?

13. What is polyploidy? When is this condition useful?

14. Explain why genetic engineering can be compared to reprogramming a computer game.

15. How are large DNA molecules cut up?

16. What role does gel electrophoresis play in the study of DNA?

17. What is recombinant DNA?

18. Describe what occurs during a polymerase chain reaction (PCR).

19. What happens during cell transformation? What are some types of cells that have been transformed?

20. Explain what genetic markers are, and describe how scientists use them.

21. What did the successful transfer of the luciferase gene from an animal to a plant indicate about the functioning of genes?

22. What is a transgenic organism? Explain how transgenic bacteria have been useful.

23. How did Ian Wilmut clone the sheep known as Dolly?

24. Explain how a transgenic plant differs from a hybrid plant.

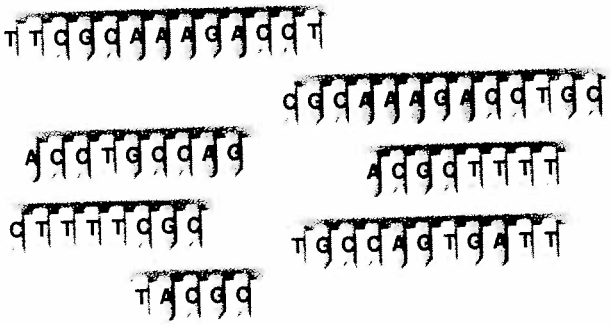
Critical Thinking

25. **Applying Concepts** Describe one or more advantages of producing needed proteins such as insulin through genetic engineering.

26. **Inferring** If a human patient's bone marrow cells were removed, altered genetically, and reimplanted, would the change be passed on to the patient's children? Explain your answer.

27. **Problem Solving** Suppose a plant breeder has a thornless rose bush with scentless pink flowers, a thorny rose bush with sweet-smelling yellow flowers, and a thorny rose bush with scentless purple flowers. How might the plant breeder develop a purebred variety of thornless sweet-smelling purple roses?

28. **Problem Solving** The following fragments were obtained when a gene that consists of ten codons was cut by restriction enzymes. What is the sequence of bases in the gene? (*Hint:* Look for overlapping sections on the fragments.)



29. **Comparing and Contrasting** Compare the advantages and disadvantages of breeding techniques and genetic engineering.

30. **Formulating Hypotheses** Almost every organism has DNA that is made of the same four nucleotides and translated by the same genetic code. Explain why this fact is significant in cell transformation.

31. **Inferring** Some people need blood transfusions because their blood lacks important proteins, such as those needed for blood clotting. People who receive blood transfusions have some risk of being exposed to disease-causing viruses. How might genetic engineering eliminate this risk?

32. **Predicting** Predict three ways in which you think genetically engineered organisms will be used in the future.

33. **Applying Concepts** Bacteria and human beings are very different organisms. Why is it sometimes possible to combine their DNA and use a bacterium to make a human protein?

34. **Applying Concepts** Your friend proposes that using genetic engineering, biologists should be able to produce an organism with any combination of characteristics. For example, they could create an animal with the body of a frog and the wings of a bat. Do you think this is a reasonable proposal? Explain your answer.

Focus on the BIG Idea

Information and Heredity In Chapter 12, you learned how DNA and RNA molecules specify the traits of an organism. Use this knowledge to illustrate how, at the molecular level, the DNA and RNA of a transgenic tobacco plant produce the trait of glowing in the dark.

Writing in Science

Your local newspaper has published an editorial against the use of genetic engineering. The editorial states that genetic engineering is still too new to use, while traditional selective breeding can accomplish anything that genetic engineering can do. Write a letter to the newspaper either in support of the newspaper's position or against it.

Performance-Based Assessment

Design a Procedure Insulin is a protein that enables body cells to take in glucose from the blood. People with one type of diabetes do not produce enough insulin, so their cells cannot take in glucose. Devise a procedure for transforming bacterial cells so that they produce human insulin, which can then be used to treat people with diabetes. Describe and illustrate the procedure for transforming the bacteria.

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Test-Taking Tip For questions containing the words NOT or EXCEPT, begin by eliminating each answer choice that *does* fit the characteristic in question. After eliminating all but one of the choices, check to see that your answer is correct by confirming that it does *not* fit the characteristic in question.

Directions: Choose the letter that best answers the question or completes the statement.

1. Which of the following can be used to produce organisms with desirable traits?
   - **A** inbreeding
   - **B** genetic engineering
   - **C** inducing mutations
   - **D** all of the above

2. Which of the following characteristics does NOT apply to a plasmid?
   - **A** made of DNA
   - **B** in animal cells
   - **C** circular
   - **D** accepts foreign DNA

Questions 3–4

A researcher chooses a plasmid with a gene that confers resistance to the antibiotic ampicillin. She isolates and tries to insert a human gene that codes for a protein into the plasmid. Next, she transforms bacteria using the plasmid. She then cultures the new bacteria on a nutrient medium containing ampicillin.

3. What can the researcher conclude about the bacteria that grow on the nutrient medium? ***BI 5.e**
   - **A** They are resistant to ampicillin.
   - **B** They contain recombinant DNA.
   - **C** They contain a human gene.
   - **D** all of the above

4. Which of the following would indicate that the bacteria contain the human gene? ***BI 5.e**
   - **A** They produce the human protein encoded by the human gene.
   - **B** They produce ampicillin.
   - **C** both A and B
   - **D** neither A nor B

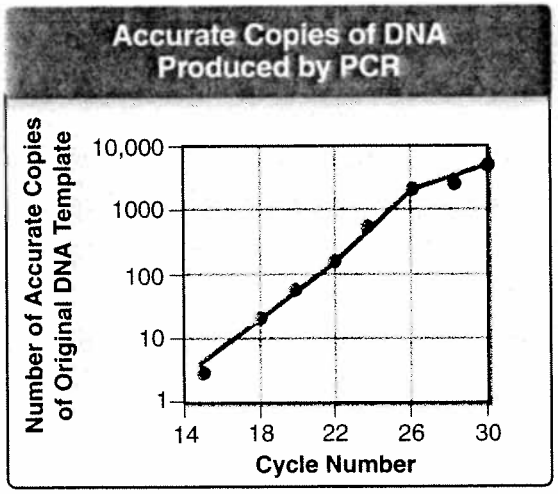
Questions 5–8 Each of the lettered choices below refers to the following numbered statements. Select the best lettered choice. A choice may be used once, more than once, or not at all.

- **A** Gel electrophoresis
- **B** Plasmid
- **C** Polymerase chain reaction
- **D** Inbreeding

5. Used to insert new genes into plant cells **BI 5.c**
6. Makes many copies of a DNA sample
7. Continued breeding of individuals with similar characteristics
8. Separates DNA fragments

Questions 9–10

The graph below shows the number of accurate copies of DNA produced by polymerase chain reaction (PCR).



9. What can you conclude about cycles 18–26?
   - **A** PCR produced accurate copies of template DNA at an exponential rate.
   - **B** The amount of DNA produced by PCR doubled with each cycle of the reaction.
   - **C** The DNA copies produced by PCR were not accurate copies of the original DNA template.
   - **D** A and B only

10. Based on the graph, which of the following might have happened between cycles 26 and 28?
    - **A** PCR stopped producing accurate copies of the template.
    - **B** The rate of the reaction slowed down.
    - **C** All the template DNA was used up.
    - **D** A and C only