

## Lesson Overview

### 15.3 Applications of Genetic Engineering

# Agriculture and Industry



How can genetic engineering benefit agriculture and industry?



Ideally, genetic modification could lead to better, less expensive, and more nutritious food as well as less harmful manufacturing processes.

# Agriculture and Industry

Almost everything we eat and much of what we wear come from living organisms.

Researchers have used genetic engineering to try to improve the products we get from plants and animals.

Genetic modification could lead to better, less expensive, and more nutritious food as well as less harmful manufacturing processes.

### GM Crops

Since their introduction in 1996, genetically modified (GM) plants have become an important component of our food supply.

One genetic modification uses bacterial genes that produce a protein known as Bt toxin.

This toxin is harmless to humans and most other animals, but enzymes in the digestive systems of insects convert Bt to a form that kills the insects.

Plants with the Bt gene do not have to be sprayed with pesticides.

In addition, they produce higher yields of crops.

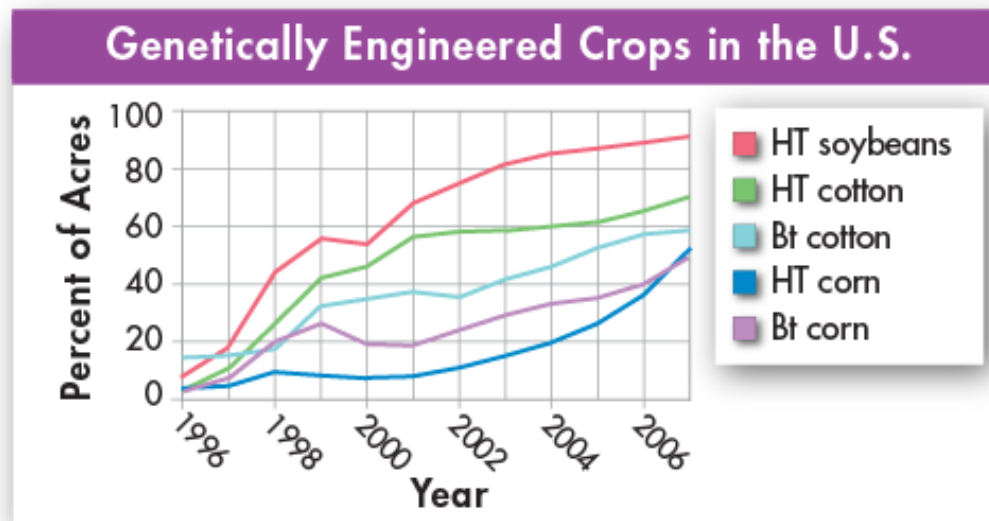
### GM Crops

Other useful genetic modifications include resistance to herbicides, which are chemicals that destroy weeds, and resistance to viral infections.

## GM Crops

### A Summary of the Adoption of GM Crops from 1996-2007

The modified traits shown in the graph include herbicide tolerance (HT) and insect resistance (Bt).



### GM Crops

Some transgenic plants may soon produce foods that are resistant to rot and spoilage.

Engineers are currently developing GM plants that may produce plastics for the manufacturing industry.

### GM Animals

Transgenic animals are becoming more important to our food supply.

About 30 percent of the milk in U.S. markets comes from cows that have been injected with hormones made by recombinant-DNA techniques to increase milk production.

Pigs can be genetically modified to produce more lean meat or high levels of healthy omega-3 acids.

Using growth-hormone genes, scientists have developed transgenic salmon that grow much more quickly than wild salmon.



### GM Animals

Scientists in Canada combined spider genes into the cells of lactating goats. The goats began to produce silk along with their milk.

The silk can be extracted from the milk and woven into a thread that can be used to create a light, tough, and flexible material.

### GM Animals

Scientists are working to combine a gene for lysozyme—an antibacterial protein found in human tears and breast milk—into the DNA of goats.

Milk from these goats may help prevent infections in young children who drink it.

### GM Animals

Researchers hope that cloning will enable them to make copies of transgenic animals, which would increase the food supply and could help save endangered species.

In 2008, the U.S. government approved the sale of meat and milk from cloned animals.

Cloning technology could allow farmers to duplicate the best qualities of prize animals without the time and complications of traditional breeding.

# Health and Medicine



How can recombinant-DNA technology improve human health?



Today, recombinant-DNA technology is the source of some of the most important and exciting advances in the prevention and treatment of disease.

### Preventing Disease

Golden rice is a GM plant that contains increased amounts of provitamin A, also known as beta-carotene—a nutrient that is essential for human health. Two genes engineered into the rice genome help the grains produce and accumulate beta-carotene.

Provitamin A deficiencies produce serious medical problems, including infant blindness. There is hope that provitamin A-rich golden rice will help prevent these problems.

Other scientists are developing transgenic plants and animals that produce human antibodies to fight disease.

### Preventing Disease

In the future, transgenic animals may provide us with an ample supply of our own proteins.

Several laboratories have engineered transgenic sheep and pigs that produce human proteins in their milk, making it easy to collect and refine the proteins.

Many of these proteins can be used in disease prevention.

### Medical Research

Transgenic animals are often used as test subjects in medical research. They can simulate human diseases in which defective genes play a role.

Scientists use models based on these simulations to follow the onset and progression of diseases and to construct tests of new drugs that may be useful for treatment.

This approach has been used to develop models for disorders like Alzheimer's disease and arthritis.

### Treating Disease

Recombinant-DNA technology can be used to make important proteins that could prolong and even save human lives.

For example, human growth hormone, which is used to treat patients suffering from pituitary dwarfism, is now widely available because it is mass-produced by recombinant bacteria.

Other products now made in genetically engineered bacteria include insulin to treat diabetes, blood-clotting factors for hemophiliacs, and potential cancer-fighting molecules such as interleukin-2 and interferon.



# Treating Disease

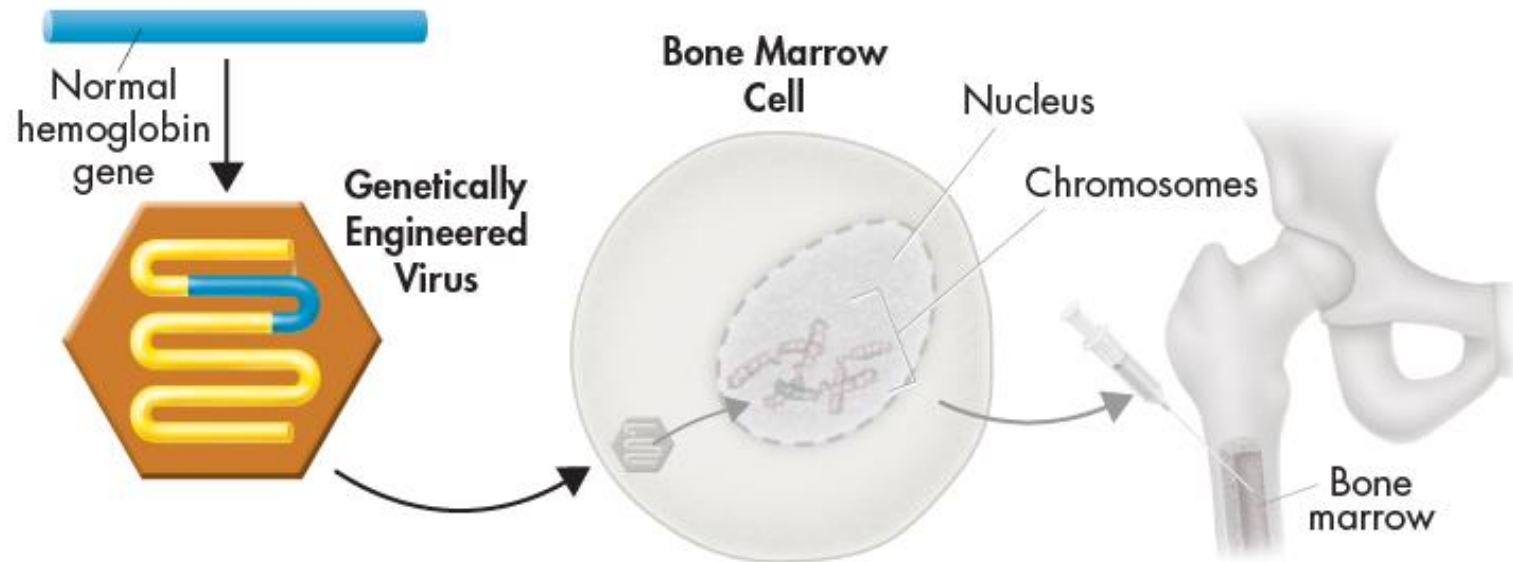
**Gene therapy** is the process of changing a gene to treat a medical disease or disorder.

In gene therapy, an absent or faulty gene is replaced by a normal, working gene.

This process allows the body to make the protein or enzyme it needs, which eliminates the cause of the disorder.

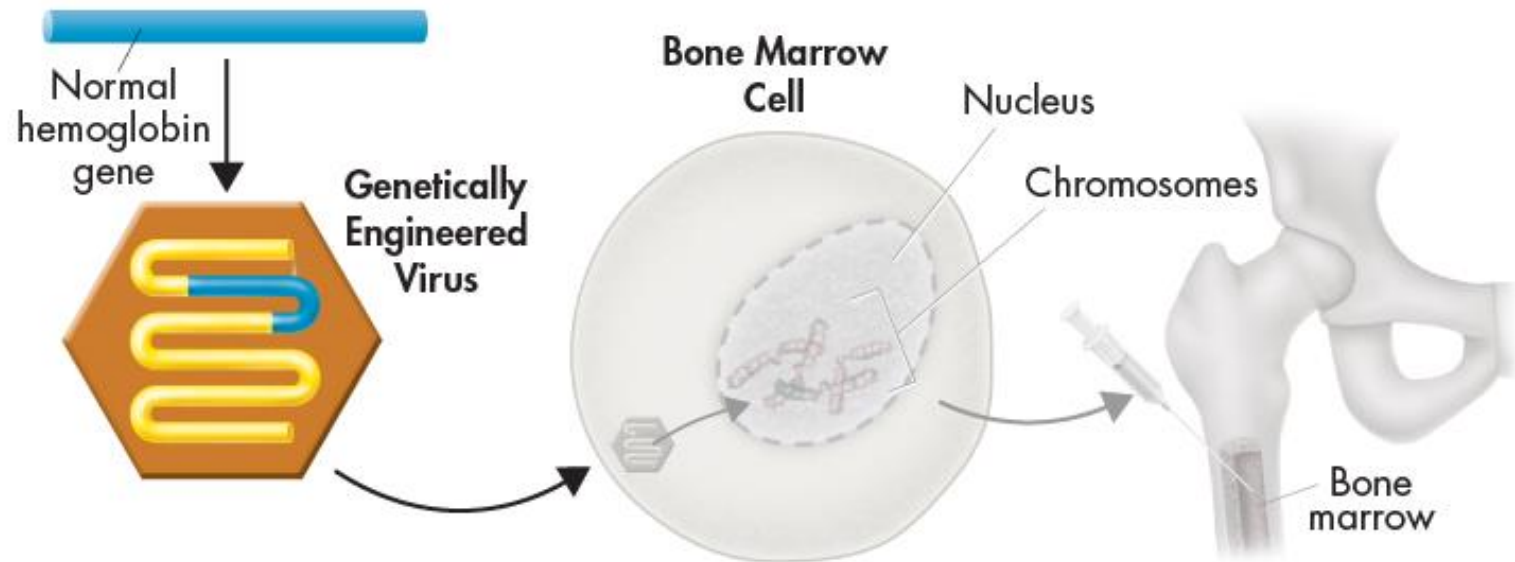
## Treating Disease — One Example of Gene Therapy

To deliver therapeutic genes to target cells researchers engineer a virus that cannot reproduce or cause harm.



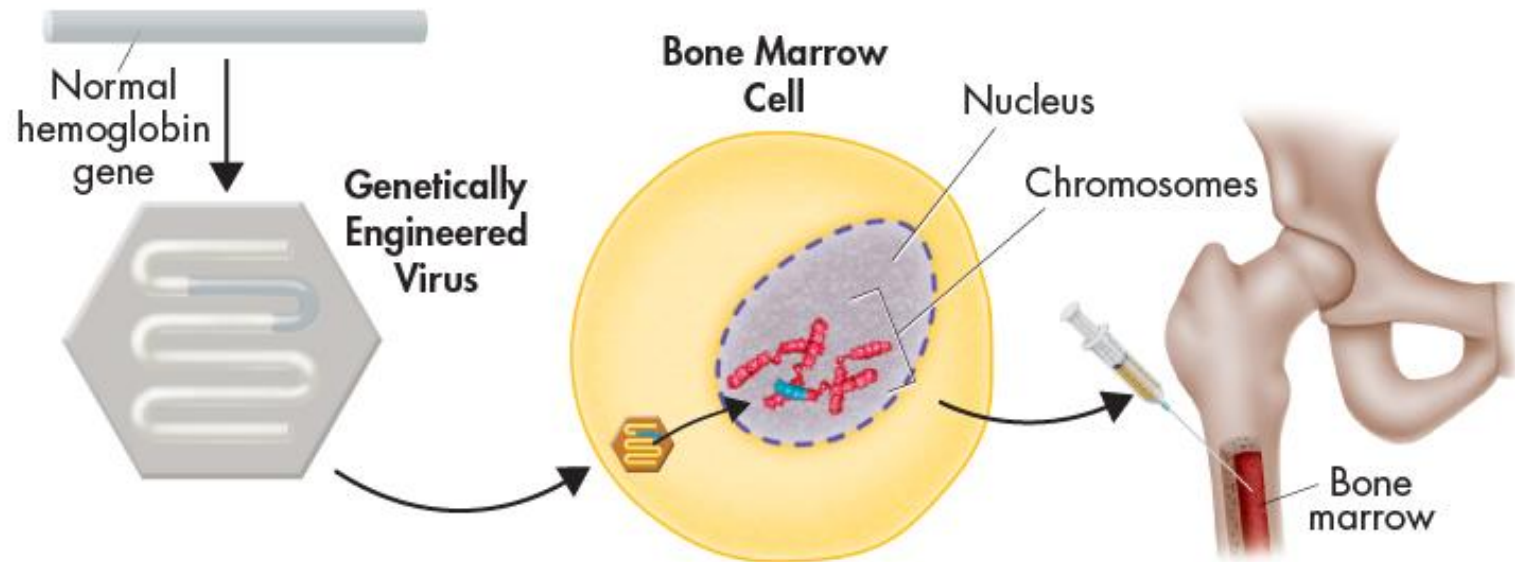
## Treating Disease — One Example of Gene Therapy

The DNA containing the therapeutic gene is inserted into the modified virus.



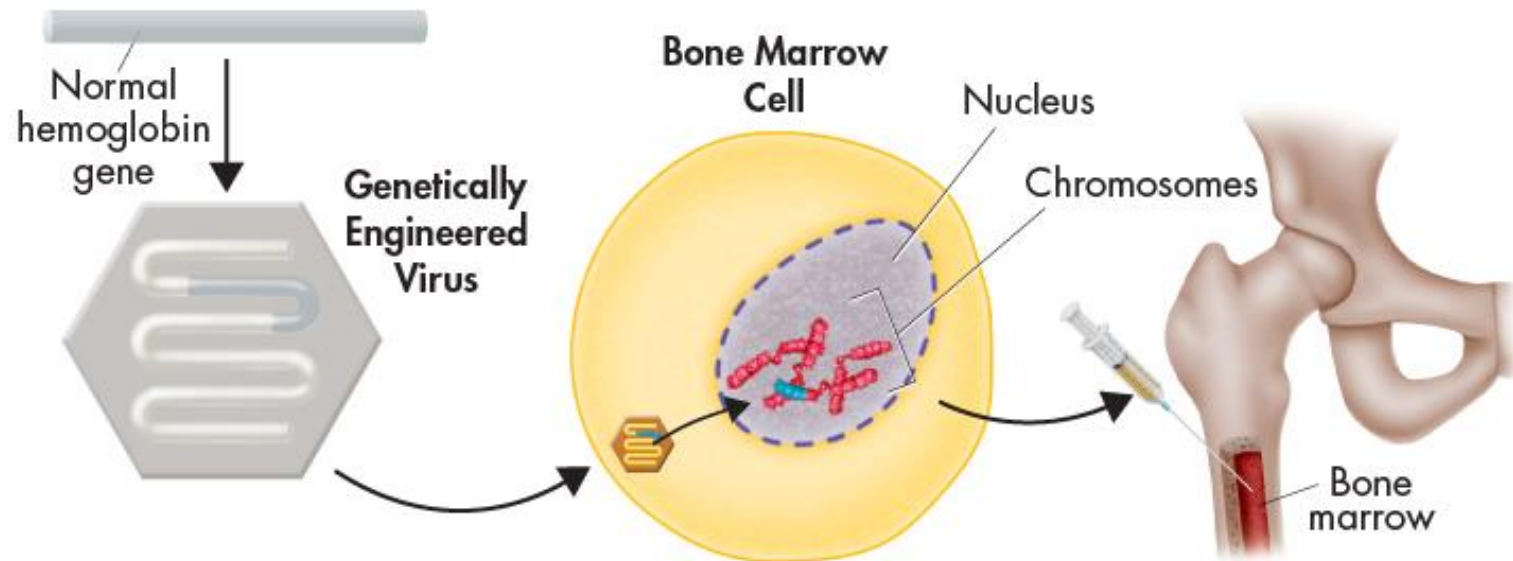
## Treating Disease — One Example of Gene Therapy

The patient's cells are then infected with the genetically engineered virus.



## Treating Disease — One Example of Gene Therapy

In theory the virus will insert the healthy gene into the target cell and correct the defect.



# Treating Disease

Gene therapy can be risky.

In 1999, 18-year-old Jesse Gelsinger volunteered for a gene therapy experiment designed to treat a genetic disorder of his liver. He suffered a massive reaction from the viruses used to carry genes into his liver cells, and he died a few days later.

For gene therapy to become an accepted treatment, we need more reliable ways to insert working genes and to ensure that the DNA used in the therapy does no harm.

# Genetic Testing

Genetic testing can be used to determine if two prospective parents are carrying the alleles for a genetic disorder such as cystic fibrosis (CF).

Because the CF allele has slightly different DNA sequences from its normal counterpart, genetic tests use labeled DNA probes that can detect and distinguish the complementary base sequences found in the disease-causing alleles.

Some genetic tests search for changes in cutting sites of restriction enzymes, while others use PCR to detect differences between the lengths of normal and abnormal alleles.

Genetic tests are now available for diagnosing hundreds of disorders.

## Examining Active Genes

The same genes are not active in every cell. By studying which genes are active and which are inactive in different cells, scientists can understand how the cells function normally and what happens when genes don't work as they should.

Scientists use **DNA microarray** technology to study hundreds or even thousands of genes at once to understand their activity levels.



## Examining Active Genes

A DNA microarray is a glass slide or silicon chip to which spots of single-stranded DNA have been tightly attached.

Typically each spot contains a different DNA fragment.

Differently colored tags are used to label the source of DNA.



## Examining Active Genes

For example, to compare the genes in cancer cells with genes in normal cells, the mRNA would first be isolated from both types of cells.

Enzymes are used to copy the mRNA base sequence into single-stranded DNA labeled with fluorescent colors—red for the cancer cell and green for the normal cell.

### 1 Preparing the cDNA Probe

**a** mRNA samples are isolated from two different types of cells or tissues, such as cancer cells and normal cells.

mRNA from  
cancer cells



mRNA from  
normal cells



**b** Enzymes are used to prepare complementary DNA molecules (cDNA) from both groups of mRNA. Contrasting fluorescent labels are attached to both groups of cDNA (red to one, green to the other).

cDNA from  
cancer cells



cDNA from  
normal cells



## Examining Active Genes

Both samples of labeled DNA would be mixed together and they would then compete to bind to the complementary DNA sequences already in the microarray.

### 2 Preparing the Microarray

**a** DNA fragments corresponding to different genes are bound to the wells in a microarray plate.

**b** Single strands of DNA are attached to wells in the plate.

### 3 Combining the Probe and Microarray Samples

Labeled cDNA molecules bind to complementary sequences on the plate.

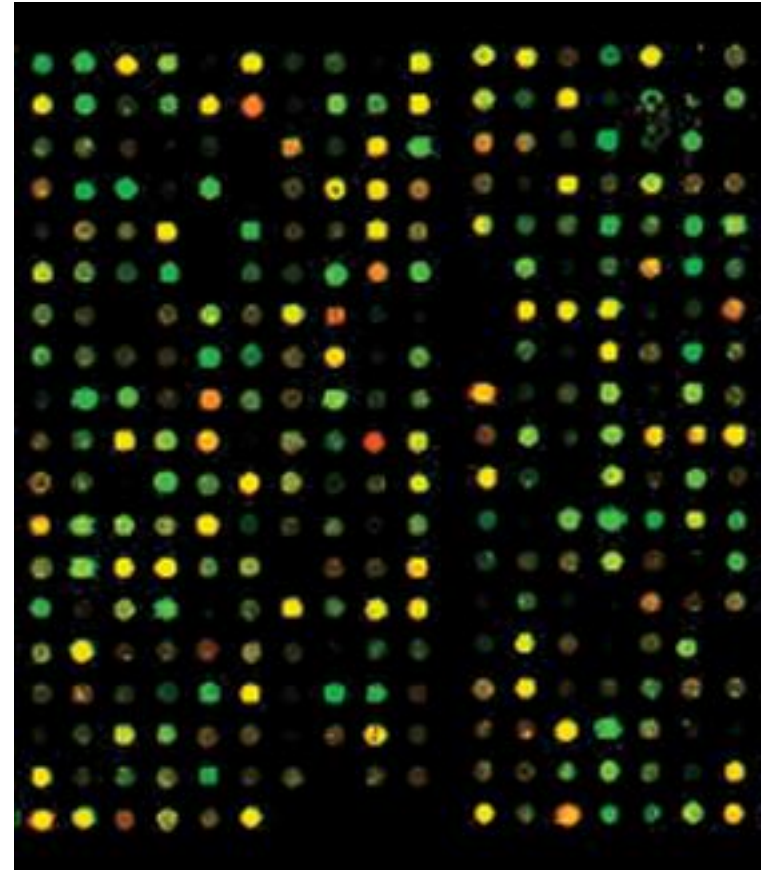


## Examining Active Genes

If the cancer cell produces more of a particular form of mRNA, then more red-labeled molecules will bind at the spot for that gene, turning it red.

Where the normal cell produces more mRNA for another gene, the spot will be green.

Where there is no difference between the two cell types, the spot will be yellow because it contains both colors.



# Personal Identification



How is DNA used to identify individuals?



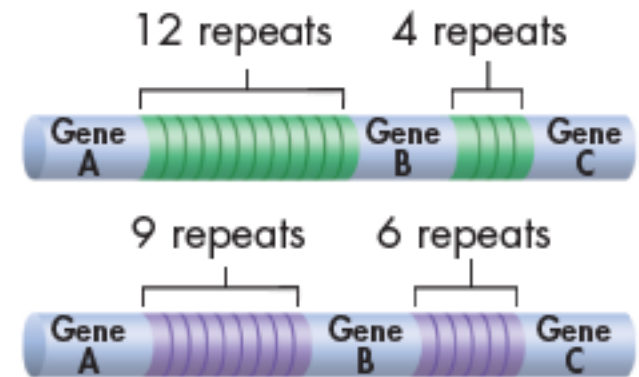
DNA fingerprinting analyzes sections of DNA that may have little or no function but that vary widely from one individual to another.

## Personal Identification

No individual is exactly like any other genetically—except for identical twins, who share the same genome.

Chromosomes contain many regions with repeated DNA sequences that do not code for proteins. These vary from person to person. Here, one sample has 12 repeats between genes A and B, while the second has 9 repeats between the same genes.

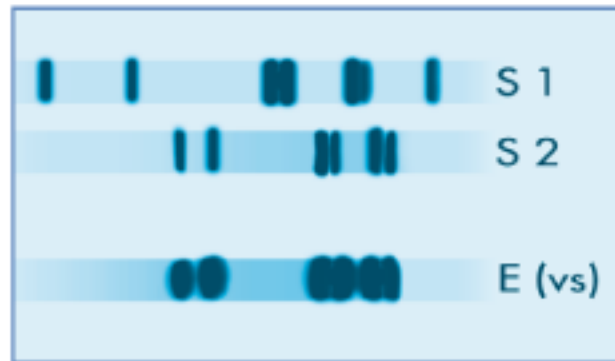
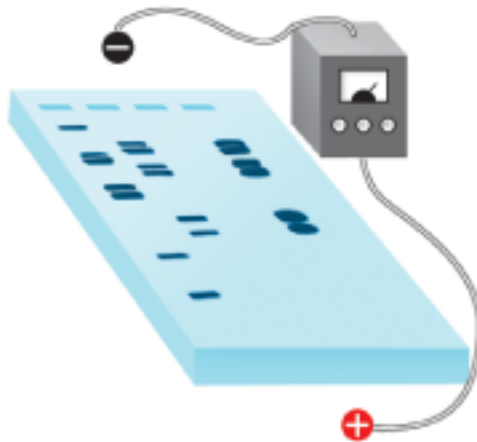
**DNA fingerprinting** can be used to identify individuals by analyzing these sections of DNA that may have little or no function but that vary widely from one individual to another.



## Personal Identification

In DNA fingerprinting, restriction enzymes first cut a small sample of human DNA into fragments containing genes and repeats. Note that the repeat fragments from these two samples are of different lengths.

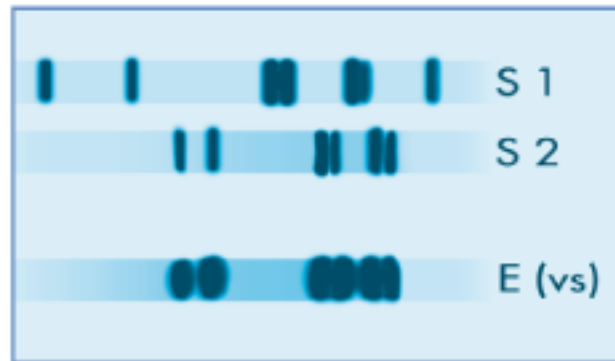
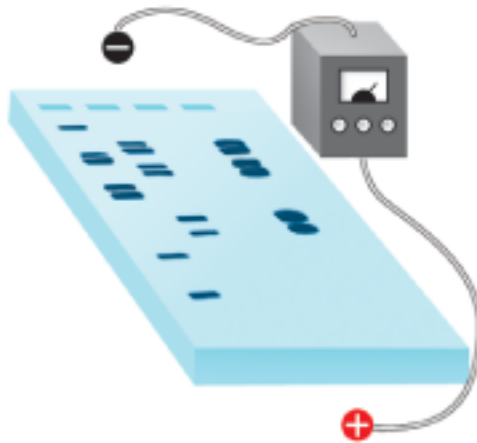
Next, gel electrophoresis separates the restriction fragments by size.



DNA fingerprint

## Personal Identification

A DNA probe then detects the fragments that have highly variable regions, revealing a series of variously sized DNA bands.



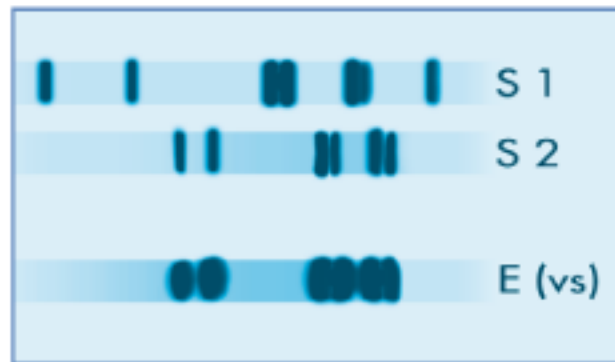
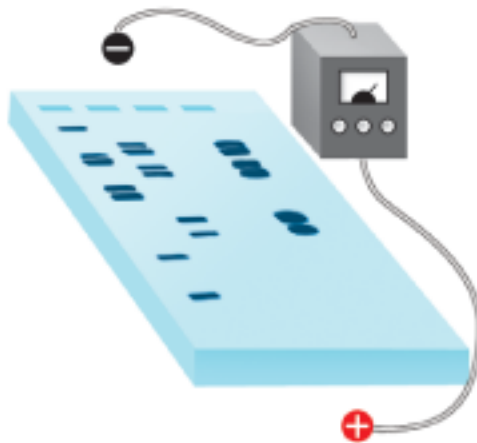
DNA fingerprint



## Personal Identification

If enough combinations of enzymes and probes are used, the resulting pattern of bands can be distinguished statistically from that of any other individual in the world.

DNA samples can be obtained from blood, sperm, or tissue—even from a hair strand if it has tissue at the root.



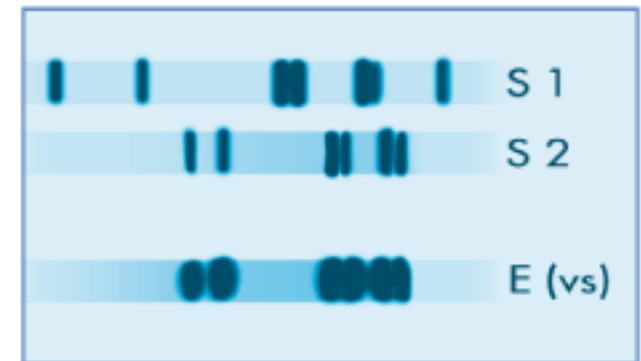
DNA fingerprint

## Forensic Science

The precision and reliability of DNA fingerprinting has revolutionized **forensics**—the scientific study of crime scene evidence.

DNA fingerprinting has helped solve crimes, convict criminals, and even overturn wrongful convictions.

To date, DNA evidence has saved more than 110 wrongfully convicted prisoners from death sentences.



DNA fingerprint

# Forensic Science

DNA forensics is used in wildlife conservation as well.

African elephants are a highly vulnerable species. Poachers, who slaughter the animals mainly for their precious tusks, have reduced their population dramatically.

To stop the ivory trade, African officials now use DNA fingerprinting to identify the herds from which black-market ivory has been taken.

# Establishing Relationships

When genes are passed from parent to child, genetic recombination scrambles the molecular markers used for DNA fingerprinting, so ancestry can be difficult to trace.

The Y chromosome, however, never undergoes crossing over, and only males carry it. Therefore, Y chromosomes pass directly from father to son with few changes.

# Establishing Relationships

Similarly, the small DNA molecules found in mitochondria are passed, with very few changes, from mother to child in the cytoplasm of the egg cell.

Because mitochondrial DNA (mtDNA) is passed directly from mother to child, your mtDNA is the same as your mother's mtDNA, which is the same as her mother's mtDNA.

This means that if two people have an exact match in their mtDNA, then there is a very good chance that they share a common maternal ancestor.

# Establishing Relationships

Y-chromosome analysis has helped researchers settle longstanding historical questions.

One such question—did President Thomas Jefferson father the child of a slave?—may have been answered in 1998.

DNA testing showed that descendants of the son of Sally Hemings, a slave on Jefferson's Virginia estate, carried his Y chromosome.

This result suggests Jefferson was the child's father, although the Thomas Jefferson Foundation continues to challenge that conclusion.