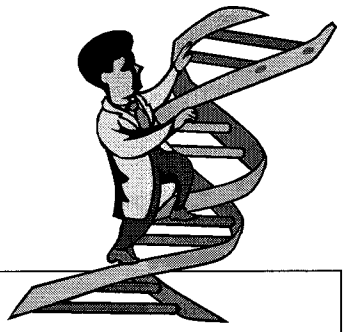
Molecular Genetics and Technology

Section 12.1
DNA, Genes, and Chromosomes



Pre-View 12.1

- **DNA** – a long molecule in the shape of a double helix and made up of nucleotides; contains genetic "instructions"
- **Nucleotide** – the type of molecule that makes up DNA and RNA; contains a sugar, a phosphate group, and a nitrogen base
- **Crick and Watson** – the two scientists who discovered the structure and shape of DNA
- **Chromosome** – a single strand of DNA tightly coiled around special proteins
- **Nucleotide sequence** – the order of nucleotides that determines which protein is made
- **Gene** – a section of DNA that carries the information on how to make one protein

The Basics

DNA, or deoxyribonucleic acid, holds the genetic information for an organism. It is a long molecule made up of smaller units called nucleotides. **Nucleotides** have three parts: a sugar, a phosphate group, and a nitrogen base. In DNA, the sugar is called deoxyribose. The bases can be adenine (A), thymine (T), guanine (G), and cytosine (C). These four bases form complementary pairs: A pairs with T, and C pairs with G.

In 1953 two scientists named **Crick** and **Watson** discovered that DNA is made of two chains of nucleotides that are joined together at the nitrogen bases by hydrogen bonds. By using special X-ray techniques, another scientist named **Rosalind Franklin** discovered that DNA is made of two strands and that the sugar-phosphate molecules make up its backbone. Watson and Crick put this information together with what they knew, and they discovered that DNA is twisted into a shape called a double helix (figure 12-1). The complementary base pairs make up the "rungs" of the double helix "ladder" structure.

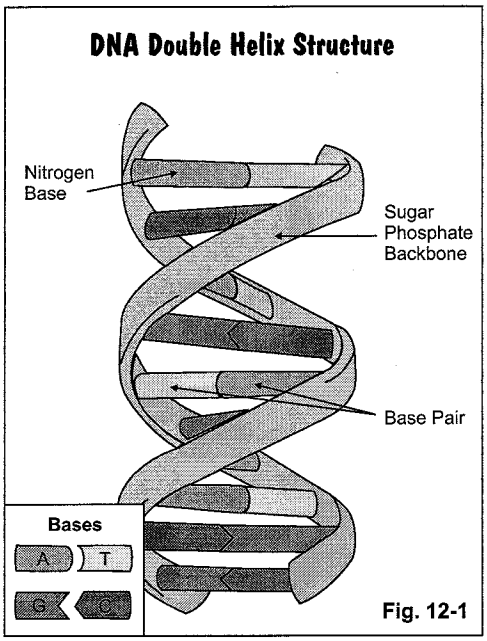


Fig. 12-1

Chromosomes and DNA

Different organisms have different numbers of chromosomes. For example, humans have 46 chromosomes (23 pairs), fruit flies have 8 chromosomes, and potato plants have 48 chromosomes. From previous sections, you should remember the following about chromosomes:

- Chromosomes in eukaryotic cells (cells other than bacteria cells) are found in the nucleus of the cell.
- Chromosomes contain the genetic material of an organism.
- When somatic cells (such as skin cells, liver cells, and brain cells) multiply by the process of mitosis, the number of chromosomes in new daughter cells is the same as the number in the parent cell.
- When sex cells (gametes, or sperm and egg) are formed by meiosis, each gamete contains half the number of chromosomes as the parent cell.

But what is a chromosome, and how is it related to DNA? One **chromosome** consists of one long strand of DNA and special types of protein that are all tightly packed together. In other words, the nucleus of a human skin cell contains 46 very long strands of DNA that help to make up the 46 chromosomes.

Genes and Proteins

What makes each individual different from others? In humans, we have different hair and eye colors, different heights, different fingerprints, different facial structures, different blood types, etc. Plants have different leaf shapes, different flower colors, different seed types, etc. What controls these differences? Believe it or not, the answer is protein. The proteins in any organism dictate the physical properties of that organism, so proteins are really important molecules to living organisms.

The nucleotides that make up DNA are not in some random order. Instead, they are in an order called a **nucleotide sequence** that determines the types of proteins made. If a nucleotide sequence changes, then the information that it carries will change. For example, if a section of DNA has a nucleotide sequence of A-T-T-G-C-C, then it carries different information than a sequence that is A-T-A-G-C-G. So the nucleotide sequence is really the "code" that carries genetic information.

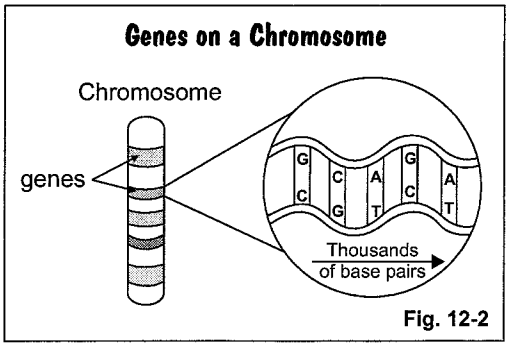


Fig. 12-2

A section of DNA that carries the information to make one protein is called a **gene**, so a gene is a portion of DNA. One chromosome may have more than 1,000 genes on it, and each gene may be made up of thousands of nucleotide base pairs (figure 12-2).

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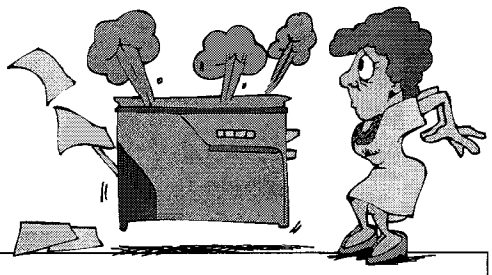
Section 12.2
DNA Replication



Pre-View 12.2

- **Central Dogma of Molecular Biology** – information is transferred from DNA to RNA to proteins, but once the information is in the form of a protein, the transfer cannot be reversed
- **DNA Replication** – the process of copying a strand of DNA

Once Francis Crick understood the structure of DNA as a double helix, he also recognized that this structure enabled it to be copied. Crick established the **central dogma of molecular biology**, which in his words, "deals with the detailed residue-by-residue transfer of sequential information." So the central dogma of molecular biology deals with the transfer of information from DNA. The information can be transferred to another strand of DNA, or it can be transferred to RNA. Then the information from RNA can be transferred to proteins. But once a protein is formed, the information cannot be transferred back to a nucleic acid (DNA or RNA). The transfer of information from DNA can be seen in the cellular processes of DNA replication, transcription, and translation. Let's look at replication first.

DNA Replication

DNA controls the production of every protein in a cell. Since cells are constantly dividing to form new cells, the DNA must be copied exactly in order for the new cell to function properly.

You've already seen that DNA replicates (makes an exact copy) during the cell cycle before mitosis. Replication ensures that cells will have the correct number of chromosomes. Now let's look at *how* DNA is copied.

The process is called **DNA replication**. Replication takes place during interphase and includes several steps:

1. The two strands of DNA unwind and separate, like unzipping a zipper. They "unzip" when the hydrogen bonds between the base pairs are broken, so the nitrogen bases are exposed.
2. Floating around in the nucleus are free nucleotides that are not hooked together. They start to pair with the exposed bases to form complementary base pairs. For example, if a nucleotide on the DNA strand has adenine as a base, then a free nucleotide with a thymine base would pair with it. This type of replication is called semi-conservative since the new molecules of DNA will have one side of the original DNA and the other side will be formed new from free nucleotides.
3. The sugar and phosphate parts of the free nucleotides bond together to form a complete strand that will make up the new side of the DNA molecule. The original strand bonds to the new strand.
4. Since the nitrogen bases have to form complementary base pairs, replication results in two molecules of DNA that are identical.

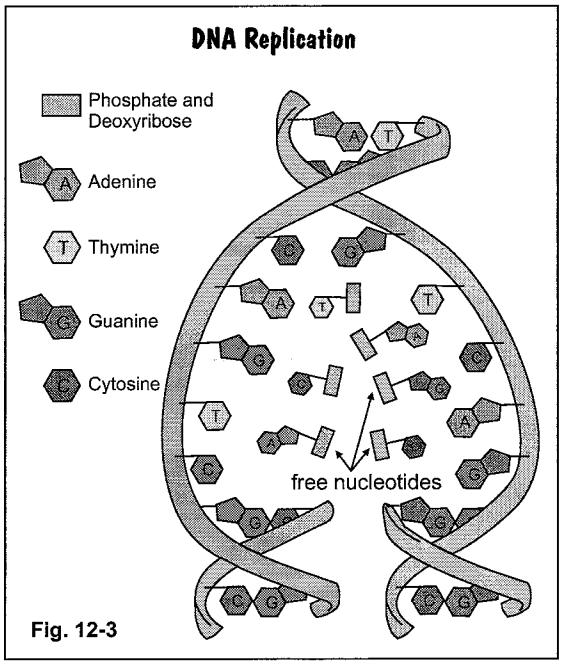
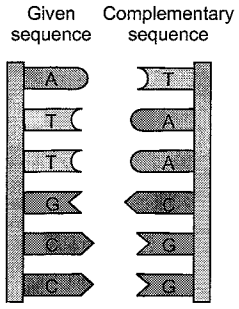


Fig. 12-3

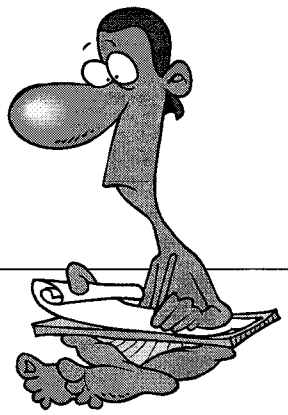


Example: During DNA replication, a section of the DNA has a nucleotide sequence of A-T-T-G-C-C. What would be the sequence of nucleotides that forms the complement to this section of DNA?

This section of DNA gives only one side of the DNA "ladder" and is asking for the nucleotides that would make up the other side. To answer this question, you must remember that A and T bond together and G and C bond together. The complement to this sequence is T-A-A-C-G-G.

Molecular Genetics and Technology

Section 12.3
Transcription and Translation



Pre-View 12.3

- **RNA** – a single strand of nucleotides; different types are used to translate instructions from DNA into making proteins
- **Transcription** – the process occurring in the nucleus of a cell that copies the instructions from a part of DNA onto a strand of messenger RNA
- **Messenger RNA** – a type of RNA that transfers the code from DNA in the nucleus to the cytoplasm
- **Codon** – a sequence of three nucleotide bases that represents the code for one amino acid
- **Translation** – the process occurring in the cytoplasm of a cell that builds proteins
- **Ribosomal RNA** – a type of RNA that "reads" the codons from messenger RNA
- **Transfer RNA** – a type of RNA that carries an amino acid and transfers it to the protein chain being assembled in the ribosome
- **Stop codon** – a sequence of three nucleotide bases that indicates the end of protein synthesis

How do the genes on a chromosome determine how proteins are made? The sequence of nucleotide bases on a strand of DNA is like a language. The only letters in the language are A, T, C, and G, which stand for the four nucleotide bases. Words in this language are made up of three letters. There are 64 possible "words" that can be made from the four letters. Genes are like sentences made up of these three letter words. Each three letter word represents an amino acid. There are 20 amino acids. Some of the 64 "words" represent the same amino acid, and other "words" are like a period at the end of the sentence and indicate a "stop." Amino acids bond together to form polypeptides, and polypeptides bond together to form proteins. Each "word" represents an amino acid, and the sequence of amino acids in the "sentence" determines the type of protein that is made. To help you visualize this relationship, study figure 12-4.

The DNA Sequence of a Gene is the "Code" for a Protein

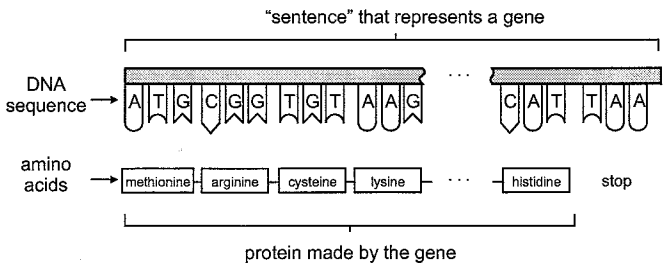


Fig. 12-4

Figure 12-4 shows a few of the steps in the process of making proteins, but some of the steps are not shown. These steps are called transcription and translation. Let's look at those in more detail.

Transcription

RNA is different from DNA in that it contains the sugar ribose instead of deoxyribose. It pairs A with U instead of T, and it is a single strand, not a double strand. There are different types of RNA: messenger RNA, transfer RNA, and ribosomal RNA. The DNA, which is inside the nucleus, has the information to make the proteins, but the proteins are actually made outside of the nucleus on the ribosomes. Something has to happen to send the information from the DNA to the ribosomes. That "something" is **transcription**, a process that copies the instructions in the DNA onto a strand of **messenger RNA (mRNA)**.

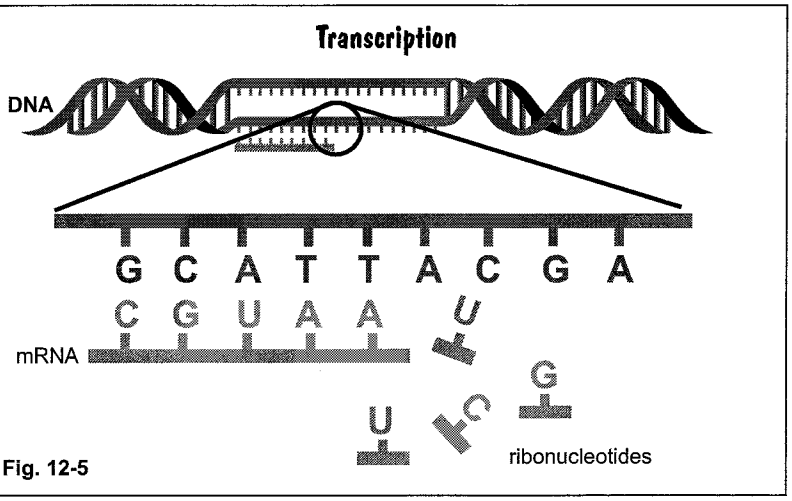
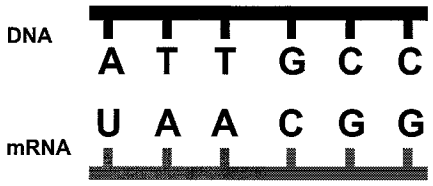


Fig. 12-5

Transcription begins when DNA unzips as it did in replication. This time free RNA nucleotides pair with the nitrogen bases on one strand of the unzipped DNA. Since RNA contains uracil (U) instead of thymine (T), adenine (A) pairs with uracil (U), and cytosine (C) still pairs with guanine (G). If the DNA strand has the nucleotide sequence of G-C-A-T-T-A-C-G-A, the bases on the RNA would be C-G-U-A-A-U-G-C-U. When the base pairing is finished, the mRNA breaks away from the DNA strand, and the two DNA strands zip back together. The mRNA goes out of the nucleus and into the cytoplasm of the cell.

The nitrogen bases in the mRNA also form groups of three bases called **codons**. Each codon is the "code" for an amino acid. (A codon is the three letter "word" that we talked about earlier.) Combinations of the twenty different amino acids then make up proteins in all organisms. Since the nucleotide sequence can create an almost endless number of different proteins and results in all the different kinds of living organisms, it is called the *universal genetic code.*

Example 1: During transcription, a section of the DNA has a nucleotide sequence of A-T-T-G-C-C. What would be the sequence of nucleotides that forms the mRNA complement for this section of DNA?



Instead of asking for the nucleotides that form the other "side" of the DNA, this question is asking for the RNA nucleotides that would match up with this sequence. Remember for RNA, U instead of T bonds to A, and G and C still bond together. The RNA complement would be U-A-A-C-G-G.

Translation

Now that the mRNA has been made and is in the cytoplasm, the process of translation begins. **Translation** builds proteins, and it takes place after the ribosomes attach to the mRNA. The **ribosomal RNA (rRNA)** attaches to the mRNA and starts to "read" the sequence, three bases at a time. Now another form of RNA called **transfer RNA (tRNA)** is used to carry amino acids to the ribosome. Transfer RNA has a three nucleotide sequence called an anticodon that will form base pairs with the codons of the mRNA. For example, if the mRNA codon has the sequence A-U-C, then the tRNA anticodon would be U-A-G. The tRNA carries a specific amino acid that is determined by the anticodon sequence. As the amino acids are placed by the tRNA, a bond forms between the two amino acids, and the tRNA is released. This process is repeated over and over and builds a chain of amino acids. When the rRNA reads a special **stop codon**, translation stops, and the chain is released into the cytoplasm. The polypeptide may then be used in cellular processes, or it may bond with other polypeptides to form proteins.

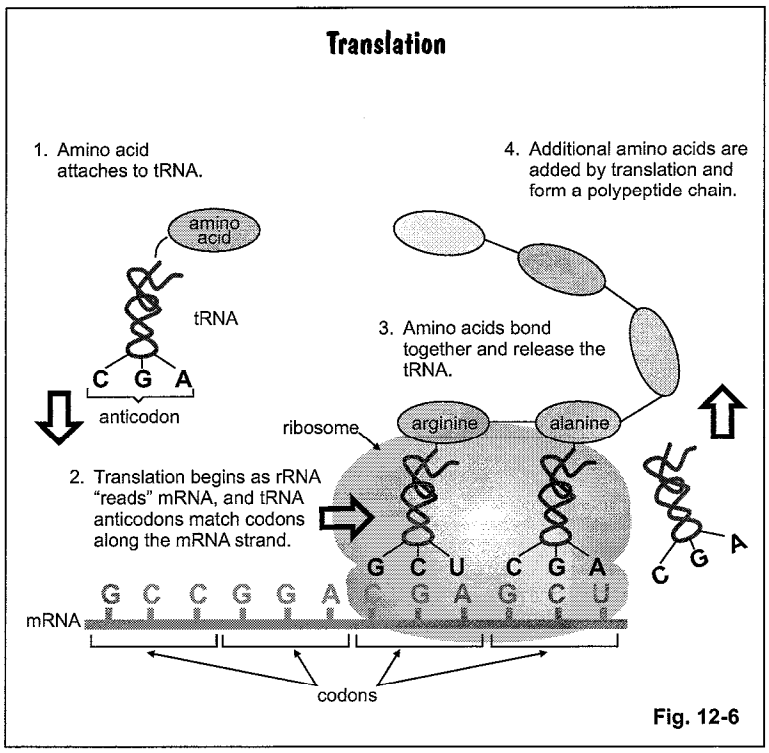
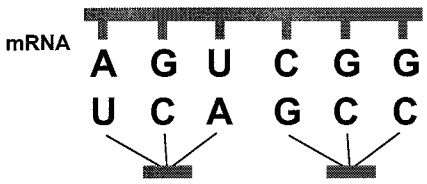


Fig. 12-6

Example 2: During translation, a section of the mRNA has a nucleotide sequence of A-G-U-C-G-G. What would be the transfer RNA complement?



When codons from mRNA are matched up with anticodons from tRNA, U bonds with A and C bonds with G. The tRNA complement to the given mRNA would be U-C-A-G-C-C.

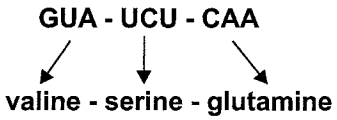
As you can see in the diagram of translation, the series of three-letter codons in the mRNA correspond to an amino acid. The chart below shows the amino acid coded by each mRNA codon. You'll notice many duplicates.

Messenger RNA (mRNA) Codon Chart

First Base	Second Base				Third Base
	U	C	A	G	
U	Phenylalanine UUU	Serine UCU	Tyrosine UAU	Cysteine UGU	U
	Phenylalanine UUC	Serine UCC	Tyrosine UAC	Cysteine UGC	C
	Leucine UUA	Serine UCA	STOP UAA	STOP UGA	A
	Leucine UUG	Serine UCG	STOP UAG	Tryptophan UGG	G
C	Leucine CUU	Proline CCU	Histidine CAU	Arginine CGU	U
	Leucine CUC	Proline CCC	Histidine CAC	Arginine CGC	C
	Leucine CUA	Proline CCA	Glutamine CAA	Arginine CGA	A
	Leucine CUG	Proline CCG	Glutamine CAG	Arginine CGG	G
A	Isoleucine AUU	Threonine ACU	Asparagine AAU	Serine AGU	U
	Isoleucine AUC	Threonine ACC	Asparagine AAC	Serine AGC	C
	Isoleucine AUA	Threonine ACA	Lysine AAA	Arginine AGA	A
	Start/Methionine AUG	Threonine ACG	Lysine AAG	Arginine AGG	G
G	Valine GUU	Alanine GCU	Aspartic acid GAU	Glycine GGU	U
	Valine GUC	Alanine GCC	Aspartic acid GAC	Glycine GGC	C
	Valine GUA	Alanine GCA	Glutamic acid GAA	Glycine GGA	A
	Valine GUG	Alanine GCG	Glutamic acid GAG	Glycine GGG	G

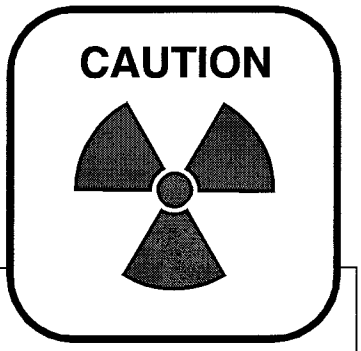
Example 3: Part of a strand of mRNA reads GUA-UCU-CAA. Which amino acids does this section of mRNA code for?

Read the chart above to answer this question. At first, the chart might seem a little confusing, but it is actually easy to read. The first codon given in the question is GUA. In the first column of the chart, go down to row labeled as G. Read across to find the amino acids in the second base column under the U. The third base is A, which is the third amino acid in that portion of the column. GUA corresponds to valine. Repeat these steps, and you should see that UCU corresponds to serine and CAA corresponds to glutamine.



Molecular Genetics and Technology

Section 12.4
Genetic Mutations



Pre-View12.4

- **Mutations** – mistakes made in the DNA
- **Gene mutation** – a mutation that changes one gene
- **Point mutation** – a type of gene mutation that occurs if a nucleotide is added, deleted, or changed in a nucleotide sequence; may result in one or more wrong amino acids being added to a protein
- **Frameshift mutation** – a gene mutation that occurs when a single nucleotide is added or deleted and causes a shift in how the codons are read; may result in one or more wrong amino acids being added
- **Chromosomal mutation** – a mutation caused when a chromosome or a part of a chromosome is duplicated, deleted, or attached incorrectly
- **Inversion** – a chromosomal mutation that occurs if a broken piece of a chromosome is reattached backwards
- **Translocation** – a chromosomal mutation that occurs if a broken piece of a chromosome reattaches to another chromosome
- **Mutagen** – external things that can change DNA, such as radiation or chemicals
- **Carcinogen** – a mutagen that is directly involved in causing cancer
- **Nondisjunction** – the term used when a chromosome doesn't separate correctly during meiosis; may result in a chromosomal mutation in offspring

We all make mistakes, don't we? Sometimes cells make mistakes, too, when they copy their DNA. **Mutations** are mistakes in DNA sequencing, and they can affect the genetic information that is passed to offspring. Sometimes the mistakes are so small that they are never noticed, but sometimes they can cause a lot of problems.

Gene Mutations

One type of mutation is a **gene mutation**. It changes just one gene. Gene mutations may happen when one nucleotide is substituted for another nucleotide, or when a nucleotide is added to or taken away from a gene. These changes can cause a protein to be changed so much that it can't function properly. Suppose that you had a sentence made of 3 letter words (like codons):

THE RAT HID AND THE CAT SAT AND GOT FAT.

If we substituted a different letter for the letter R, words are still formed, but the sentence doesn't make sense:

substitution ↙

THE PAT HID AND THE CAT SAT AND GOT FAT.

If we add a letter or delete a letter somewhere, it's even worse because all of the "words" after the insertion or deletion change:

insertion ↙

THE RAT HIX DAN DTH ECA TSA TAN DGO TFA T

deletion ↙

THE RAH IDA NDT HEC ATS ATA NDG OTF AT

Remember, amino acids make up polypeptide chains, polypeptide chains make up proteins, and proteins are a vital component of living materials and carry out vital cellular processes. Remember also that genes in the DNA are made up of nucleotide sequences that are "read" in groups of threes similar to the three-word sentences shown on the previous page. The sequence of the letters in the mRNA determines the amino acid that is added to the polypeptide chain. If one or more amino acids added to that polypeptide chain are wrong, the organism will not be able to build proteins with the correct structure. Look at figure 12-7 to review the different types of gene mutations and how they affect protein production. Notice that the amino acids that make up the protein can change when different gene mutations occur. Gene mutations are sometimes called **point mutations** because the mutation occurs at only one point in the DNA. Insertions or deletions of a single nucleotide are also called **frameshift mutations** because they shift how the codons are read and can result in different amino acids being added to the protein. (Note: Since some nucleotide sequences "code" for the same amino acid, not all gene mutations result in a different amino acid.) Both point mutations and frameshift mutations may also create a stop codon, which will stop protein synthesis. The resulting protein will be shorter than it is supposed to be.

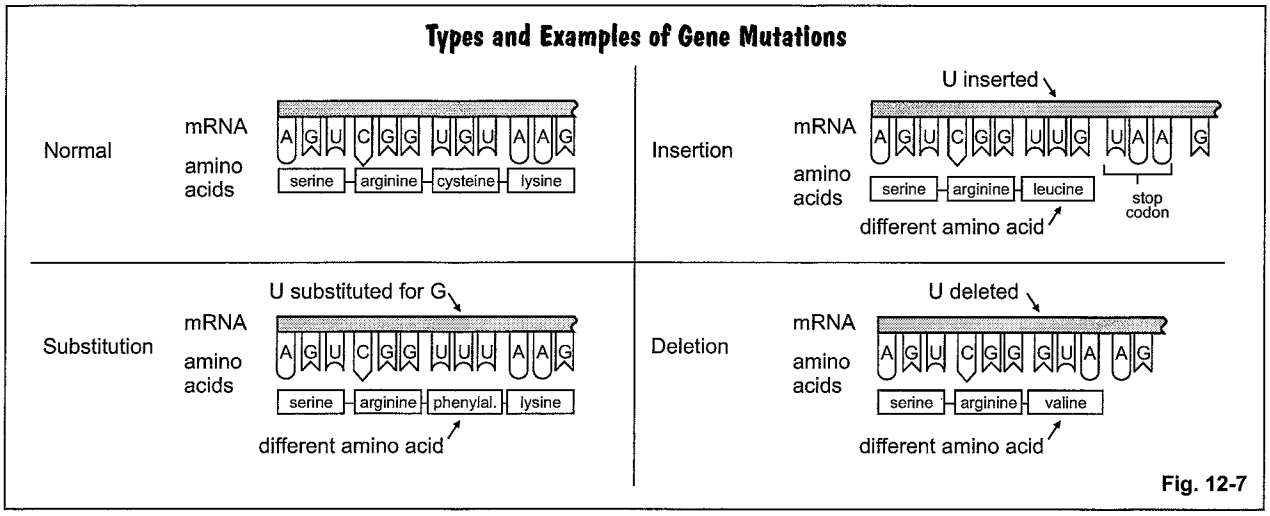


Fig. 12-7

Chromosome Mutations

The other type of mutation is a **chromosomal mutation**, where the structure or numbers of chromosomes change. The structure of a chromosome can change if a part of a chromosome is broken off or lost during the processes of mitosis or meiosis. The following types of chromosomal mutations can occur by a change in chromosome structure.

- A broken part can sometimes reattach to a sister chromatid and cause **duplication** of genetic information in one chromatid and **deletion** of genetic information in the other.
- If the broken part reattaches backwards, it is called an **inversion**.
- The broken part may also attach to another chromosome and is called **translocation**.

In any of these cases, the genes on the broken portion of the chromosome are now in the wrong place. Figure 12-8 shows the different types of chromosomal mutations.

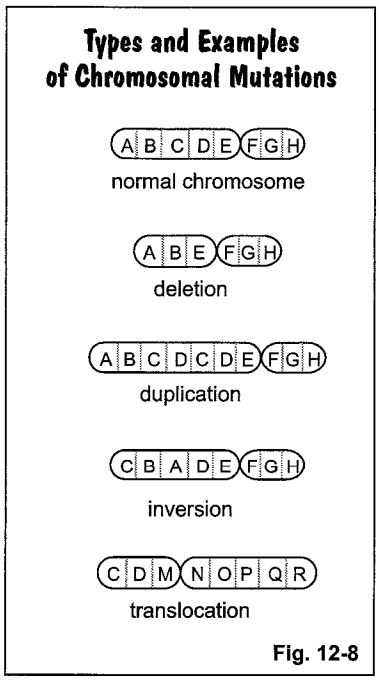


Fig. 12-8

Mutations During Mitosis

Gene mutations can either be passed on from a parent to a child, or they can be acquired during an individual's lifetime. When mutations occur during an organism's lifetime, the mutations are normally the result of mistakes that occur during mitosis.

Mitosis, as you may recall, is the process that reproduces the cells in your body. Somatic cells, such as liver cells, skin cells, and blood cells, are constantly being replaced in the body by the process of mitosis. Most mutations, especially gene mutations, occur during the process of mitosis when the DNA is being copied. Thankfully, cells have processes to help catch and repair mistakes. When a mistake isn't repaired, it can lead to cellular malfunctions. These malfunctions affect the cells that reproduce the mistake. These types of mistakes that occur in somatic cells affect that particular individual only. They are not passed on to offspring.

We don't know all the causes of mutations, but scientists have linked several things to them. **Mutagens** are external agents that can change the DNA. Some types of radiation and some chemicals are mutagens. A common result of genetic mutations is **cancer**. Mutagens that are linked to cancer are called **carcinogens.** Being exposed to ultraviolet radiation from the sun and from tanning booths increases the chances of having the mutations that cause skin cancers. Radiation from x-rays, especially from repeated exposure, can cause mutations in the cells of internal organs. Tobacco, asbestos, benzene, some chemical pesticides, and many other industrial chemicals are common carcinogens.

Mutations During Meiosis

When a mutation occurs during the process of meiosis, that mutation can be passed on to offspring. The mutation becomes part of the offspring's DNA and will be found in almost every cell. This mutation can then be passed on to the next generation. Existing genetic disorders are passed on to offspring when the defective gene becomes part of the gamete formed by meiosis.

Gene Mutations: Gene mutation cause many common genetic disorders. Most of these are recessive, meaning an individual must inherit a defective gene from both parents in order to be affected by the disorder. Gene mutations on somatic chromosomes that are inherited include sickle cell anemia, Tay-Sachs disease, and cystic fibrosis. **Sickle cell disease** is caused by a single substitution in a gene that forms the protein hemoglobin. Because of the substitution, the amino acid valine is added instead of glutamic acid. The resulting hemoglobin protein is a different shape and is less functional. A parent that has the sickle cell gene can pass that gene on to his or her children just like any other trait. **Tay-Sachs disease** is a frameshift mutation that can occur in several different ways but results in a defective enzyme needed to break down a certain type of fat. **Cystic fibrosis** results when a defective gene makes thick, sticky mucus.

Some gene mutations occur on the sex chromosomes. Two common diseases caused by a gene mutation on the X chromosome are **red-green color blindness** and **hemophilia**.

Chromosomal Mutations: Chromosomal mutations can pass on defective chromosomes, or they can cause too many or too few chromosomes to be passed on. If the mutation occurs during meiosis, the defective chromosomes may be passed on to the offspring. If a chromosome does not separate correctly during meiotic division (called **nondisjunction**), a gamete can have an extra or a missing chromosome. If the defective gamete is fertilized, the resulting individual will have some form of genetic disorder.

One of the most common examples of a chromosomal mutation is **Down's syndrome**. The most common type of Down's syndrome is trisomy 21, which means that the person affected has three copies of chromosome 21 instead of just two. The affected person has 47 chromosomes in each body cell instead of 46. A person with Down's syndrome usually has mild to severe mental retardation and is more likely to have heart problems and other health issues. About 1 out of every 730 babies is born with Down's syndrome. Although Down's syndrome affects people of all races, we know that the risk of having a child with Down's syndrome increases after the mother is 35 years old. For example, the probability of a 35 year-old woman having a baby with Down's syndrome is one out of 400, and by the time she is 45, it increases to one out of 35.

Karyotypes

How do geneticists identify chromosomal mutations? One way is by using a karyotype. A **karyotype** can be used to see if there is an abnormal number of chromosomes or if one or more chromosomes are misshapen. To make a karyotype, the geneticist obtains a sample of cells from the individual being tested. The cells are processed, and a picture is taken of the stained chromosomes during metaphase when they are easiest to see. The picture is enlarged so the geneticist can cut the chromosomes apart and arrange them in pairs by length and location of the centromeres. From this, the geneticist can see if there are too many or too few chromosomes or if there has been a chromosomal deletion, duplication, inversion, or translocation. Figure 12-9 shows a normal human male karyotype.

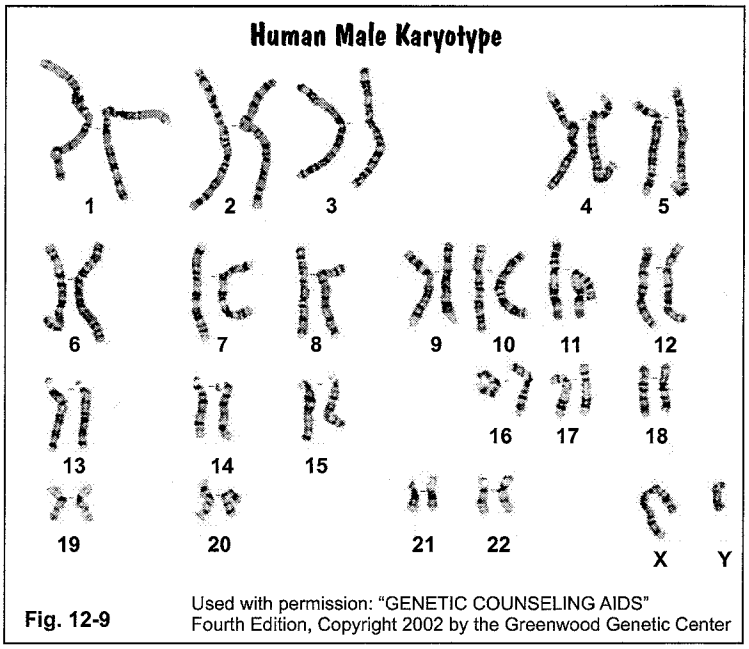
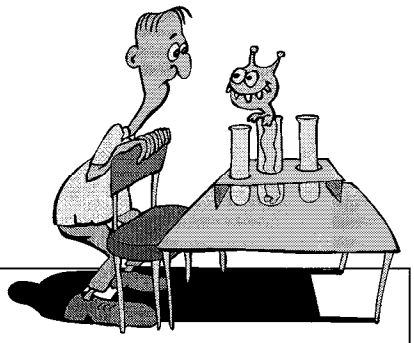


Fig. 12-9

Molecular Genetics and Technology

Section 12.5
DNA Technology



Pre-View 12.5

- **Molecular genetics** – the study of DNA
- **Genetic engineering** – the field of manipulating and changing an organism's DNA
- **DNA extraction** – the process of separating DNA from the rest of the cell
- **Restriction enzymes** – enzymes used to cut DNA into pieces
- **Gel electrophoresis** – a technology that separates DNA fragments so that they can be analyzed
- **DNA fingerprinting** – a technique that uses gel electrophoresis to analyze a person's unique pattern of DNA
- **Recombinant DNA** – DNA that is formed by joining a short piece of DNA from one organism to the DNA of another organism
- **Transformation** – the process used to place recombinant DNA back into a living cell
- **Plasmids** – circular pieces of DNA found in bacteria cells
- **Transgenic** – a term used to describe an organism that contains the DNA from a different organism
- **Reproductive cloning** – the process of creating an organism that is genetically identical to a donor organism

As our technology has improved, a whole new branch of science called **molecular genetics** has been created. In molecular genetics, scientists study DNA molecules and make changes in the DNA. These studies have developed into a field called **genetic engineering**, which involves manipulating and making changes in an organism's DNA.

DNA Extraction and Gel Electrophoresis

Many different techniques are used when studying DNA, but scientists first have to separate the DNA from the rest of the cell in a process called **DNA extraction**. Since most DNA molecules are very long, the DNA must be cut into smaller pieces to make them easier to study. Scientists can cut the DNA exactly where needed by using special **restriction enzymes**. Each restriction enzyme will fit only one certain nucleotide sequence, so the DNA molecules are cut precisely where the scientists need them to be cut. Once the DNA is cut into pieces called fragments, the DNA fragments are separated by using **gel electrophoresis**.

During gel electrophoresis, DNA fragments are placed in a special gel. The gel is in a chamber that is connected to a power source. When the power is turned on, the negatively charged DNA fragments start to move to the positive end of the gel. Smaller fragments move faster than larger ones, so the fragments make a pattern on the gel. These patterns can be used to compare the DNA of different organisms, to match the DNA of a specific organism, and to identify one certain gene out of the thousands of genes in the genome of one individual.

Gel electrophoresis is also used in **DNA fingerprinting** (figure 12-10). Like a fingerprint, each person's DNA is unique. Gel electrophoresis separates DNA fragments that are then treated with radioactive probes, and the end result is a pattern of bands that is unique to each person. This DNA fingerprint can be used to help prove or disprove a criminal's identity. In figure 12-10, blood evidence is compared to two suspects in a crime. The DNA fingerprinting from suspect 2 matches the DNA fingerprint from the evidence.

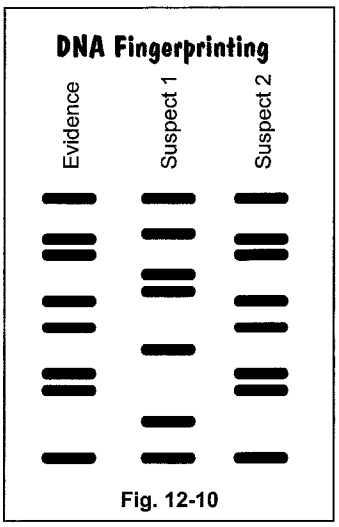
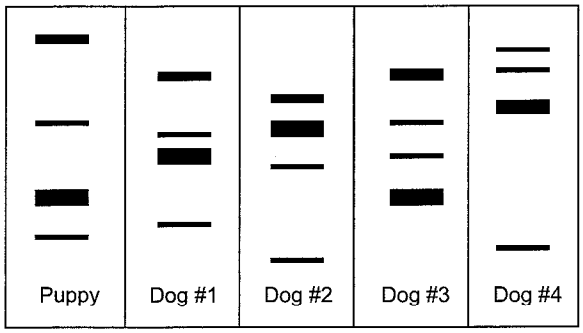


Fig. 12-10

DNA fingerprinting can also be used to determine the father of an individual. Remember, individuals get half of their genetic information from the mother and the other half from the father. Consider the example below.

Example: A breeder of Labrador retrievers needs to confirm the father of a litter of puppies, so he does a DNA fingerprint to compare the DNA of one of the puppies to four possible fathers.



Based on the DNA fingerprint above, which dog is the father?

Since half of the puppy's DNA comes from the father, two of the bands from the puppy should match two of the bands of the father. The bands will be in the same location on the fingerprint. The only dog that has two bands that match the puppy's is dog #3. Dog #3 must be the father.

Recombinant DNA

Besides identifying criminals and solving paternity disputes, why else would anyone want to extract and separate DNA? It sounds like a lot of trouble, doesn't it? Scientists can use these techniques to make something called **recombinant DNA**, and it has many practical applications. Recombinant DNA is made by taking short pieces of DNA from one organism and joining it to the DNA of a completely different organism. Once the recombinant DNA is made, it can be placed back into a living cell in a process called **transformation**.

Transformation is very useful in medicine because scientists can transform bacteria so they will have human DNA in them. Why is this good? One way is by having bacteria produce human hormones. For example, many people do not produce enough insulin, a hormone that is needed when digesting carbohydrates. This lack of insulin causes one form of diabetes. For a long time, diabetics would get shots of insulin made from sheep or pigs. Because this insulin was not identical to human insulin, it sometimes caused allergic reactions. Now scientists can produce human insulin by using recombinant DNA and bacterial transformation.

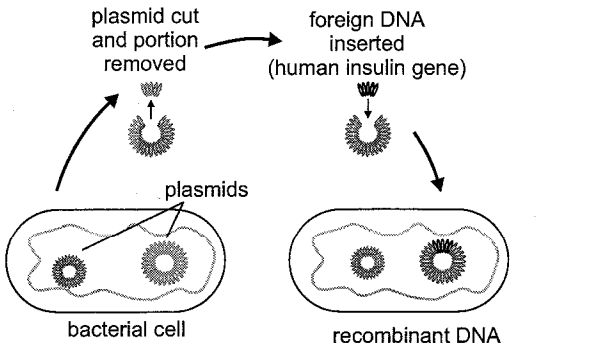


Fig. 12-11

Bacterial cells are prokaryotic cells; they are small, simple cells that grow and reproduce quickly in a limited amount of space. Bacterial cells also contain small circular pieces of DNA called **plasmids**. The gene for the production of insulin is "cut" from a piece of human DNA with the same restriction enzyme used to cut bacterial plasmids. The piece of human DNA is placed in the bacterial plasmid, and the recombinant DNA is put back into the bacteria cells. When the bacteria grow and reproduce, the transformed cells (containing the insulin-producing gene) will produce human insulin, which can be extracted and made into medicine. Since the human insulin gene is used, this insulin does not cause a reaction, plus it can be produced quickly.

Scientist use this same technology to produce **growth hormones**. Instead of having to harvest **human growth hormone** (HGH) from deceased humans, scientists now have bacteria to produce the hormone. (HGH has several medical uses, one of which is to help children grow to a normal height.) Bovine growth hormone (for cows) is used to increase milk production. Porcine growth hormone (for pigs) is used to increase the amount of pork. Both bovine growth hormone and porcine growth hormone are produced by transformed bacteria.

Now scientists are working on methods to "replace" defective genes with normal genes. If these methods become perfected, they could have a tremendous impact on treating and eliminating genetic diseases. Huntington's disease, cystic fibrosis, and sickle cell anemia, which are all diseases that are caused by a single gene, could be eliminated.

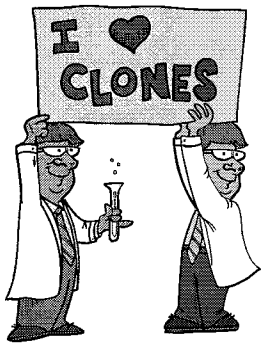
Transgenic Organisms

Can this new DNA technology be useful in other ways? Some scientists think so. Genetic engineers have taken genes from one organism and put them into another. When organisms contain genes from a different organism, they are called **transgenic**.

Genetic engineers have developed several transgenic animals and plants. Transgenic cows have extra copies of growth hormone genes. These animals will grow larger and faster, and they have meat that is less fatty than beef from regular cows. As a result, the people who raise them should be able to take them to market more quickly and get more money per animal. The price we pay at the store should decrease since more meat will be available. Transgenic plants have been produced that are more resistant to diseases and pests, so farmers can get larger crops without using as many chemicals and insecticides. Plants have also been modified so that they are not killed by herbicides. Farmers can treat their fields with herbicides to kill weeds without harming the crop itself. Companies that create genetically modified organisms believe that genetically modified foods can be more nutritious and less expensive to grow.

Transgenic organisms may also have disadvantages. Many people are concerned that transgenic plants could pollinate wild plants and produce plants that could not be controlled with weed killers or that would be harmful to beneficial insects. Cases have already been documented where organic crops (non-genetically modified crops grown without chemical pesticides) have been cross-pollinated with genetically modified ones that are grown in the same area, which in turn voids their "organic" status. Another concern is that the genes added from another organism could cause allergies or other medical problems when eaten by some people. Some wonder if the extra growth hormone in transgenic beef could affect the humans who consume it or if the antibiotic-resistant genes sometimes used in transformation could spread into the environment and cause bacteria to be antibiotic resistant. All of these concerns address a new type of pollution termed "genetic pollution." Some countries as well as some counties across the United States have banned genetically modified food crops due to these concerns.

Cloning



Reproductive cloning is another recent technique with many possibilities but also with potential drawbacks. It involves transferring the genetic material of a donor cell into an egg cell that has had its nucleus removed. The egg is then stimulated by chemicals or electricity to cause it to divide. Next, it is implanted into the uterus of a female for further development until birth. The cloned organism is genetically identical to the original or parent organism. Clones are especially useful in medical research, and scientists are developing ways to use clones to save endangered species. Could we some day clone a human being? If we could, should we?