# 9.4 Genetic Engineering

**KEY CONCEPT** **DNA sequences of organisms can be changed.**

**MAIN IDEAS**
- Entire organisms can be cloned.
- New genes can be added to an organism's DNA.
- Genetic engineering produces organisms with new traits.

**VOCABULARY**
- clone
- genetic engineering
- recombinant DNA
- plasmid
- transgenic
- gene knockout

### *Connect to Your World*

Glowing mice are used in cancer research. Glowing plants are used to track genetically modified crops. And, in 1999, British researchers introduced glowing yeast cells that locate water pollution. The scientists put a gene for a fluorescent protein into yeast. Under normal conditions, the yeast cells do not glow. But they do glow when certain chemicals are present. The glow identifies areas that need to be cleaned. New biotechnology applications seem to be developed on a daily basis. What advances will you see during your lifetime?

**MAIN IDEA**

## Entire organisms can be cloned.

The term *cloning* might make you think of science fiction and horror movies, but the process is quite common in nature. A **clone** is a genetically identical copy of a gene or of an organism. For example, some plants clone themselves from their roots. Bacteria produce identical genetic copies of themselves through binary fission. And human identical twins are clones of each other.

People have cloned plants for centuries. The process is fairly easy because many plants naturally clone themselves and also because plants have stem cell tissues that can develop into many types of cells. Some simple animals, such as sea stars, can essentially clone themselves through a process called regeneration. Mammals, however, cannot clone themselves.

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Animal Cloning

To clone a mammal, scientists swap DNA between cells with a technique called nuclear transfer. First, an unfertilized egg is taken from an animal, and the egg's nucleus is removed. Then the nucleus of a cell from the animal to be cloned is implanted into the egg. The egg is stimulated and, if the procedure is successful, the egg will begin dividing. After the embryo grows for a few days, it is transplanted into a female. In 1996 a sheep named Dolly became the first clone of an adult mammal. The success of Dolly led to the cloning of adult cows, pigs, and mice. Now, a biotechnology company has even said that it can clone people's pets.

But pet owners who expect cloning to produce an exact copy of their furry friend will likely be disappointed. As you can see from the cat called CC in **FIGURE 4.1**, a clone may not look like the original, and it will probably not behave like the original, either. Why? Because, as you have learned, many factors, including environment, affect the expression of genes.

**FIGURE 4.1** The cat named CC—for Copy Cat or Carbon Copy—is the first successful clone of a cat (right). The original cat is on the left.

Cloning brings with it some extraordinary opportunities. For example, scientists are studying how to use organs from cloned mammals for transplant into humans. This use of cloning could save an enormous number of lives each year and would not cause rejection problems in the organ recipient. Cloning could even help save endangered species. Cells from endangered species could be taken and used to produce clones that would increase the population of the species.

Cloning is also controversial. Many people think the success rate is too low to be attempted. The success rate in cloning mammals has improved substantially, but it varies widely by species. As cloning has become more common, ecological concerns have been raised. Cloned animals in a wild population would reduce biodiversity because the clones would be genetically identical.

**CONNECT TO**

**BIODIVERSITY**

In the chapter **Biology in the 21st Century,** you learned that biodiversity can be defined as the number of different species in an area. You will learn much more about genetic diversity within a species in the **Evolution** unit.

**Apply Given the opportunity, would you have a pet cloned? Explain your answer based on your knowledge of genetics, biotechnology, and cloning.**

MAIN IDEA

## New genes can be added to an organism's DNA.

Genetic research relies on cloning, but not the cloning of organisms. Instead, it relies on the cloning of individual genes. A clone of a gene is a copy of that one segment of DNA. In some cases, scientists insert cloned genes from one organism into a different organism. This changing of an organism's DNA to give the organism new traits is called **genetic engineering.** Genetic engineering is possible because the genetic code is shared by all organisms.

Genetic engineering is based on the use of recombinant DNA technology. **Recombinant DNA** (ree-KAHM-buh-nuhnt) is DNA that contains genes from more than one organism. Scientists use recombinant DNA in several ways. For example, recombinant DNA is used to produce crop plants that make medicines and vitamins. Large amounts of medicines are made through this process, which has been called "pharming." Scientists are also studying ways of using recombinant DNA to make vaccines to protect against HIV, the virus that causes AIDS.

Bacteria are commonly used in genetic engineering. One reason is because bacteria have tiny rings of DNA called plasmids. **Plasmids,** as shown in **FIGURE 4.2**, are closed loops of DNA that are separate from the bacterial chromosome and that replicate on their own within the cell. Recombinant DNA is found naturally in bacteria that take in exogenous DNA (or DNA from a different organism) and add it to their own. Scientists adapted what happens in nature to make artificial recombinant DNA. First, a restriction enzyme is used to cut out the desired gene from a strand of DNA. Then plasmids are cut with the same enzyme. The plasmid opens, and when the gene is added to the plasmid, their complementary sticky ends are bonded together by a process called ligation. The resulting plasmid contains recombinant DNA, as shown in **FIGURE 4.3.**

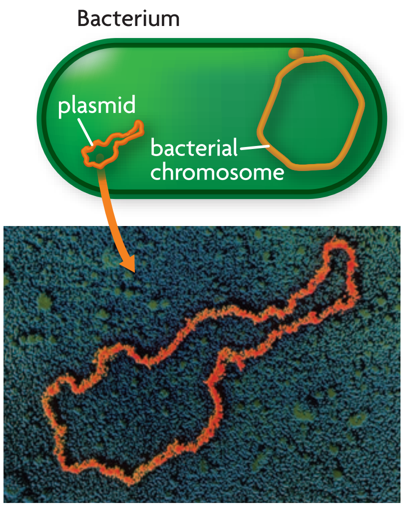


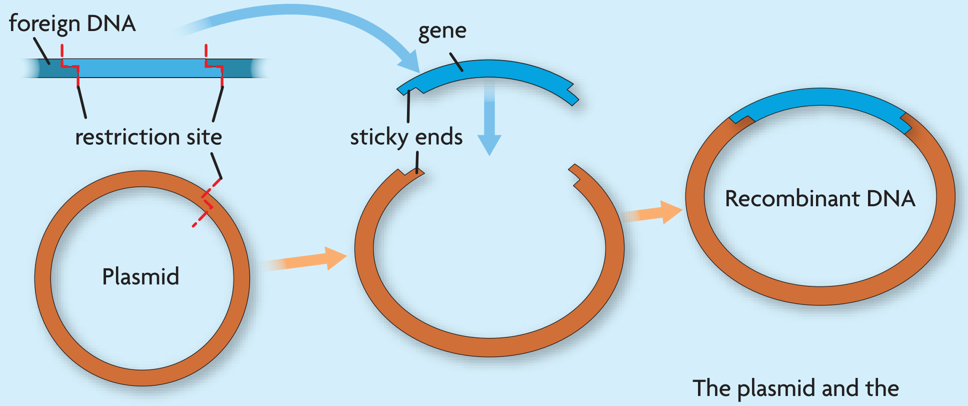

**FIGURE 4.2** A plasmid is a closed loop of DNA in a bacterium that is separate from the bacterial chromosome. (colored TEM; magnification 48,000×)



**Summarize How does genetic engineering rely on a shared genetic code?**

## FIGURE 4.3 Making Recombinant DNA

**Foreign DNA can be inserted into a plasmid to make recombinant DNA.**

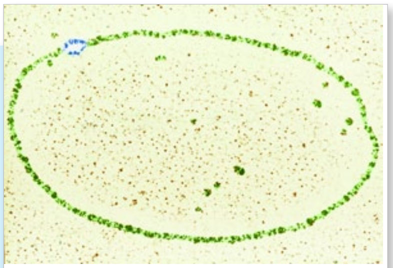



A plasmid and the foreign DNA with the gene are cut with the same restriction enzyme.

The sticky ends of the plasmid and the foreign gene match.

The plasmid and the foreign gene are bonded together to form recombinant DNA.

**Apply Why are sticky ends important for making recombinant DNA?**



Plasmids are small rings of DNA used in genetic engineering. Foreign genes (various colors) can be inserted into plasmids. (colored TEM, magnification unknown).

MAIN IDEA

# Genetic engineering produces organisms with new traits.

After a gene is added to a plasmid, the genetically engineered plasmids can be put into bacteria. In a way, bacteria are turned into tiny gene factories that make copy after copy of the plasmid. As a result, the transformed bacteria make many copies of the new gene. The bacteria will express the new gene and make that gene's product. The bacteria with the recombinant plasmid are described as transgenic. A **transgenic** organism has one or more genes from another organism inserted into its genome. For example, the gene for human insulin can be put into plasmids. The plasmids are inserted into bacteria. The transgenic bacteria make human insulin that is collected and used to treat people with diabetes.

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Bacterial Transformation

## Genetic Engineering of Plants

Genetic engineering of plants is directly related to genetic engineering of bacteria. To change a plant's DNA, a gene is inserted into a plasmid and the plasmid is inserted into bacteria. After the bacteria infect the plant, the new gene becomes a part of the plant's DNA and is expressed like any other gene.

This technique has allowed scientists to give plants new traits, such as resistance to frost, diseases, and insects. For instance, certain bacteria, called *Bt*, produce a natural protein pesticide. Farmers used to spray their crops with *Bt* bacteria to prevent the crops from being attacked by insects. But by genetically engineering the crop plants, the plants can make the bacterial pesticide themselves. These genetically engineered crops, which are also called genetically modified (GM), are now common in the United States. They include *Bt* potatoes and corn. GM crops are even more important in developing countries because by increasing crop yields, more food is produced quickly and cheaply.

**READING TOOLBOX**

**VOCABULARY**

The prefix *trans-* means "across," and the root *genic* means "referring to genes." When genes are transferred across different organisms, transgenic organisms are produced.

QUICKLAB MODELING

## Modeling Plasmids and Restriction Enzymes

Restriction enzymes are enzymes that cut DNA at precise locations. These enzymes allow scientists to move a gene from one organism into another. In this lab, you will use DNA sequences from a datasheet to simulate the use of restriction enzymes.

**PROBLEM** How do different restriction enzymes cut a plasmid?

**PROCEDURE**

1. Make models of 3 plasmids. Cut out the DNA sequences from the copies of Figure 1 on the datasheet. Use tape to attach the appropriate piece of yarn to each end. The yarn represents the entire plasmid. The finished plasmid should be a circle.
2. Use the scissors to cut a plasmid at the correct sites for *Eco*RI.
3. Use the sequences for sites of *Hind*III and *Sma*I to repeat step 2 with the other two plasmids.

**MATERIALS**

- 3 copies of Plasmid Sequence Datasheet
- scissors
- 10 cm clear tape
- 3 sets of five 5-cm yarn pieces

**ANALYZE AND CONCLUDE**

1. **Apply** How many DNA fragments would you get if you cut the same plasmid with both *Eco*RI and *Sma*I?
2. **Infer** Why might scientists use different restriction enzymes to cut out different genes from a strand of DNA?

### Genetic Engineering in Animals

In general, transgenic animals are much harder to produce than GM plants because animals are more resistant to genetic manipulation. To produce a transgenic animal, a researcher must first get a fertilized egg cell. Then the foreign DNA is inserted into the nucleus and the egg is implanted back into a female. However, only a small percentage of the genetically manipulated eggs mature normally. And only a portion of those that develop will be transgenic. That is, only a small number will have the foreign gene as a part of their DNA. But those animals that are transgenic will have the gene in all of their cells—including reproductive cells—and the transgenic trait will be passed on to their offspring.

**FIGURE 4.4** This knockout mouse has been bioengineered so researchers can use it as a model to study obesity.

Transgenic mice are often used as models of human development and disease. The first such animal was called the oncomouse. This mouse is more likely to develop cancer, because a gene that controls cell growth and differentiation was mutated. Researchers use the oncomouse to study both cancer and anti-cancer drugs. Other types of transgenic mice are used to study diabetes, brain function and development, and sex determination.

Some mice have genes that have been purposely "turned off." These mice, called **gene knockout** mice, are very useful for studying a gene's normal function because a researcher can observe specific changes in gene expression and traits. For example, scientists are using a gene knockout mouse to study obesity, as you can see in **FIGURE 4.4.** Other mice, called knockdown mice, are created using RNAi technology to decrease the expression of a specific gene or to silence the expression temporarily. Recall that RNAi technology shuts down expression of a gene by preventing a gene from making its protein. Scientists use knockdown technology to study metabolic pathways in animals.

Scientists are also developing new tools that make it easier to modify the genomes of both plants and animals. One particularly effective tool, called CRISPR (pronounced like *crisper*), is based on a mechanism some bacteria use as a kind of immune defense against viruses that infect them. In bacteria, the CRISPR mechanism identifies viral DNA and directs an enzyme to chop the foreign DNA into pieces. As a tool in biotechnology, CRISPR can be used to target particular DNA sequences with a high degree of precision, allowing researchers to delete, modify, or even replace genes in the cells of any organism, even human cells. CRISPR is proving particularly effective for studying diseases that involve many genes, such as some cancers, because its accuracy and ease of use make it possible to manipulate many genes at once. CRISPR also makes it much more practical for scientists to genetically engineer animal cells as compared with earlier methods.

### Concerns About Genetic Engineering

Scientists have genetically engineered many useful organisms by transferring genes between species to give individuals new traits. At the same time, there are concerns about possible effects of genetically engineered organisms on both human health and the environment. And at an even more basic level, some people wonder whether genetic engineering is ethical in the first place.

Questions have been raised about GM crops, even though scientists have not yet found negative health effects of GM foods. Critics say that not enough research has been done, and that some added genes might cause allergic reactions or have other unknown side effects. Scientists also have concerns about the possible effects of GM plants on the environment and on biodiversity. For example, what would happen if genetically engineered *Bt* plants killed insects that pollinate plants, such as bees and butterflies? In some instances, transgenic plants have cross-pollinated with wild type plants in farming regions. Scientists do not yet know what long-term effect this interbreeding might have on the natural plants. In addition, all organisms in a transgenic population have the same genome. As a result, some scientists worry that a decrease in genetic diversity could leave crops vulnerable to new diseases or pests.

**Infer Why is it important that a transgenic trait is passed on to the transgenic organism's offspring?**

## 9.4 Formative Assessment

### REVIEWING MAIN IDEAS

1. Why is the offspring of asexual reproduction a **clone**?
2. What are **plasmids,** and how are they used in **genetic engineering**?
3. Describe two applications of **transgenic** organisms.

### CRITICAL THINKING

4. **Compare and Contrast** How is the cloning of genes different from the cloning of mammals?
5. **Summarize** How are restriction enzymes used to make both **recombinant DNA** and transgenic organisms?

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### CONNECT TO ECOLOGY

6. Do you think cloning endangered species is a good idea? What effect might this have on an ecosystem?