BIOLOGY Life on Earth

WITH PHYSIOLOGY Tenth Edition

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13

Biotechnology

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Chapter 13 At a Glance

- 13.1 What Is Biotechnology?
- 13.2 How Does DNA Recombine in Nature?
- 13.3 How Is Biotechnology Used in Forensic Science?
- 13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?
- 13.5 How Is Biotechnology Used in Agriculture?

Chapter 13 At a Glance *(continued)*

- 13.6 How Is Biotechnology Used to Learn About the Genomes of Humans and Other Organisms?
- 13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?
- 13.8 What Are the Major Ethical Issues of Modern Biotechnology?

13.1 What Is Biotechnology?

- **Biotechnology** is the use, and especially the alteration, of organisms, cells, or biological molecules to produce food, drugs, or other goods
  - Traditional applications of biotechnology include the use of yeast to make bread, beer, and wine, and the selective breeding of animals

13.1 What Is Biotechnology?

- More modern uses modify the genes directly through **genetic engineering**
  - A relatively familiar application of biogenetic engineering is **cloning**, which is used to make identical copies of individual genes or even entire organisms
  - A key tool of genetic engineering is **recombinant DNA**, which is DNA that has been altered to contain genes or portions of genes from different organisms
  - Plants and animals that express DNA that has been modified or derived from other species are **transgenic or genetically modified organisms (GMOs)**

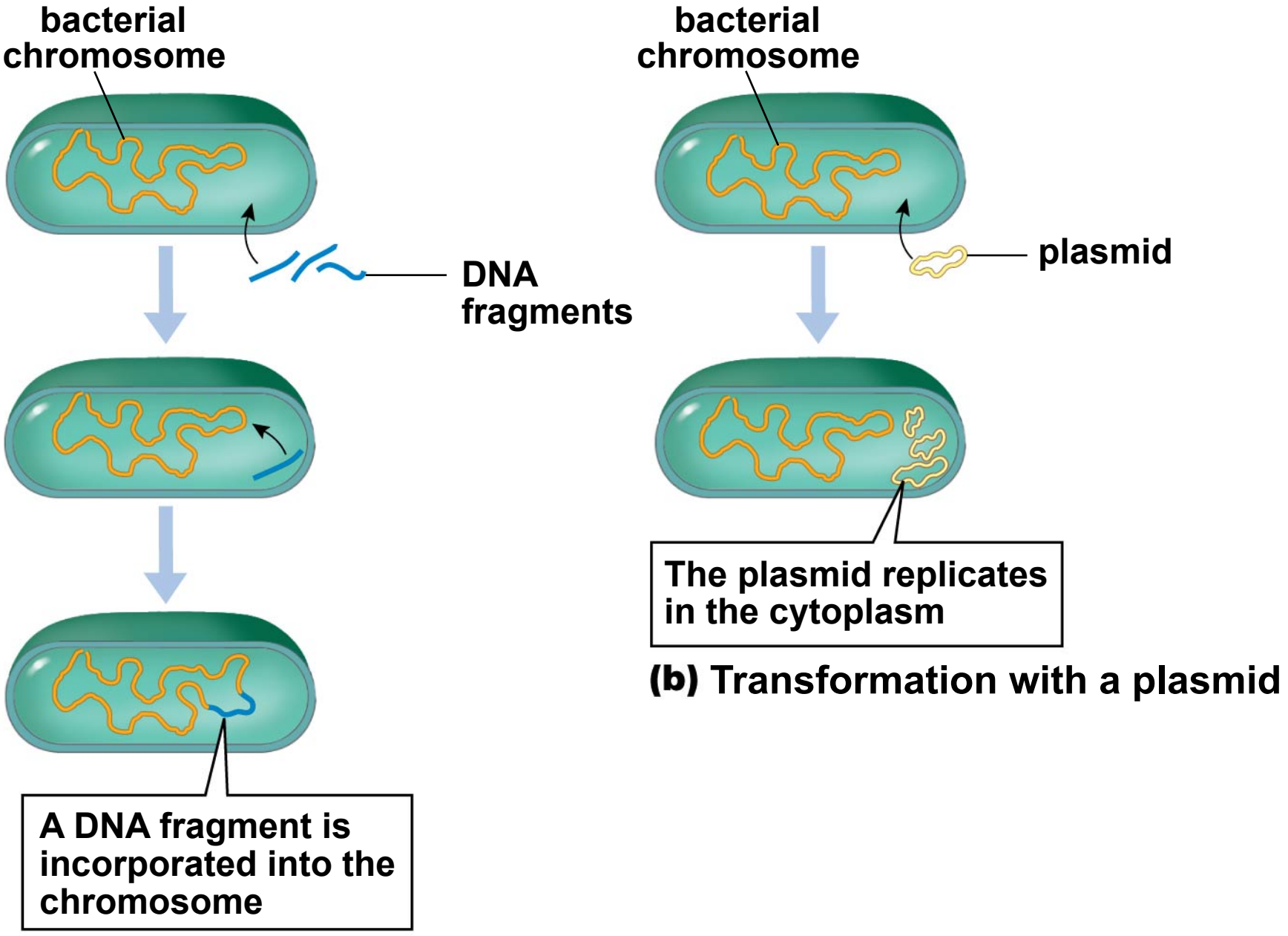
13.2 How Does DNA Recombine in Nature?

- Sexual reproduction recombines DNA
  - During meiosis I, homologous chromosomes exchange DNA
  - Therefore, every egg and every sperm contain recombinant DNA that is derived from the two parents
  - When a sperm fertilizes an egg, the resulting offspring also contains recombinant DNA

13.2 How Does DNA Recombine in Nature?

- Transformation may combine DNA from different bacterial species
  - In **transformation**, bacteria pick up pieces of DNA from the environment
  - This DNA could be part of a chromosome from another bacterium or tiny circular DNA molecules called **plasmids**
  - Passing plasmids from bacteria to yeast may also occur, a process that moves genes from prokaryotes to eukaryotes

Figure 13-1 Transformation in bacteria



13.2 How Does DNA Recombine in Nature?

- Transformation may combine DNA from different bacterial species *(continued)*
  - What are plasmids?
    - Plasmids are small pieces of DNA, not included in the chromosomes, that may be present in bacteria in multiple copies
    - Plasmids carry genes that help the bacteria survive in novel environments, such as where a new energy source is available or where antibiotics are present

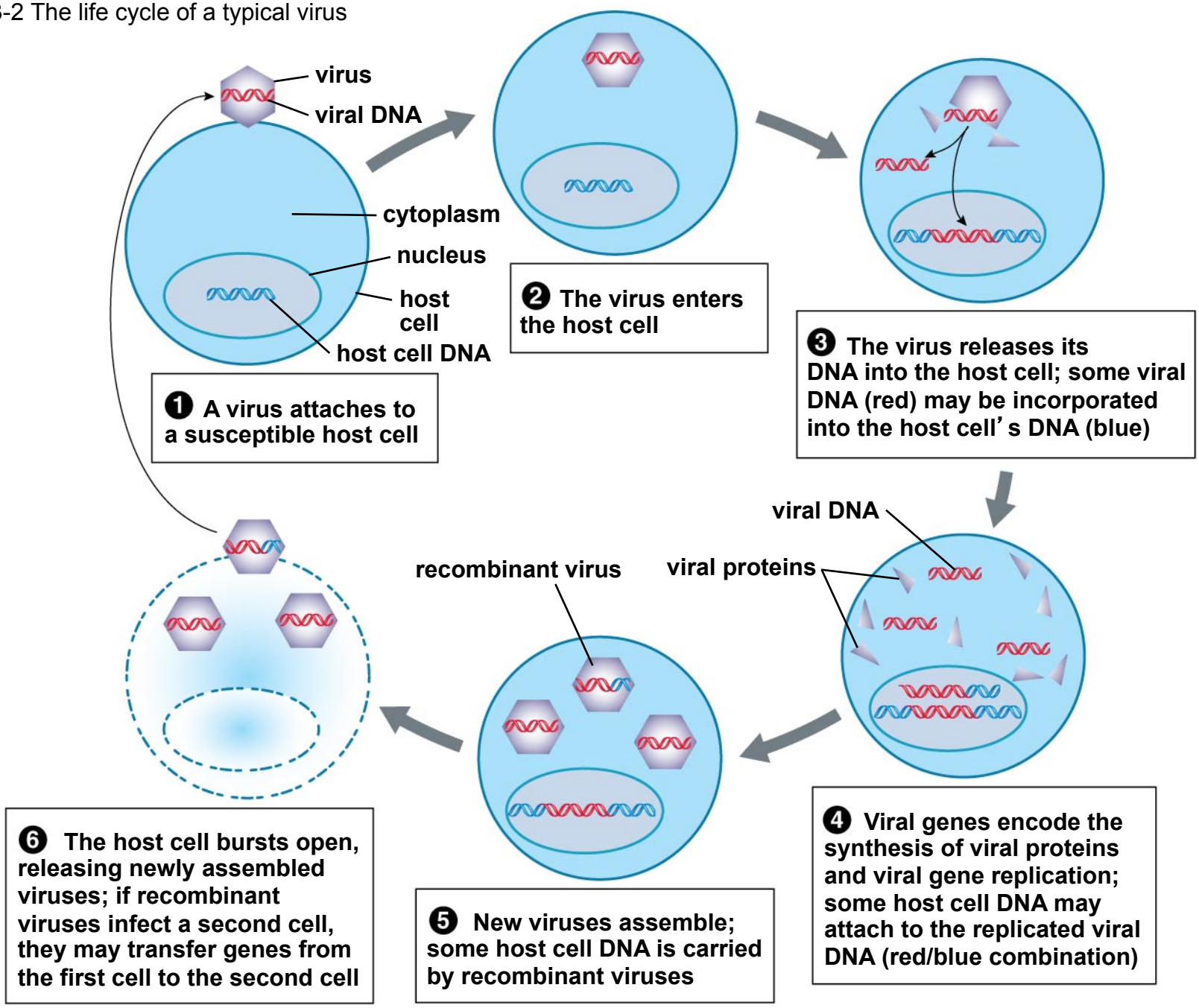
13.2 How Does DNA Recombine in Nature?

- Viruses may transfer DNA between species
  - Viruses are little more than genetic material encased in a protein coat, and can only reproduce inside cells
  - Viral reproduction follows several steps
    1. A virus first attaches to specific molecules on the surface of a suitable host cell
    2. The virus enters the cytoplasm of the host cell
    3. The virus releases its genetic material

13.2 How Does DNA Recombine in Nature?

- Viruses may transfer DNA between species *(continued)*
  - Viral reproduction follows several steps *(continued)*
    4. The host replicates the viral genetic material and synthesizes viral proteins
    5. The replicated genes and viral proteins assemble inside the cell
    6. New viruses are formed, which are released and may infect new cells

Figure 13-2 The life cycle of a typical virus



13.2 How Does DNA Recombine in Nature?

- Viruses may transfer DNA between species *(continued)*
  - In some instances, viral DNA is inserted into one of the host cell's chromosomes
  - When new viruses are produced, some of the host cell's genes may be attached to the viral DNA
  - If such a virus infects another host cell, its DNA and pieces of the previous host cell's DNA will also be inserted

13.2 How Does DNA Recombine in Nature?

- Viruses may transfer DNA between species *(continued)*
  - Most viruses infect specific host species, so that they move host DNA between different individuals of a single, or fairly closely related, species

13.2 How Does DNA Recombine in Nature?

- Viruses may transfer DNA between species *(continued)*
  - Some viruses can infect multiple species
    - Gene transfer between viruses that infect multiple species can produce extremely lethal recombined viruses, as occurred when bird flu and human flu viruses recombined and caused global epidemics and hundreds of thousands of deaths in 1957 and 1968

13.3 How Is Biotechnology Used in Forensic Science?

- Applications of DNA biotechnology vary, depending on the goals of those who use it
  - PCR is used by forensic scientists to identify victims and criminals, and is used extensively in biotechnology and biomedicine

13.3 How Is Biotechnology Used in Forensic Science?

- Applications of DNA biotechnology vary, depending on the goals of those who use it *(continued)*
  - Biotechnology firms need to identify specific genes and insert them in organisms such as bacteria, animals, or plants
  - Biomedical firms and physicians need to detect defective alleles and develop ways to fix them or insert normally functioning alleles into patients

13.3 How Is Biotechnology Used in Forensic Science?

- Applications of DNA biotechnology vary, depending on the goals of those who use it *(continued)*
  - The polymerase chain reaction amplifies DNA
    - Developed by Kary Mullis of the Cetus Corporation, the **polymerase chain reaction (PCR)** produces virtually unlimited copies of a very small DNA sample

13.3 How Is Biotechnology Used in Forensic Science?

- Applications of DNA biotechnology vary, depending on the goals of those who use it *(continued)*
  - The polymerase chain reaction amplifies DNA *(continued)*
    - PCR involves two major steps
      1. Marking the DNA segment to be copied
      2. Running repetitive reactions to make multiple copies

13.3 How Is Biotechnology Used in Forensic Science?

- The polymerase chain reaction amplifies DNA *(continued)*
  - PCR requires small pieces of DNA (called *primers*) that are complementary to the gene sequences targeted for copying
    - One primer is complementary to one strand of the double helix and the other primer is complementary to the other strand

13.3 How Is Biotechnology Used in Forensic Science?

- The polymerase chain reaction amplifies DNA *(continued)*
  - One of the two primers pairs at one end of the targeted area; the other primer pairs to the other end of the targeted area
  - In actual DNA replication, primers are necessary to give DNA polymerase a place from which to build

13.3 How Is Biotechnology Used in Forensic Science?

- The polymerase chain reaction amplifies DNA *(continued)*
  - A PCR "run" is basically DNA replication in a tiny test tube
    - Template DNA, primer, nucleotides, and DNA polymerase are all in the reaction mix
    - The DNA polymerase is a special enzyme that can function at the relatively high temperatures required for PCR

13.3 How Is Biotechnology Used in Forensic Science?

- The polymerase chain reaction amplifies DNA *(continued)*
  - A PCR cycle involves four steps
    1. The test tube is heated to 90–95°C to cause the double-stranded template DNA to separate into single strands
    2. The temperature is lowered to 50°C to allow the two primers to form complementary base pairs with the two original DNA strands

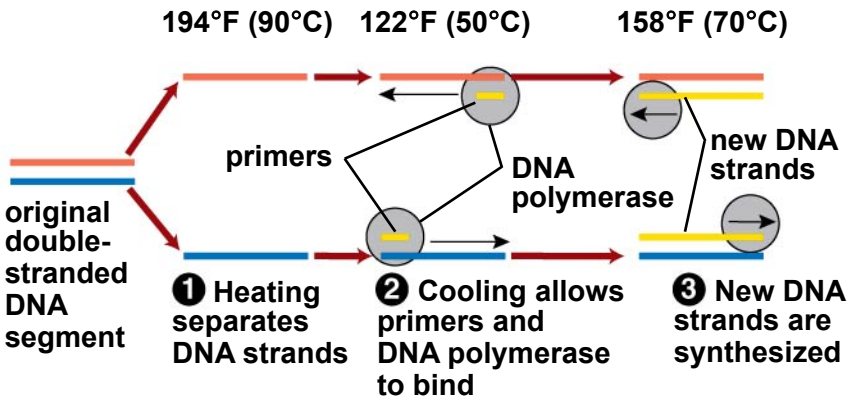
13.3 How Is Biotechnology Used in Forensic Science?

- The polymerase chain reaction amplifies DNA *(continued)*
  - A PCR cycle involves four steps *(continued)*
    3. The temperature is raised to 70–72°C so that DNA polymerase can use the free nucleotides to make copies of the DNA segment bounded by the primers
    4. This cycle is repeated, usually 30 to 40 times, until the reactants are used up

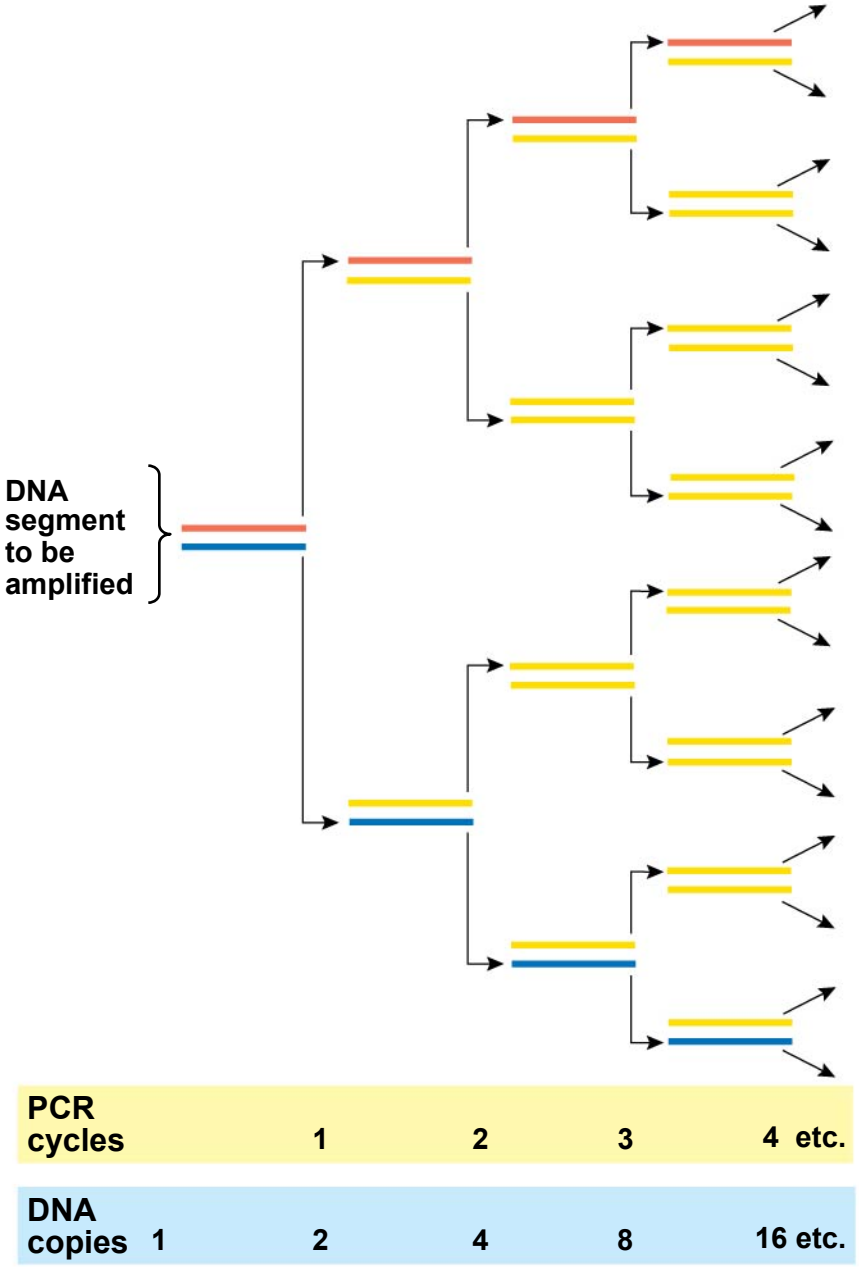
Author Animation: Polymerase Chain Reaction (PCR)

Animation: Polymerase Chain Reaction (PCR)

Figure 13-3 PCR copies a specific DNA sequence



(a) One PCR cycle



(b) Each PCR cycle doubles the number of copies of the DNA

Figure 13-4 Thomas Brock surveys Mushroom Spring

13.3 How Is Biotechnology Used in Forensic Science?

- Differences in short tandem repeats can identify individuals by their DNA
  - Forensic scientists have found that small, repeating segments of DNA, called **short tandem repeats (STRs)**, can be used with astonishing accuracy to identify people
    - Each STR is short (consisting of 2 to 5 nucleotides), repeated (as many as 5 to 50 times), and tandem (having all the repetitions right alongside one another)
  - STRs are repeated sequences of DNA within the chromosomes that do not code for proteins

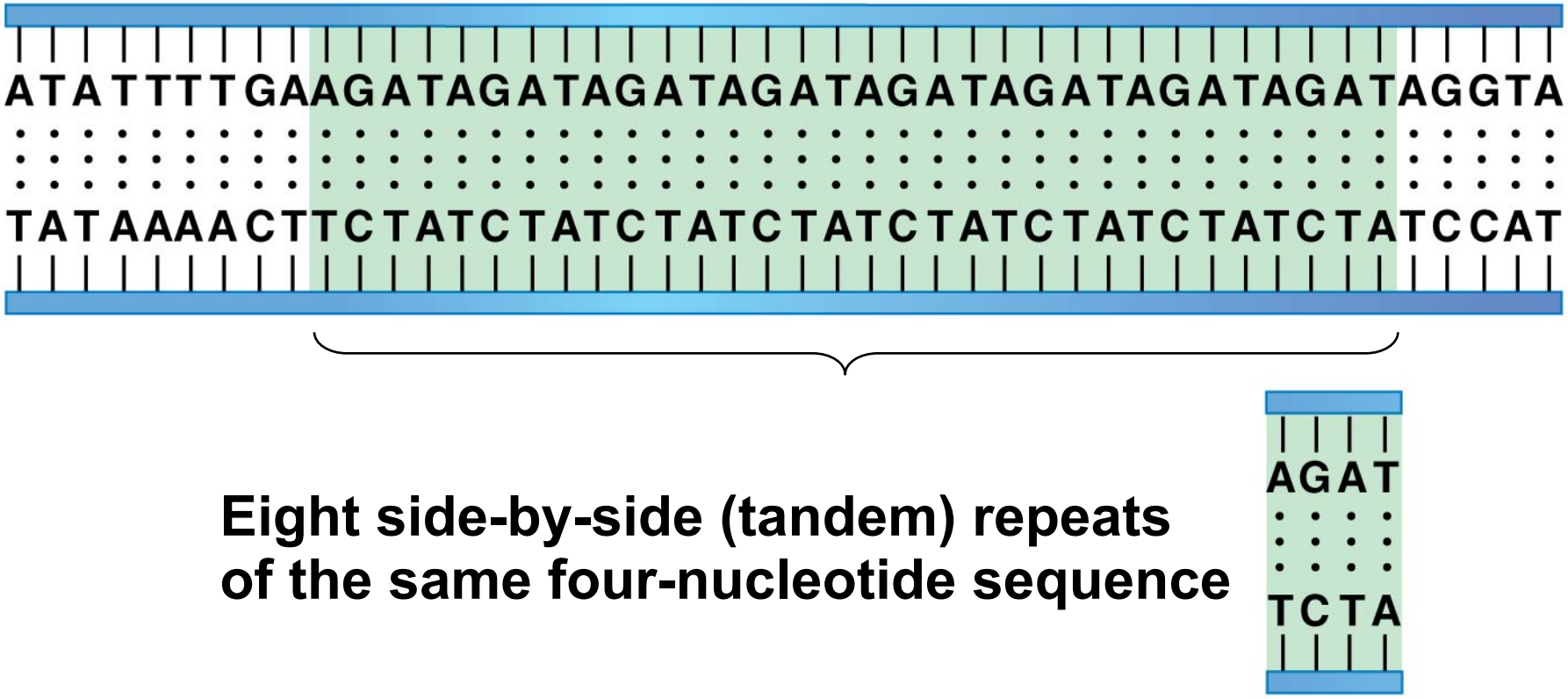
13.3 How Is Biotechnology Used in Forensic Science?

- Differences in short tandem repeats can identify individuals by their DNA *(continued)*
  - STRs vary greatly between different human individuals, like genetic fingerprints
  - Different people may have different alleles of the STRs
    - In the case of an STR, each allele simply has a different number of repeats of the same few nucleotides

13.3 How Is Biotechnology Used in Forensic Science?

- Differences in short tandem repeats can identify individuals by their DNA *(continued)*
  - The U.S. Department of Justice established a standard set of 13 STRs, each four nucleotides long, to identify individuals by DNA samples
    - There may be as few as 5 to as many as 38 repeats of these STRs

Figure 13-5 Short tandem repeats are common in noncoding regions of DNA



13.3 How Is Biotechnology Used in Forensic Science?

- Gel electrophoresis separates DNA segments
  - Mixtures of DNA fragments can be separated on the basis of size
  - **Gel electrophoresis** is a technique used to spread out DNA fragments of varying lengths in a mixture

13.3 How Is Biotechnology Used in Forensic Science?

- Gel electrophoresis separates DNA segments *(continued)*
  - There are four steps in gel electrophoresis
    1. DNA mixtures are placed into wells at one end of a slab of agarose gel, and an electric current is introduced to the gel

13.3 How Is Biotechnology Used in Forensic Science?

- Gel electrophoresis separates DNA segments *(continued)*
  - There are four steps in gel electrophoresis *(continued)*
    2. Because of its phosphates, the negatively charged DNA moves toward the positive electrode, with smaller fragments moving through the gel meshwork more quickly than larger ones
       - The mixture is thus separated into bands of DNA along the gel, according to how many nucleotides long each DNA fragment is

13.3 How Is Biotechnology Used in Forensic Science?

- Gel electrophoresis separates DNA segments *(continued)*
  - There are four steps in gel electrophoresis *(continued)*
    3. When the smallest fragments have migrated to the end of the gel, the fragments are separated into single strands and a different current drives the separated bands of DNA down onto a nylon sheet

13.3 How Is Biotechnology Used in Forensic Science?

- Gel electrophoresis separates DNA segments *(continued)*
  - There are four steps in gel electrophoresis *(continued)*
    4. The nylon paper with the DNA bound to it is bathed in a solution of labeled DNA probes that are complementary to specific DNA segments of interest in the original DNA sample
       - The targeted DNA fragments base-pair with the probe, which reveals their location on the nylon paper

Figure 13-6 Gel electrophoresis and labeling with DNA probes separates and identifies segments of DNA

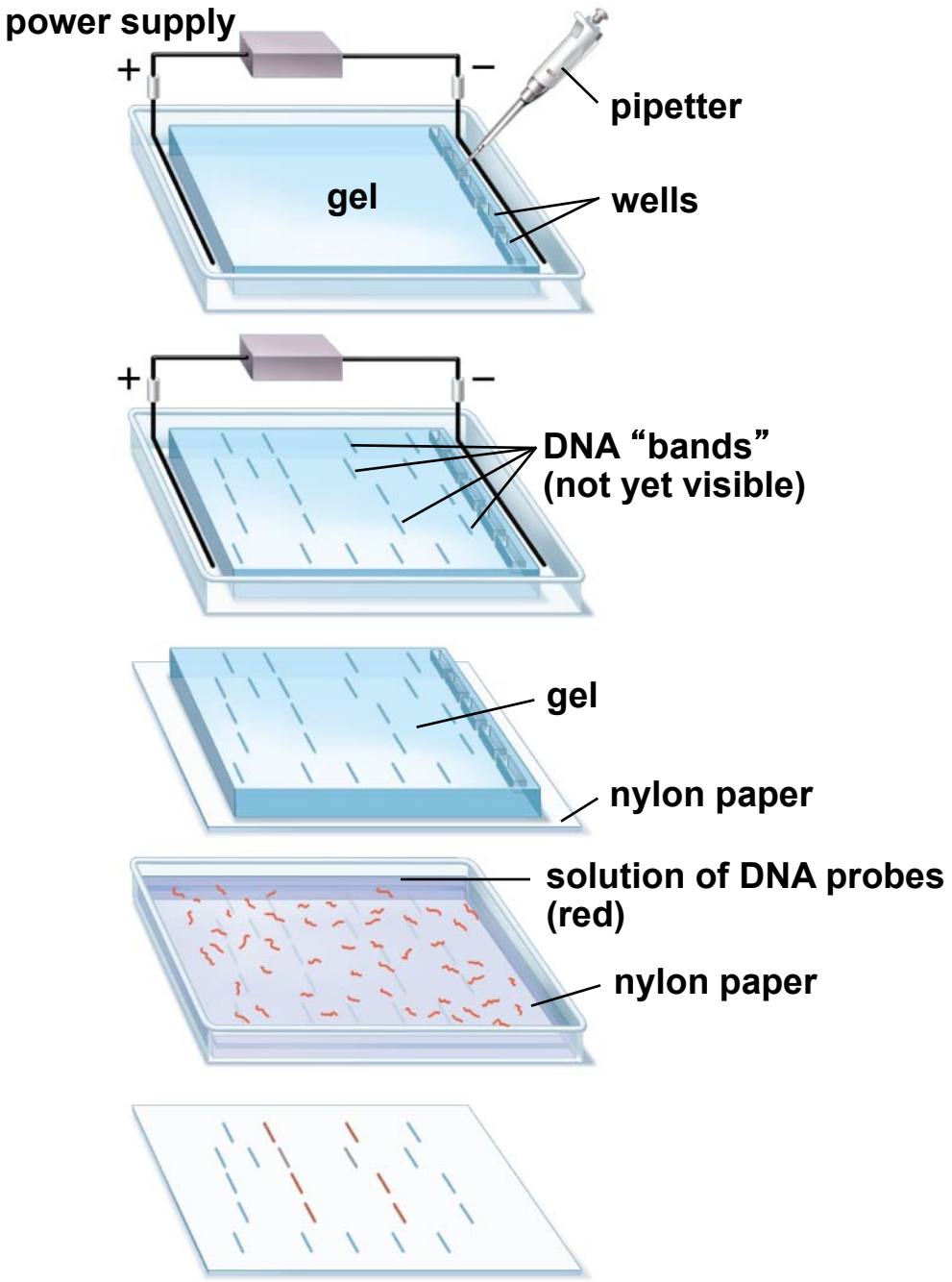
❶ DNA samples are pipetted into wells (shallow slots) in the gel. Electrical current is sent through the gel (negative at the end with the wells and positive at the opposite end).

❷ Electrical current moves the DNA segments through the gel. Smaller pieces of DNA move farther toward the positive electrode.

❸ The gel is placed on special nylon "paper." Electrical current drives the DNA out of the gel onto the nylon.

❹ The nylon paper with the DNA bound to it is bathed in a solution of labeled DNA probes (red) that are complementary to specific DNA segments in the original DNA sample.

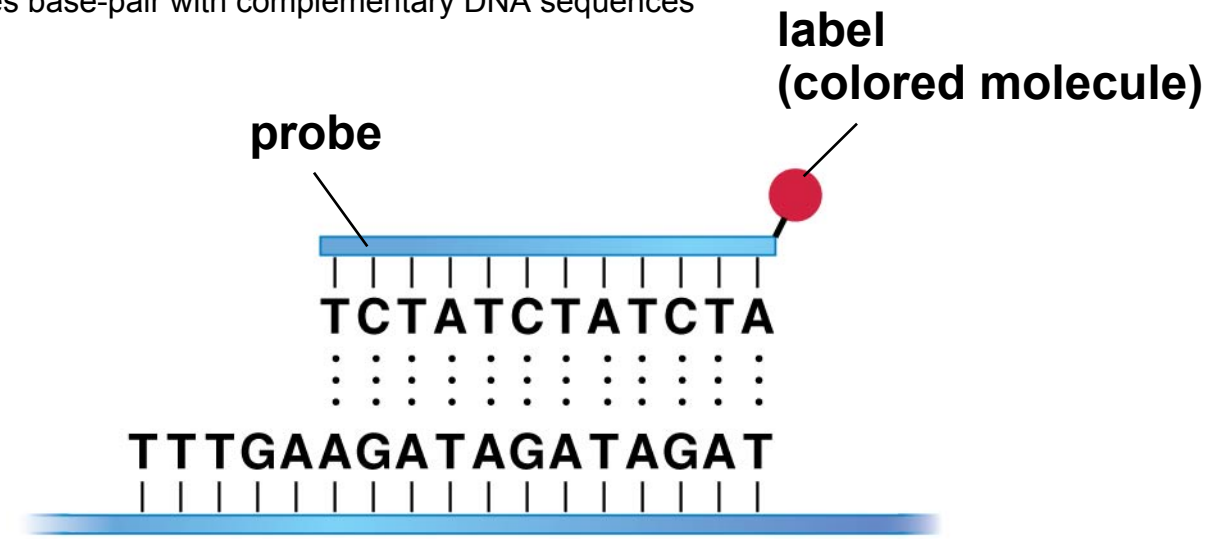
❺ Complementary DNA segments are labeled by the probes (red bands).



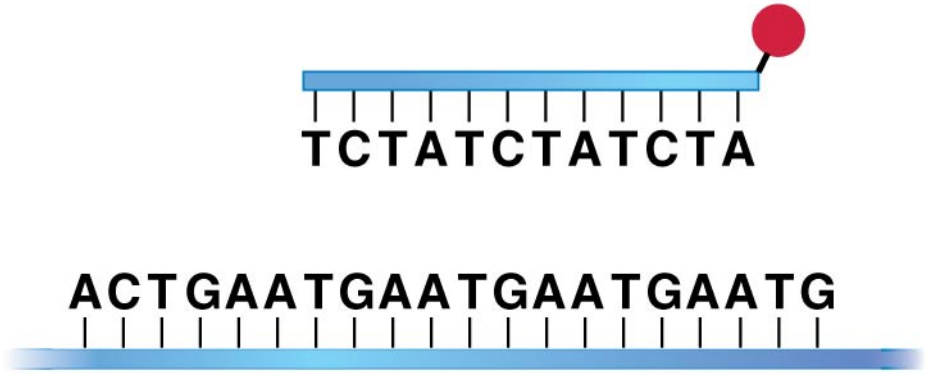
13.3 How Is Biotechnology Used in Forensic Science?

- DNA probes are used to label specific nucleotide sequences
  - **DNA probes** are short, single-stranded DNA fragments used to identify DNA in a gel pattern
    - The probe sequence is complementary to a DNA fragment somewhere in the gel pattern, so it is able to differentiate a particular stretch of DNA (such as a specific STR) from all the other DNA in the sample
  - Probes are labeled with radioactivity or a colored dye, and mark the location of a specific gene sequence when they base-pair with it

Figure 13-7 DNA probes base-pair with complementary DNA sequences



STR #1: The probe base-pairs and binds to the DNA

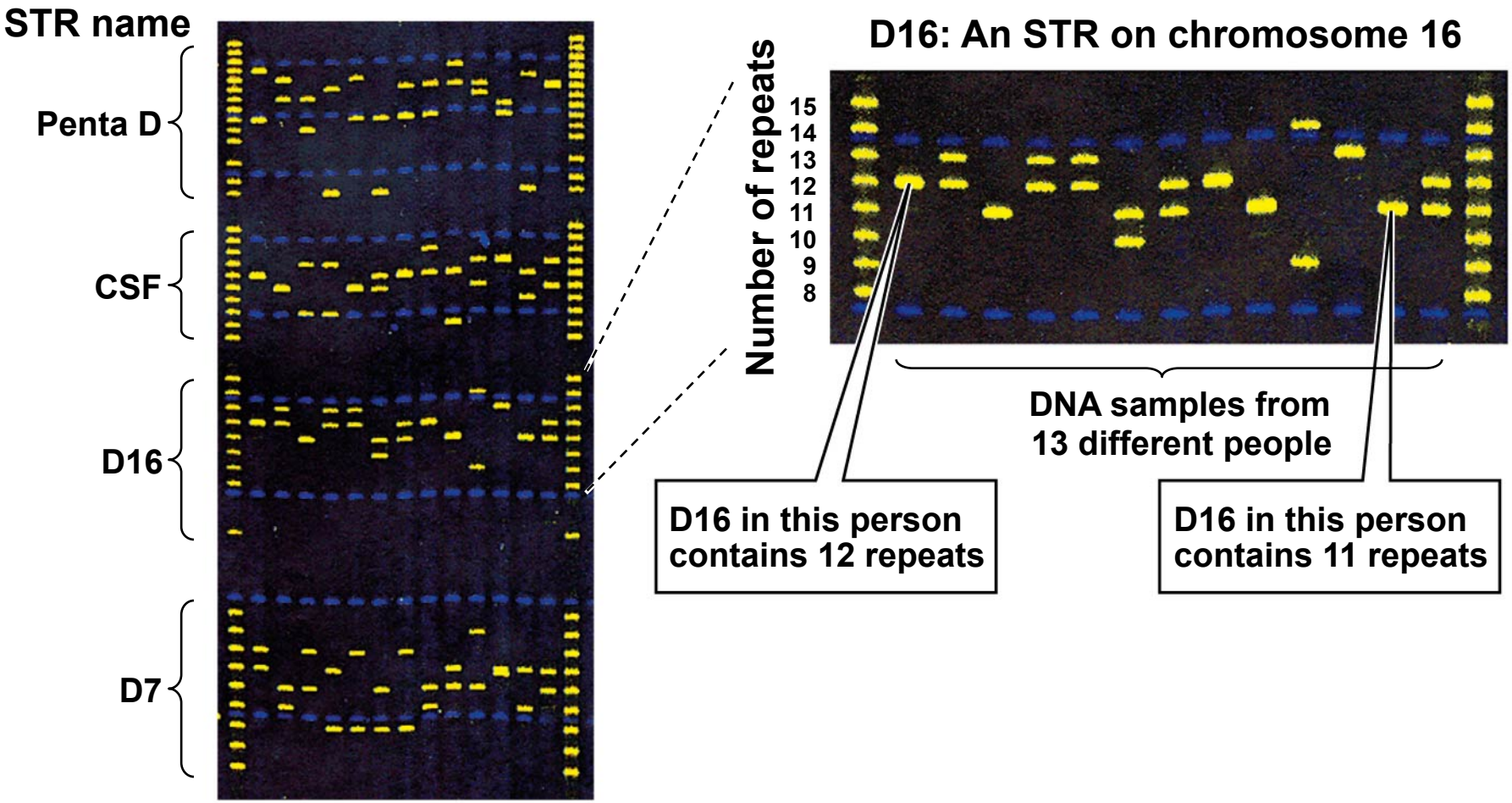


STR #2: The probe cannot base-pair with the DNA, so it does not bind

13.3 How Is Biotechnology Used in Forensic Science?

- Unrelated people almost never have identical DNA profiles
  - DNA samples run on STR gels produce a pattern, called a **DNA profile**
  - The positions of the bands on the gel are determined by the numbers of repeats in each STR allele
  - If the same STRs are analyzed, then a particular DNA sample will produce the same profile every time

Figure 13-8 DNA profiling



13.3 How Is Biotechnology Used in Forensic Science?

- Unrelated people almost never have identical DNA profiles *(continued)*
  - In the United States, anyone convicted of certain specific crimes must give a blood sample
  - Using the standard array of STRs, technicians determine the criminal's DNA profile, which is coded by the number of repeats of each STR found in the criminal's DNA
  - Computers can then determine if DNA left at a crime scene matches one of the profiles in the database, and are able to identify the person at the crime scene

13.3 How Is Biotechnology Used in Forensic Science?

- Unrelated people almost never have identical DNA profiles *(continued)*
  - The chance of two people having the same DNA profile over all 13 STR arrays is about one in a trillion
  - A suspect who differs from the crime scene banding pattern at even one STR locus is exonerated

13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- The techniques of PCR, gel electrophoresis, and identifying DNA sequences with specific probes have applications extending beyond forensic science
- Biotechnology can be used to identify, isolate, and modify genes
  - Combine genes from different organisms
  - Move genes from one species to another

13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- Three major steps are involved in making GMOs

1. Obtain the desired gene
2. Clone the gene
3. Insert the gene into the cells of the host organism

13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- The desired gene is isolated
  - Two common methods to obtain genes
    1. Chromosomes can be isolated from cells of the *gene donor*
    2. DNA fragments containing the desired gene can be separated from the rest of the DNA by gel electrophoresis

13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- The gene is cloned
  - Once the gene is obtained, it can be used to create a transgenic organism
  - **DNA cloning** is the simplest method to generate various copies of the gene in large quantities
  - The most common method of DNA cloning is to insert the gene into a bacterial plasmid, which will replicate when bacteria containing plasmid multiply

13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- The gene is cloned *(continued)*
  - Using **restriction enzymes**, genes are inserted into plasmids
    - Each of the restriction enzymes cut DNA at a specified nucleotide sequence
    - There are hundreds of different restrictions
      - Straight cut
      - Staggered cut

13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- The gene is cloned *(continued)*
  - Restriction enzymes are used to insert a gene into a plasmid by cutting the DNA on both sides of the gene and to split open the circle of the plasmid
  - The ends of the DNA containing the gene and the opened-up plasmid have complementary nucleotides
  - DNA ligase provides a permanent bond between the genes and plasmids

Figure 13-9 Restriction enzymes cut DNA at specific nucleotide sequences

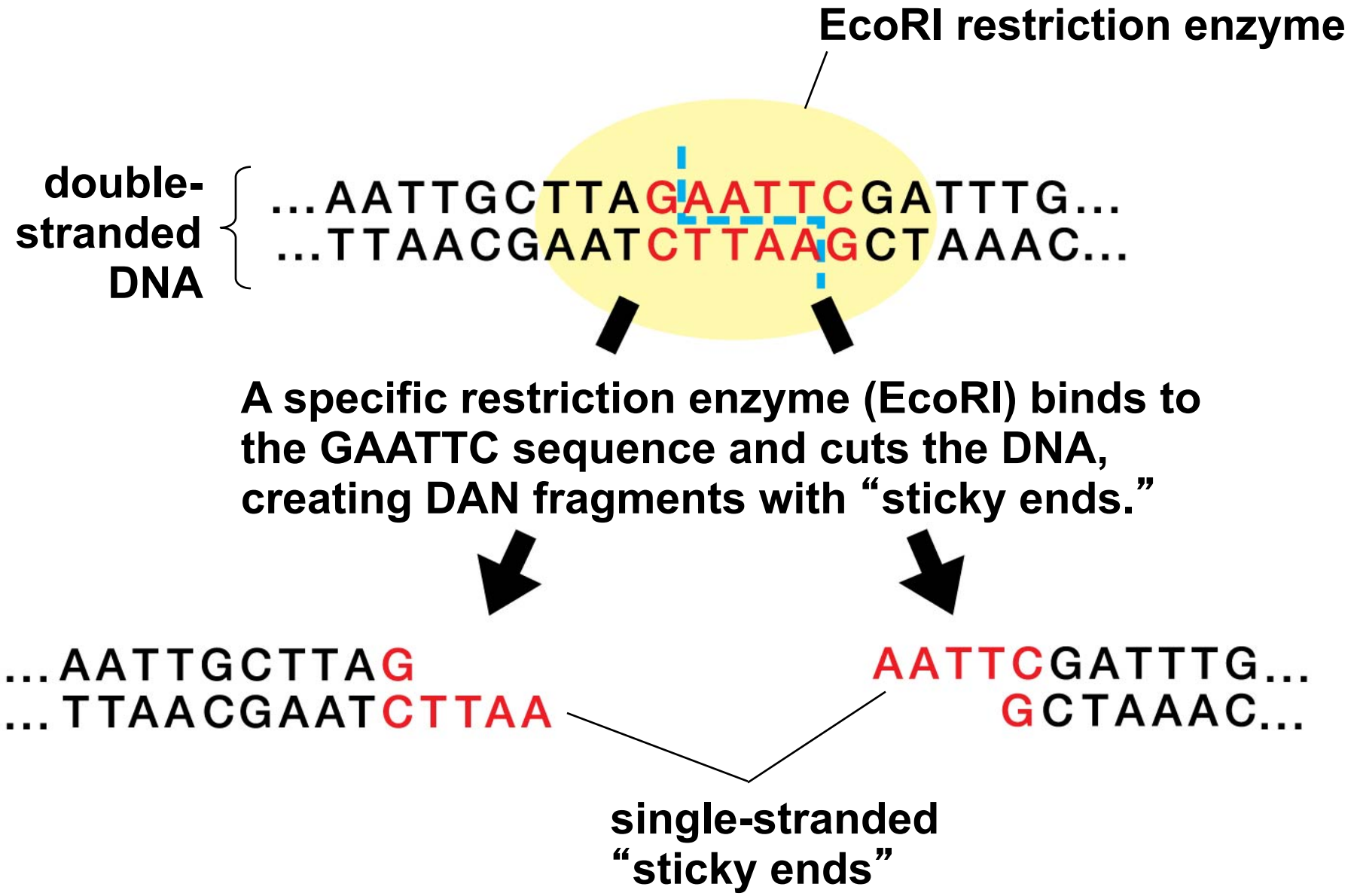
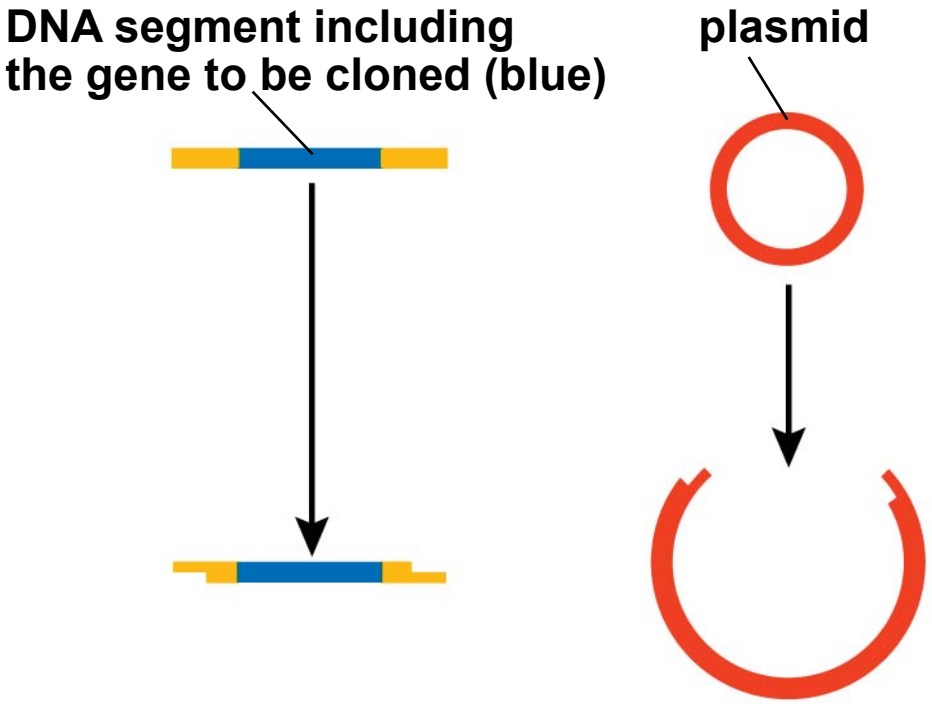
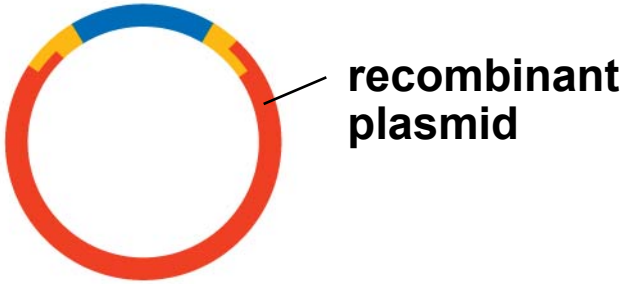


Figure 13-10 Inserting a gene into a plasmid for DNA cloning



❶ The plasmid and the DNA segment containing the desired gene are cut with the same restriction enzyme.



❷ The plasmids and the DNA segment containing the gene, both with the same complementary sticky ends, are mixed together; DNA ligase bonds the genes into the plasmids.

13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- The gene is inserted into a host organism
  - **Transfecting**, which is inserting the gene into the host organism and having it be expressed in the appropriate cells, at the appropriate times, and at the desired level, is difficult

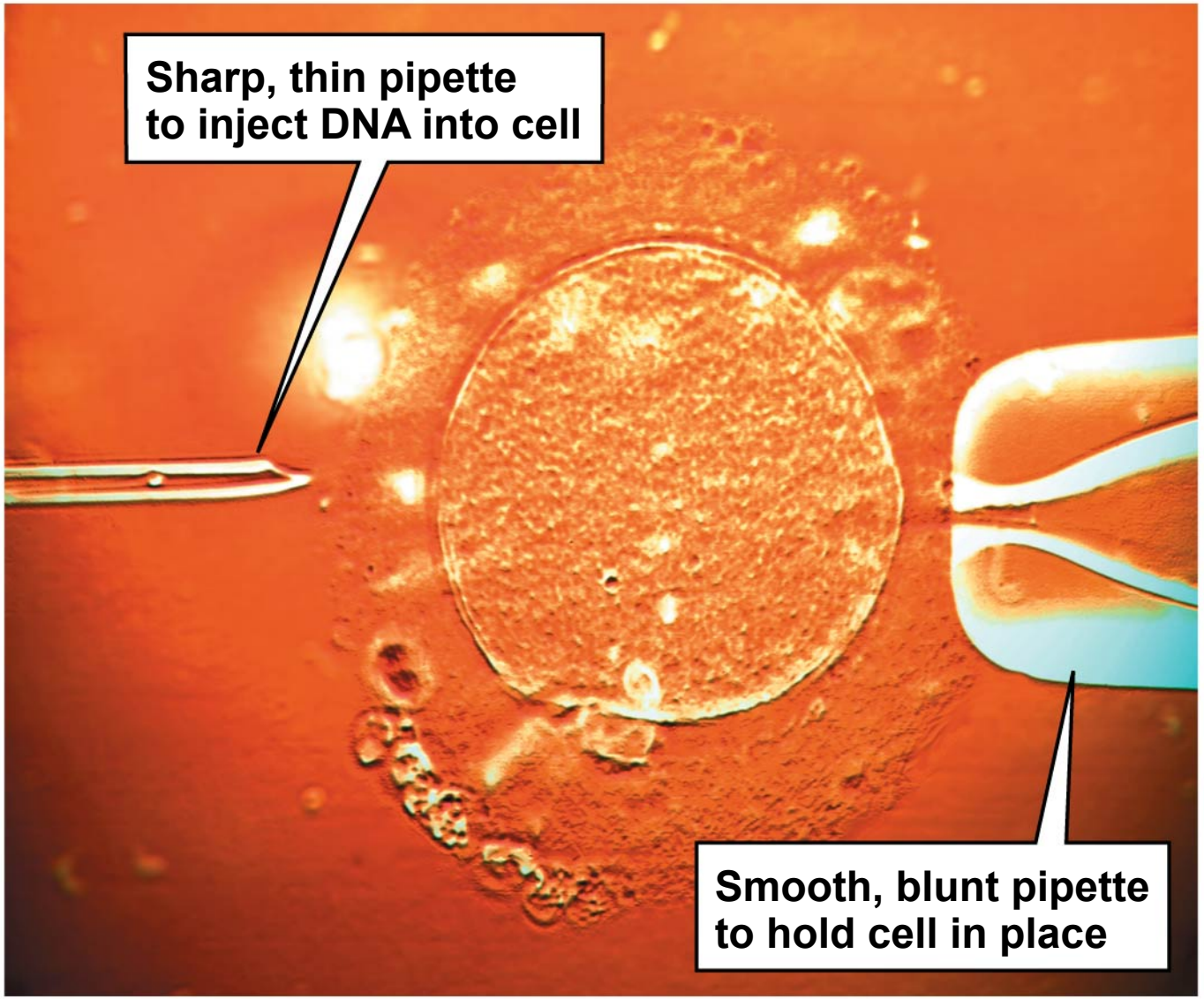
13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- The gene is inserted into a host organism *(continued)*
  - Transfection occurs in various ways
    - The recombinant plasmids or genes purified from them are inserted into harmless bacteria or viruses called *vectors*
    - The bacteria or viruses insert the new gene into the chromosomes of the host organism's cells

13.4 How Is Biotechnology Used to Make Genetically Modified Organisms?

- The gene is inserted into a host organism *(continued)*
  - Transfecting may occur through the use of a "gene gun"
    - Microscopically small pellets of gold or tungsten are coated with DNA and then shot at cells or organisms
    - This is hit or miss, but is quite effective
  - Transfecting may also occur through the direct injection of plasmids or purified genes into animal cells

Figure 13-11 Transfecting a fertilized egg by injecting foreign DNA



13.5 How Is Biotechnology Used in Agriculture?

- The main goals of agriculture are to grow as much food as possible, as cheaply as possible, with minimal loss from pests
  - Many commercial farmers and seed suppliers use biotechnology to achieve these goals
  - Some people feel the risks of genetically modified food to human health or the environment are not worth the benefits

Table 13-1

TABLE 13-1 Genetically Engineered Crops with USDA Approval

Genetically Engineered Trait	Potential Advantage	Examples
Resistance to herbicide	Application of herbicide kills weeds but not crop plants, producing higher crop yields	Beet, canola, corn, cotton, flax, potato, rice, soybean, tomato
Resistance to pests	Crop plants suffer less damage from insects, producing higher crop yields	Corn, cotton, potato, rice, soybean
Resistance to disease	Plants are less prone to infection by viruses, bacteria, or fungi, producing higher crop yields	Papaya, potato, squash
Sterile	Transgenic plants cannot cross with wild varieties, making them safer for the environment and more economically productive for the seed companies that produce them	Chicory, corn
Altered oil content	Oils can be made healthier for human consumption or can be made similar to more expensive oils (such as palm or coconut)	Canola, soybean

13.5 How Is Biotechnology Used in Agriculture?

- Many crops are genetically modified
  - In 2011, about 88% of the corn, 90% of the cotton, and 94% of the soybeans grown in the United States were transgenic; that is, they contained the genes from other species
  - Globally, more than 365 million acres of land were planted with transgenic crops in 2010

13.5 How Is Biotechnology Used in Agriculture?

- Many crops are genetically modified *(continued)*
  - Crop plants are commonly modified to improve insect and herbicide resistance
    - Herbicide-resistant crops withstand applications of weed-killing chemicals
    - The *Bt gene* (from the *Bacillus thuringiensis* bacterium) can be inserted into plants to produce insect-killing protein in crops
      - The protein encoded by the Bt gene damages the digestive tracts of insects, but not mammals

Figure 13-12 *Bt* plants resist insect attack

13.5 How Is Biotechnology Used in Agriculture?

- Genetically modified plants may be used to produce medicines
  - Medically useful genes can be inserted into plants
    - Plants have been engineered to produce harmless hepatitis B virus and *E. coli* proteins, stimulating an immune response when eaten
    - Plants could be engineered to produce human antibodies, conferring passive immunity to microbial infection merely by eating the plant

13.5 How Is Biotechnology Used in Agriculture?

- Genetically modified animals may be useful in agriculture and medicine
  - Transgenic animals can be engineered by incorporating genes into chromosomes of a fertilized egg, which is allowed to grow to term
    - The genes are often introduced to the egg via a disabled virus
    - If viable offspring are produced, they are bred to create homozygotes for the desired trait

13.5 How Is Biotechnology Used in Agriculture?

- Genetically modified animals may be useful in agriculture and medicine *(continued)*
  - Pigs have been genetically modified to produce omega-3 fatty acids
  - Goats have been engineered to carry genes for spider silk, which appears in their milk and produces a meshwork stronger than steel or Kevlar

13.5 How Is Biotechnology Used in Agriculture?

- Genetically modified animals may be useful in agriculture and medicine *(continued)*
  - Sheep can be engineered to produce medically important proteins in their milk that are useful in treating cystic fibrosis or blood clotting factors
  - In 2010 researchers successfully produced transgenic chickens that cannot spread H5N1 influenza virus

13.6 How Is Biotechnology Used to Learn About the Genomes of Humans and Other Organisms?

- The Human Genome Project was launched in 1990 with the goal of determining the nucleotide sequence of all the DNA in our entire set of genes, our genome
- Findings from the Human Genome Project
  - By 2003, molecular biologists, from several countries, sequenced the human genome with 99.99% accuracy

13.6 How Is Biotechnology Used to Learn About the Genomes of Humans and Other Organisms?

- Findings from the Human Genome Project *(continued)*
  - There are 20,000 to 25,000 human genes
  - Genes make up only 2% of the total DNA
  - New genes, including many disease-associated genes, were discovered, but it's not really known what most of DNA does

13.6 How Is Biotechnology Used to Learn About the Genomes of Humans and Other Organisms?

- Why was this project undertaken?
  - Knowing the DNA sequence of a novel gene may allow biologists to predict the function of the protein the gene encodes

13.6 How Is Biotechnology Used to Learn About the Genomes of Humans and Other Organisms?

- Why was this project undertaken? *(continued)*
  - Knowing the sequence of a gene allows predictions about what the amino acid sequence of the encoded protein will be
    - The amino acid sequence can then be compared with proteins whose functions are already known, and if matches are found, inferences can be made about the new gene's function
    - Knowing the nucleotide sequences of human genes will aid in the treatment of many diseases

13.6 How Is Biotechnology Used to Learn About the Genomes of Humans and Other Organisms?

- Why was this project undertaken? *(continued)*
  - Even though most human DNA is the same for everyone on the planet, examining the genomes of many individuals uncovers unique sets of alleles in individuals

13.6 How Is Biotechnology Used to Learn About the Genomes of Humans and Other Organisms?

- Why was this project undertaken? *(continued)*
  - These may correlate with their observed medical conditions, predispositions to disease, and differential responses to treatment
    - Knowledge of these individual differences is already allowing treatment protocols to be refined to take the differences into account
  - Comparison of our genome with those of other species will clarify the genetic differences that help to make us human

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders
  - Two methods are commonly used to find out if a person carries a normal allele or a malfunctioning allele
    1. Restriction enzymes may cut different alleles of a gene at different locations, yielding distinctive fragments characteristic of one allele or the other
    2. Different alleles bind to different DNA probes

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Using PCR to obtain disease-specific alleles
    - DNA sequences of the genes are now responsible for determining genetic disorders
    - PCR can be used to isolate and amplify disease-specific genes for various types of diagnostic procedures
    - Medical testing companies have designed primers that amplify only the defective alleles that cause a specific disorder

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- Restriction enzymes may cut different alleles of a gene at different locations
  - Sickle-cell anemia is an inherited form of anemia—not having enough red blood cells—caused by a point mutation in which thymine replaces adenine near the beginning of the globin gene

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- Restriction enzymes may cut different alleles of a gene at different locations *(continued)*
  - A common diagnostic test for sickle-cell anemia relies on the fact that restriction enzymes cut DNA only at a specific nucleotide sequence
  - To diagnose the presence of sickle-cell alleles, DNA is extracted from cells of a patient, a parent, or even a fetus

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders
  - Different alleles bind to different DNA probes
    - DNA probing is especially useful where there are many different alleles at a single gene locus

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Different alleles bind to different DNA probes *(continued)*
    - Cystic fibrosis is a disease caused by any of 1,200 total possible defective *CFTR* alleles, although all but 32 of these alleles are extremely rare

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Different alleles bind to different DNA probes *(continued)*
    - Cystic fibrosis "arrays" containing a specific probe for each of a number of *CFTR* alleles are used to screen for any of the common cystic fibrosis alleles

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders (continued)
  - Different alleles bind to different DNA probes (continued)
    - Because of complementarity, each probe binds only to the CFTR allele for which it was designed

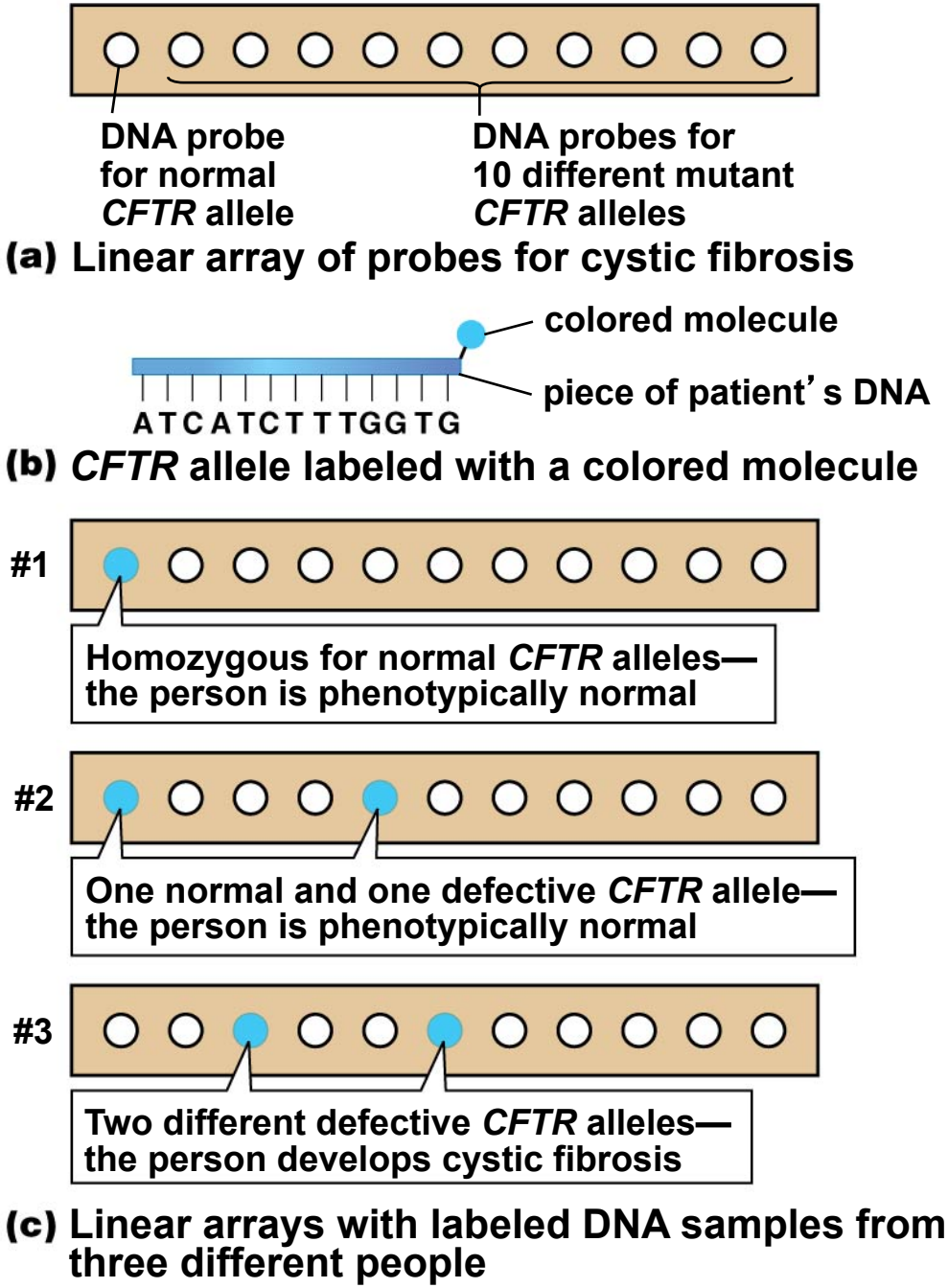
13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Different alleles bind to different DNA probes *(continued)*
    - During screening, the sample is cut up and converted into single-stranded DNA, then labeled with a colored molecule

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Different alleles bind to different DNA probes *(continued)*
    - An array is then bathed with the sample solution and scanned for which *CFTR* probe the sample binds to

Figure 13-13 A cystic fibrosis diagnostic array



13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Different alleles bind to different DNA probes *(continued)*
    - An expanded version of this type of DNA analysis is known as a microarray
    - A microarray contains thousands of probes for a variety of disease-related alleles, such as those for heart disease, breast cancer, and arthritis

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Different alleles bind to different DNA probes *(continued)*
    - Such microarrays can be used to diagnose disease, as well as susceptibility to disease, and can suggest treatments based on individual genetic makeup

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can help to treat disease
  - There are two principal applications of DNA technology for treating disease
    1. Producing medicines, mostly in bacteria, using recombinant DNA techniques
    2. **Gene therapy,** which seeks to cure diseases by inserting, deleting, or altering genes in a patient's cells

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can help to treat disease *(continued)*
  - Using biotechnology to produce medicines
    - Recombinant proteins are currently being used to treat many disorders, although cures through DNA technology have been slow in coming
      - Human insulin is produced inexpensively and rapidly in recombinant bacteria for diabetics
      - Growth hormone and blood clotting factors are produced safely and inexpensively in recombinant bacteria

Table 13-2

TABLE 13-2 Examples of Medical Products Produced by Recombinant DNA Methods

Type of Protein	Purpose	Example	Method of Production
Human hormones	Used in the treatment of diabetes and growth deficiency	Humulin™ (human insulin)	Human gene inserted into bacteria
Human cytokines (regulate immune system function)	Used in bone marrow transplants and to treat cancers and viral infections, including hepatitis and genital warts	Leukine™ (granulocyte-macrophage colony stimulating factor)	Human gene inserted into yeast
Antibodies (immune system proteins)	Used to fight infections, cancers, diabetes, organ rejection, and multiple sclerosis	Herceptin™ (antibodies to a protein expressed in some breast cancer cells)	Recombinant antibody genes inserted into cultured hamster cells
Viral proteins	Used to generate vaccines against viral diseases and for diagnosing viral infections	Engerix-B™ (hepatitis B vaccine)	Viral gene inserted into yeast
Enzymes	Used in the treatment of heart attacks, cystic fibrosis, and other diseases, and in the production of cheeses and detergents	Activase™ (tissue plasminogen activator)	Human gene inserted into cultured hamster cells

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Treating AIDS by gene therapy
    - The human immunodeficiency virus enters several kinds of immune cells, including a type called *helper T cells* that play a crucial role in responses to infection
    - HIV binds to a receptor protein, called CCR5, found on the surface of susceptible immune cells
    - HIV then moves into the cells and begins its deadly infectious cycle

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Treating AIDS by gene therapy *(continued)*
    - Biotechnology offers the possibility of eliminating the CCR5 receptor in patients with AIDS and curing, or at least greatly alleviating, their disease
    - Molecular biologists can manufacture specialized enzymes tailor-made to cut up specific genes, such as the one that encodes the CCR5 receptors

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Treating AIDS by gene therapy *(continued)*
    - The treatment process
      - Immune cells are removed from a patient
      - The *CCR5* gene is damaged with the enzyme
      - *CCR5*-deleted cells are transfused back into the patient
      - In two small clinical trials, the numbers of functioning immune cells were greatly increased in most of the patients receiving this treatment

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Treating severe combined immune deficiency by gene therapy
    - Severe combined immune deficiency (SCID) is a rare disorder in which a child fails to develop an immune system
      - About 1 in 80,000 children is born with some form of SCID

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Treating severe combined immune deficiency by gene therapy *(continued)*
    - Most forms of SCID are caused by defective recessive alleles of one of several genes
    - In one type of SCID, affected children are homozygous recessive for a defective allele that normally codes for an enzyme called adenosine deaminase (ADA-SCID)

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Treating severe combined immune deficiency by gene therapy *(continued)*
    - In the first version of gene replacement therapy, white blood cells were removed from the patient, infected with a recombinant virus carrying a normal gene, and returned to the patient's bloodstream
    - This technique was somewhat successful but had to be repeated as white blood cells containing the recombinant gene died

13.7 How Is Biotechnology Used for Medical Diagnosis and Treatment?

- DNA technology can be used to diagnose inherited disorders *(continued)*
  - Treating severe combined immune deficiency by gene therapy *(continued)*
    - A second type of SCID, called X-linked SCID, caused by a defective recessive allele of a gene, is located on the X chromosome
      - Twenty children received gene therapy to insert a functional copy of the gene into their bone marrow stem cells

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Modern biotechnology offers the promise of greatly changing our lives, and the lives of many other organisms on Earth
- Two important issues
  1. The use of genetically modified organisms in agriculture
  2. The prospects for genetically modifying human beings

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Should GMOs be permitted in agriculture?
  - The goal of breeding or genetically modifying plants or livestock is to make them more productive, efficient, or useful
  - Genetic modification differs from selective breeding ("traditional biotechnology")
    - Genetic engineering is much more rapid
    - Genetic engineering can transfer genes between species
    - Genetic engineering can produce new genes never seen before on Earth

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Should GMOs be permitted in agriculture? *(continued)*
  - There are distinct benefits from using genetically modified plants
    - Transgenic crops decrease applications of pesticides, saving fuel, labor, and money
    - GM plants can be sold at a lower price owing to farm savings
    - Genetically engineered crops are potentially more nutritious; e.g., “golden rice” produces more vitamin A

Figure E13-6 Golden rice

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Are foods from GMOs dangerous to eat?
  - In most cases, there is no reason to think that GMOs are dangerous to eat
  - Various safety concerns have been raised about eating GMOs
    - Could ingestion of Bt protein in insect-resistant plants be dangerous to humans?
    - Are transgenic animals producing extra growth hormone dangerous to eat?

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Are foods from GMOs dangerous to eat? *(continued)*
  - Various safety concerns have been raised about eating GMOs *(continued)*
    - Could GM crops cause allergic reactions?
      - Soybeans containing a gene from Brazil nuts were shown to have the potential to cause an allergic reaction in people allergic to Brazil nuts
      - The USDA now monitors GM foods for their allergenic potential

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Are GMOs hazardous to the environment?
  - The environmental effects of GMOs are much more debatable
    - *Bt* crops enable farmers to reduce the amount of pesticides used in their fields
    - This translates to less pollution
    - In 2002–2003, Chinese farmers planting *Bt* rice reduced pesticide use by 80% compared to farmers planting by conventional means

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Are GMOs hazardous to the environment? *(continued)*
  - The environmental effects of GMOs are much more debatable *(continued)*
    - The farmers suffered no instances of pesticide poisoning compared to 5% of farmers planting conventionally
    - A 10-year study about Arizona farmers using *Bt* cotton reported a decrease in pesticide use while increasing yields

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Are GMOs hazardous to the environment? *(continued)*
  - *Bt* or herbicide-resistance genes might spread outside a farmer's fields because these genes are incorporated into the genome of the transgenic crop
  - In 2006, researchers at the U.S. Environmental Protection Agency discovered herbicide-resistant grasses more than 2 miles away from a test plot in Oregon
  - Scientists concluded that some of the herbicide-resistance genes escaped in seeds

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Are GMOs hazardous to the environment? *(continued)*
  - Could GM fish reduce biodiversity in the wild population if they escape?
    - If GM fish possessed a selective advantage and escaped into the wild fish population, they could quickly replace the wild population

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Are GMOs hazardous to the environment? *(continued)*
  - Could GM fish reduce biodiversity in the wild population if they escape? *(continued)*
    - The reduced diversity in the wild fish could make them more susceptible to catastrophic disease outbreaks
    - One way out of this problem is to produce only sterile transgenic fish so that if they escape, they cannot reproduce and would therefore have a minimal effect on the environment

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Should the genome of humans be changed by biotechnology?
  - Should parents be given information about the genetic health of an unborn fetus?

13.8 What Are the Major Ethical Issues of Modern Biotechnology?

- Should the genome of humans be changed by biotechnology? *(continued)*
  - Should parents be allowed to select the genomes of their offspring?
    - Embryos from *in vitro* fertilization are currently tested before implantation
    - Many unused embryos are discarded
  - Should parents be allowed to design or correct the genomes of their offspring?

Figure 13-14 Using biotechnology to correct genetic defects in human embryos