

CK-12 Life Science For Middle School

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CHAPTER 5

Cell Division, Reproduction, and DNA

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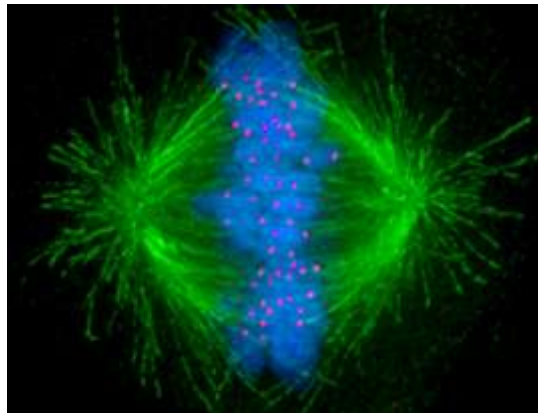
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CHAPTER 5

Cell Division, Reproduction, and DNA

5.1	Cell Division
5.2	Reproduction
5.3	DNA, RNA, and Protein Synthesis

Introduction



What has to happen for a cell to divide? Plenty. The above image shows the mitotic spindle in a human cell. The mitotic spindle separates DNA in cells that are dividing. But that is just one step in the process. Why do you think cells need to divide? Do all cells divide the same way? How do cells help us reproduce? What would happen to living things if their cells failed to divide? What happens if cells divide uncontrollably? Think about these questions as you begin to understand why and how cells divide and how cell division helps the reproduction of all living things.

5.1 Cell Division

Lesson Objectives

- Explain why cells need to divide.
- List the stages of the cell cycle and explain what happens at each stage.
- List the stages of mitosis and explain what happens at each stage.

Check Your Understanding

- What is the cell theory?
- In what part of your cells is the genetic information located?

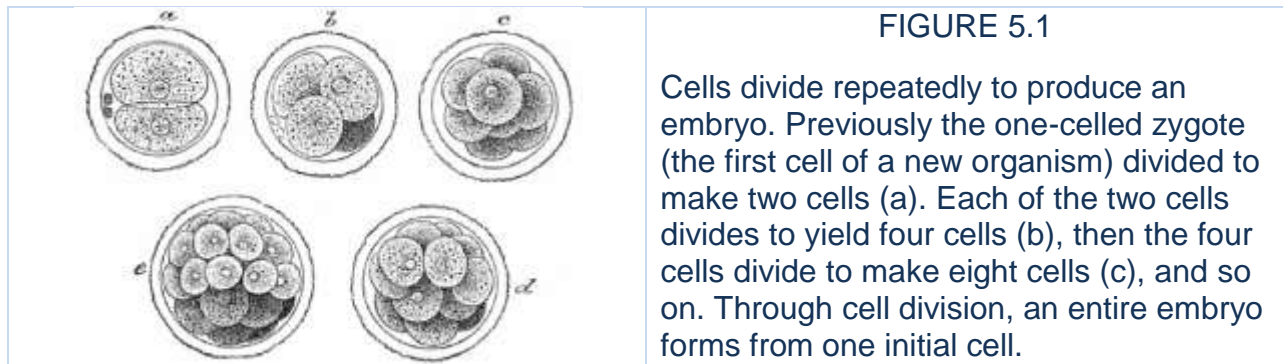
Vocabulary

- anaphase
- cancer
- cell cycle
- chromosome
- cytokinesis
- daughter cell
- interphase
- metaphase
- mitosis
- parent cell
- prophase
- sister chromatids
- spindle
- telophase

Why Cells Divide

Imagine the first stages of life. In humans, a sperm fertilizes an egg, forming the first cell. But humans are made up of trillions of cells, so where do the new cells come from? Remember that according to cell theory, all cells must come from existing cells. From that one cell, an entire baby will develop.

How does a new life go from one cell to so many? The cell divides in half, creating two cells. Then those two cells divide, for a total of four cells. The new cells continue to divide and divide. One cell becomes two, then four, then eight, and so on (Figure 5.1).



Besides the development of a baby, there are many other reasons that cell division is necessary for life:

1. To grow and develop, you must form new cells. Imagine how often your cells must divide during a growth spurt. Growing just an inch requires countless cell divisions.
2. Cell division is also necessary to repair damaged cells. Imagine you cut your finger. After the scab forms, it will eventually disappear and new skin cells will grow to repair the wound. Where do these cells come from? Some of your existing skin cells divide and produce new cells.
3. Your cells can also simply wear out. Over time you must replace old and worn-out cells. Cell division is essential to this process.

The Cell Cycle

The process of cell division in eukaryotic cells is carefully controlled. The **cell cycle** is the lifecycle of a cell, with cell division at the end of the cycle. Like a human lifecycle that is made up of different phases, like childhood, adolescence, and adulthood, there are a series of steps that lead to cell division (Figure 5.2).

These steps can be divided into two main components, interphase and mitosis.

1. Interphase: The stage when the cell mostly performs its “everyday” functions. For example, it is when a kidney cell does what a kidney cell is supposed to do.
2. Mitosis: The stage when the cell prepares to become two cells.

Most of the cell cycle consists of **interphase**, the time between cell divisions. Interphase can be divided into three stages:

1. The first growth phase (G1): During the G1 stage, the cell doubles in size and doubles the number of organelles.
2. The synthesis phase (S): The DNA is replicated during this phase. In other words, an identical copy of all the cell’s DNA is made. This ensures that each new cell has a set of genetic material identical to that of the parental cell. DNA replication will be further discussed in lesson 5.3.
3. The second growth phase (G2): Proteins are synthesized that will help the cell divide. At the end of interphase, the cell is ready to enter mitosis.

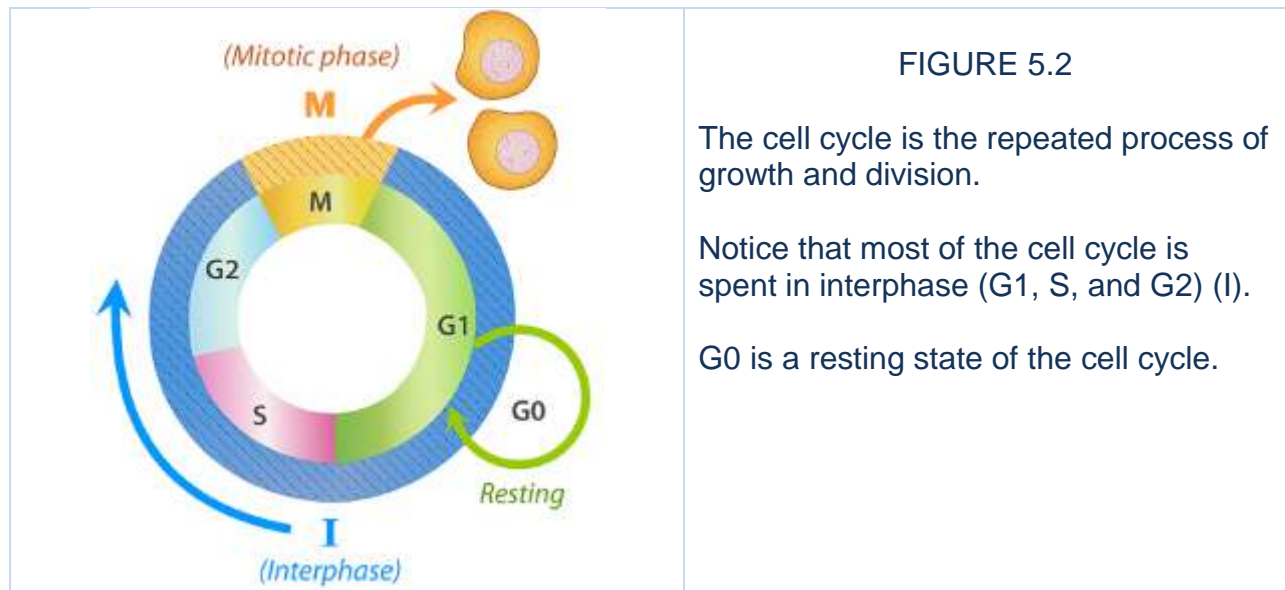


FIGURE 5.2

The cell cycle is the repeated process of growth and division.

Notice that most of the cell cycle is spent in interphase (G1, S, and G2) (I).

G0 is a resting state of the cell cycle.

During mitosis, the nucleus divides. Mitosis is followed by **cytokinesis**, when the cytoplasm divides, resulting in two cells. After cytokinesis, cell division is complete.

Scientists say that one **parent cell**, or the dividing cell, forms two genetically identical **daughter cells**, or the cells that divide from the parent cell. The term "genetically identical" means that each cell has an identical set of DNA, and this DNA is also identical to that of the parent cell. If the cell cycle is not carefully controlled, it can cause a disease called cancer, which causes cell division to happen too fast. A tumor can result from this kind of growth.

Mitosis and Chromosomes

The genetic information of the cell, or DNA, is stored in the nucleus. During mitosis, two nuclei (plural for nucleus) must form, so that one nucleus can be in each of the new cells. The DNA inside of the nucleus is also copied. The copied DNA needs to be moved into the nucleus, so each cell can have a correct set of genetic instructions.

To begin mitosis, the DNA in the nucleus wraps around proteins to form **chromosomes**. Each organism has a unique number of chromosomes. In human cells, our DNA is divided up into 23 pairs of chromosomes. After the DNA is replicated during the S stage of interphase, each chromosome has two identical molecules of DNA, called **sister chromatids**, forming the "X" shaped molecule depicted in Figure 5.3.

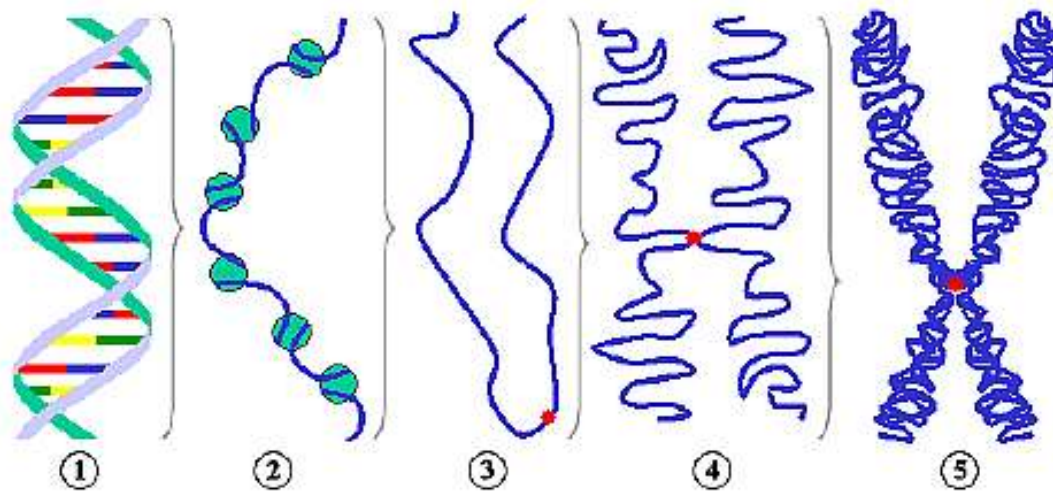


FIGURE 5.3

The DNA double helix wraps around proteins (2) and tightly coils a number of times to form a chromosome (5). This figure shows the complexity of the coiling process. The red dot shows the location of the centromere, where the microtubules attach during mitosis and meiosis.

The Four Phases of Mitosis

During mitosis, the two sister chromatids must be split apart. Each resulting chromosome is made of 1/2 of the "X". Through this process, each daughter cell receives one copy of each chromosome. Mitosis is divided into four phases (Figure 5.4):

1. **Prophase:** The chromosomes "condense," or become so tightly wound that you can see them under a microscope. The wall around the nucleus, called the nuclear envelope, disappears. **Spindles** also form and attach to chromosomes to help them move.
2. **Metaphase:** The chromosomes line up in the center of the cell. The chromosomes line up in a row, one on top of the next.
3. **Anaphase:** The two sister chromatids of each chromosome separate, resulting in two sets of identical chromosomes.
4. **Telophase:** The spindle dissolves and nuclear envelopes form around the chromosomes in both cells.

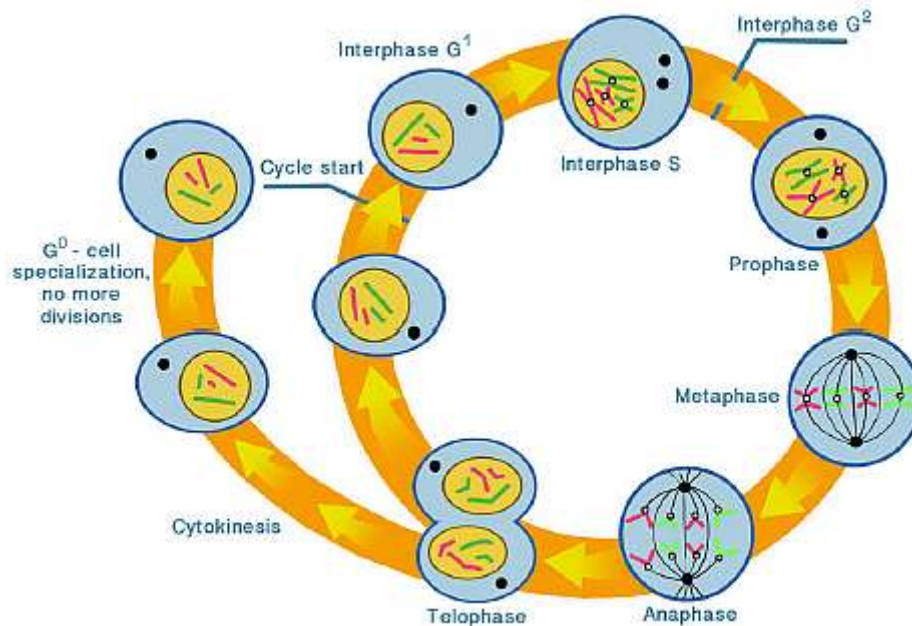


FIGURE 5.4

An overview of the cell cycle and mitosis: during prophase the chromosomes condense, during metaphase the chromosomes line up, during anaphase the sister chromatids are pulled to opposite sides of the cell, and during telophase the nuclear envelope forms.

Each new nucleus contains the exact same number and type of chromosomes as the original cell. The cell is now ready for cytokinesis, which literally means "cell movement." The cells separate, producing two genetically identical cells, each with its own nucleus. Figure 5.5 is a representation of dividing plant cells.

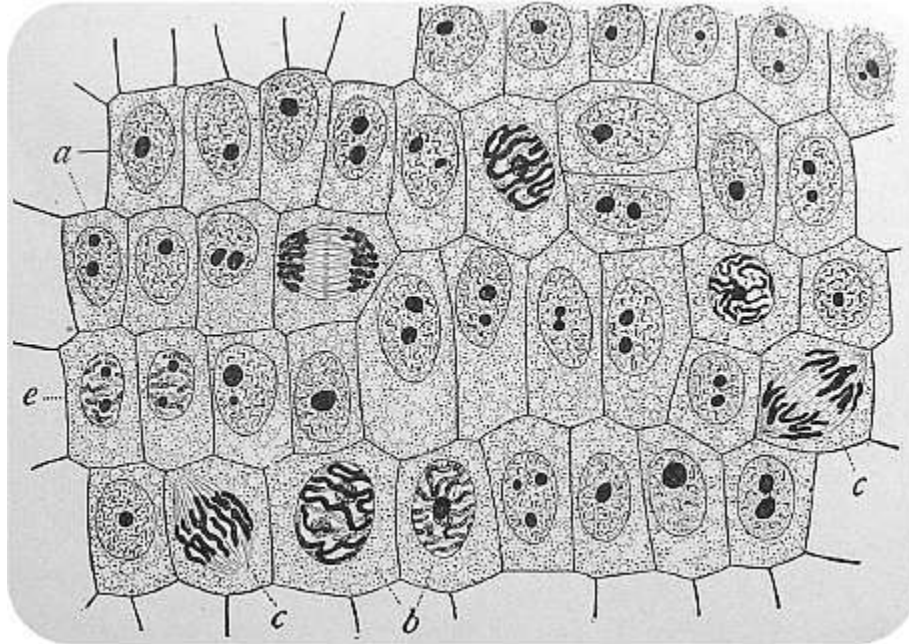


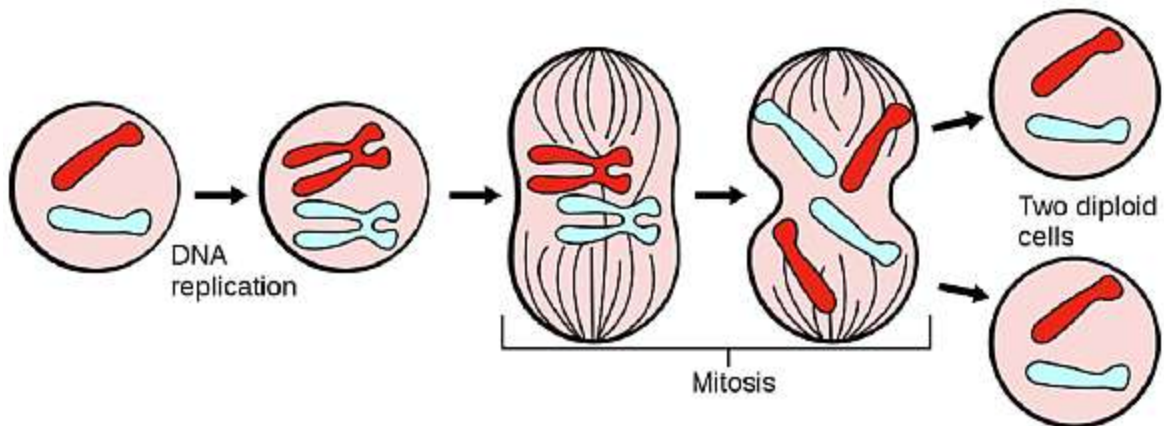
FIGURE 5.5

This is a representation of dividing plant cells. Cell division in plant cells differs slightly from animal cells as a cell wall must form. Note that most of the cells are in interphase.

Can you find examples of the different stages of mitosis?

Lesson Summary

- Cells divide for growth, development, reproduction and replacement of injured or worn-out cells.
- The cell cycle is a series of controlled steps by which a cell divides.
- During mitosis, the newly duplicated chromosomes are divided into two daughter nuclei.
- This summary diagram depicts one cell dividing into two genetically identical cells. Mitosis occurs after DNA replication. A diploid cell has two sets of chromosomes, as is shown here.



Review Questions (Recall)

1. In what phase of mitosis are chromosomes moving toward opposite sides of the cell?
2. In what phase of mitosis do the duplicated chromosomes condense?
3. What step of the cell cycle is the longest?
4. What is the term for the division of the cytoplasm?
5. What happens during the S stage of interphase?

Apply Concepts

6. Interphase used to be considered the “resting” stage of the cell cycle. Why is this not correct?
7. What are some reasons that cells divide?
8. During what stage of the cell cycle does the cell double in size?
9. Why must cell division be tightly regulated?

Critical Thinking

10. What would happen if the cells in your liver stopped going through the process of mitosis?
11. What do you think might happen if mitosis could NOT stop happening to the cells in your brain?

5.2 Reproduction

Lesson Objectives

- Name the types of asexual reproduction.
- Explain the advantage of sexual reproduction.
- List the stages of meiosis and explain what happens in each stage.

Check Your Understanding

- Can something that does not reproduce still be considered living?
- What stores the genetic information that is passed on to offspring?
- How many chromosomes are in the human nucleus?

Vocabulary

- allele
- asexual reproduction
- binary fission
- crossing-over
- cross-pollination
- diploid
- external fertilization
- gamete
- gonad
- haploid
- internal fertilization
- meiosis
- ovaries
- parthenogenesis
- sexual reproduction
- testes
- zygote

What is Reproduction?

What does reproduction mean? Can an organism be considered alive if it cannot make the next generation? Since individuals cannot live forever, they must reproduce for the species to survive. Reproduction is the ability to make the next generation.

Two methods of reproduction are:

1. **Asexual reproduction**, or the process of forming a new individual from a single parent.
2. **Sexual reproduction**, or the process of forming a new individual from two parents.

There are advantages and disadvantages to each method, but the result is always the same: a new life begins.

Asexual Reproduction

For humans to reproduce, DNA must be passed from the mother and father to the child. Humans cannot reproduce with just one parent, but it is possible in other organisms, like bacteria, some insects and some fish. These organisms can reproduce asexually, meaning that the offspring (children) have a single parent and share the exact same genetic material as the parent. This is very different from humans.

The advantage of asexual reproduction is that it can be very quick and does not require the meeting of a male and female organism. The disadvantage of asexual reproduction is that organisms cannot mix beneficial traits from both parents. An organism that is born through asexual reproduction only has the DNA from the one parent, and it is the exact copy of that parent. This can cause problems for the individual. For example, if the parent organism has a gene that causes cancer, the offspring will also have the gene that causes cancer. Organisms produced sexually may or may not inherit the cancerous gene because there are two parents mixing up their genes.

Types of organisms that reproduce asexually include:

1. Prokaryotic organisms, like bacteria. Bacteria reproduce through binary fission, where they grow and divide in half (Figure 5.6). First, their chromosome replicates (bacteria only have one chromosome) and the cell enlarges. After cell division, the two new cells each have one identical chromosome (mitosis is not necessary because bacteria do not have nuclei). Then, new membranes form to separate the two cells. This simple process allows bacteria to reproduce very rapidly.

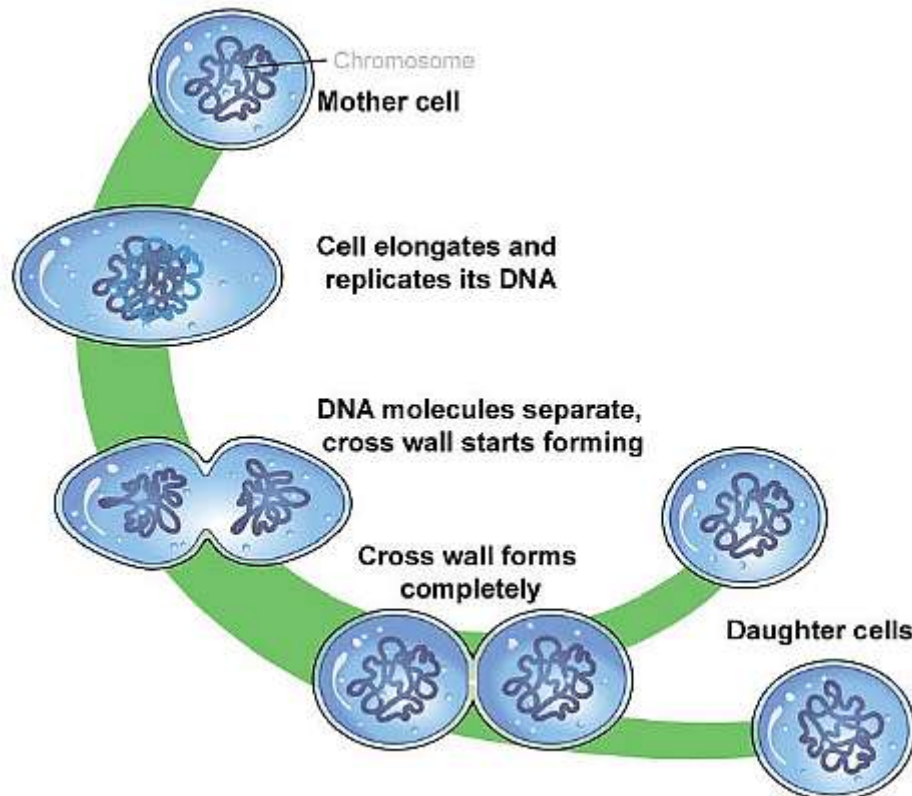


FIGURE 5.6

Bacteria reproduce by binary fission. Shown is one bacterium reproducing and becoming two bacteria.

2. Flatworms, an animal species. Flatworms divide in two, then each half regenerates into a new flatworm identical to the original.
3. Different types of insects, fish, and lizards. These organisms can reproduce asexually through a process called parthenogenesis (Figure 5.7). Parthenogenesis happens when an unfertilized egg cell grows into a new organism. The resulting organism has half the amount of genetic material of the parent.



FIGURE 5.7

This Komodo dragon was born by parthenogenesis.

Parthenogenesis is common in honeybees. In a hive, the sexually produced eggs become workers, while the asexually produced eggs become drones.

Sexual Reproduction

During sexual reproduction, two parents are involved. Most animals are dioecious, meaning there is a separate male and female sex, with the male producing sperm and the female producing eggs. When a sperm and egg meet, a **zygote**, the first cell of a new organism, is formed (Figure 5.8). The zygote will divide and grow into the embryo.



FIGURE 5.8

During sexual reproduction, a sperm fertilizes an egg.

Let's explore how animals, plants, and fungi reproduce sexually:

- Animals often have **gonads**, organs that produce eggs or sperm. The male gonads are the **testes**, which produce the sperm, and the female gonads are the **ovaries**, which produce the eggs. Sperm and egg, the two sex cells, are known as **gametes**, and can combine two different ways:

1. Fish and other aquatic animals release their gametes in the water, which is called external fertilization. These gametes will combine by chance. (Figure 5.9).



FIGURE 5.9

This fish guards her eggs, which will be fertilized externally.

2. Animals that live on land reproduce by internal fertilization. Typically males have a penis that deposits sperm into the vagina of the female. Birds do not have penises, but they do have a chamber called the cloaca that they place close to another bird's cloaca to deposit sperm.
- Plants can also reproduce sexually, but their reproductive organs are different from animals' gonads. Plants that have flowers have their reproductive parts in the flower. The sperm is contained in the pollen, while the egg is contained in the ovary, deep within the flower. The sperm can reach the egg two different ways:
 1. In **self-pollination**, the egg is fertilized by the pollen of the same flower.
 2. In **cross-pollination**, sperm from the pollen of one flower fertilizes the egg of another flower. Like other types of sexual reproduction, cross-pollination allows new combinations of traits. Cross-pollination occurs when pollen is carried by the wind to another flower. It can also occur when animal pollinators, like honeybees, or butterflies (Figure 5.10) carry the pollen from flower to flower.



FIGURE 5.10

Butterflies receive nectar when they deposit pollen into flowers, resulting in cross-pollination.

- Fungi can also reproduce sexually, but instead of female and male sexes, they have (+) and (-) strains. When the filaments of a (+) and (-) fungi meet, the zygote is formed. Just like in plants and animals, each zygote receives DNA from two parent strains.

Meiosis and Gametes

Meiosis is a process of cell division that produces sex cells, or gametes.

Gametes are reproductive cells, such as sperm and egg. As gametes are produced, the number of chromosomes must be reduced by half. Why? The zygote must contain information from the mother and from the father, so the gametes must contain half of the chromosomes found in normal body cells.

In humans, our cells have 23 pairs of chromosomes, and each chromosome within a pair is called a **homologous chromosome**. For each of the 23 chromosome pairs, you received one chromosome from your father and one chromosome from your mother. The homologous chromosomes are separated when gametes are formed. Therefore, gametes have only 23 chromosomes, not 23 pairs.

Alleles are alternate forms of genes found on chromosomes. Since the separation of chromosomes into gametes is random, it results in different combinations of chromosomes (and alleles) in each gamete. With 23 pairs of chromosomes, there is a possibility of over 8 million different combinations of chromosomes in a gamete.

Haploid vs. Diploid

A cell with two sets of chromosomes is **diploid**, referred to as $2n$, where n is the number of sets of chromosomes. Most of the cells in a human body are diploid. A cell with one set of chromosomes, such as a gamete, is **haploid**, referred to as n . Sex cells are haploid. When a haploid sperm (n) and a haploid egg (n) combine, a diploid zygote will be formed ($2n$). In short, when a diploid zygote is formed, half of the DNA comes from each parent.

Meiosis

Before meiosis begins, DNA replication occurs, so each chromosome contains two sister chromatids that are identical to the original chromosome. Meiosis is divided into two divisions: Meiosis I and Meiosis II. Each division is similar to mitosis and can be divided into the same phases: prophase, metaphase, anaphase, and telophase.

Between the two divisions, DNA replication does not occur. Through this process, one diploid cell will divide into four haploid cells.

Meiosis I

During meiosis I, the pairs of homologous chromosomes are separated from each other.

1. **Prophase I:** The homologous chromosomes line up together. During this time, a process that only happens in meiosis can occur. This process is called crossing-over (Figure 5.11), which is the exchange of DNA between homologous chromosomes. Crossing-over increases the new combinations of alleles in the gametes.

Without crossing-over, the offspring would always inherit all of the many alleles on one of the homologous chromosomes. Also during prophase I, the spindle forms, the chromosomes condense as they coil up tightly, and the nuclear envelope disappears.

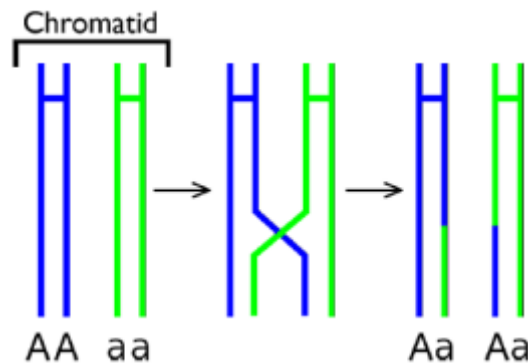


FIGURE 5.11

During crossing-over, segments of DNA are exchanged between non-sister chromatids of homologous chromosomes. Notice how this can result in an allele (A) on one chromatid being moved onto the other non-sister chromatid.

2. **Metaphase I:** The homologous chromosomes line up in pairs in the middle of the cell. Chromosomes from the mother or from the father can each attach to either side of the spindle. Their attachment is random, so all of the chromosomes from the mother or father do not end up in the same gamete. The gamete will contain some chromosomes from the mother and some chromosomes from the father.
3. **Anaphase I:** The homologous chromosomes separate.
4. **Telophase I:** The spindle fibers dissolve, but a new nuclear envelope does not need to form. This is because the nucleus will divide again. No DNA replication happens between meiosis I and meiosis II because the chromosomes are already duplicated.

Meiosis II

During meiosis II, the sister chromatids are separated and the gametes are generated. The steps are outlined below:

1. Prophase II: The chromosomes condense.
2. Metaphase II: The chromosomes line up one on top of the next along the middle of the cell.
3. Anaphase II: The sister chromatids separate.
4. Telophase II: Nuclear envelopes form around the chromosomes in all four cells.

After cytokinesis, each cell has divided again. Therefore, meiosis results in four daughter cells with half the DNA of the parent cell (Figure 5.12). In human cells, the parent cell has 46 chromosomes, so the cells produced by meiosis have 23 chromosomes. These cells will become gametes.

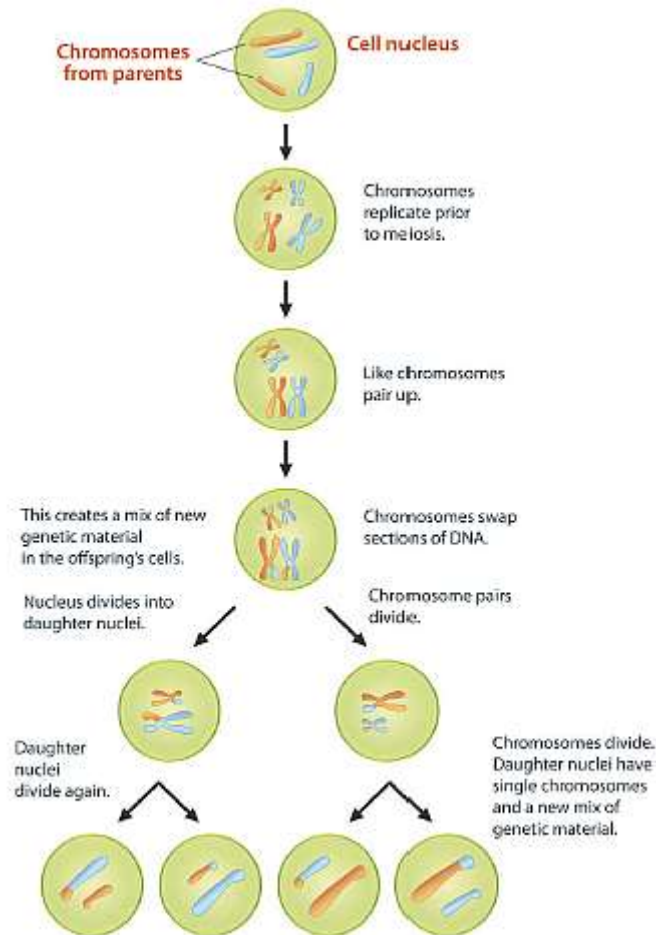


FIGURE 5.12
An overview of meiosis.

Mitosis vs. Meiosis: A Comparison

Figure 5.13 is a comparison between binary fission, mitosis, and meiosis. Mitosis and meiosis are also compared in Table 5.1.

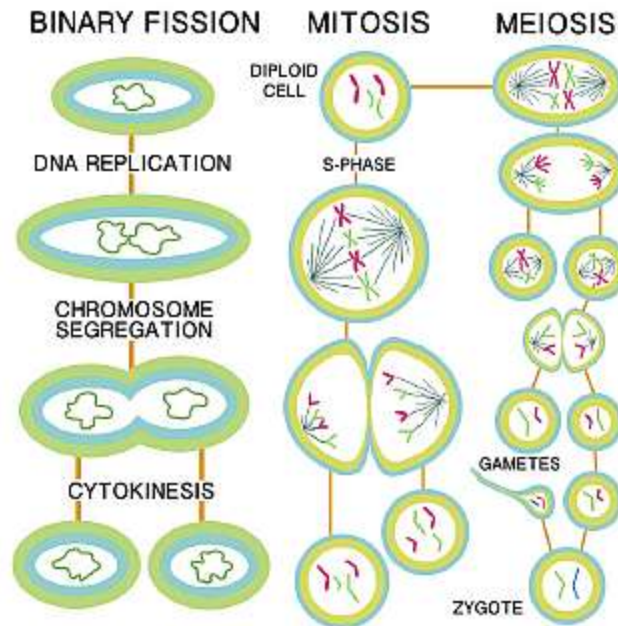


FIGURE 5.13

A comparison between binary fission, mitosis, and meiosis.

TABLE 5.1: Mitosis vs. Meiosis: A Comparison		
	Mitosis	Meiosis
Purpose:	To produce new cells	To produce gametes
Number of cells produced:	2	4
Rounds of Cell Division:	1	2
Haploid or Diploid:	Diploid	Haploid
Daughter cells identical to parent cells?	Yes	No
Daughter cells identical to each other?	Yes	No

Lesson Summary

- Organisms can reproduce sexually or asexually.
- The gametes in sexual reproduction must have half the DNA of the parent.
- Meiosis is the process of nuclear division that forms gametes.

Review Questions

Recall

1. What is parthogenesis?
2. During what phase of meiosis do homologous chromosomes separate?
3. What is the purpose of meiosis?
4. In what phase of meiosis do homologous chromosomes pair up?

Apply Concepts

5. Explain how organisms reproduce asexually.
6. Explain how birds fertilize their eggs.
7. How do most plants reproduce sexually?
8. Compare and contrast the process of mitosis and the process of meiosis.

Critical Thinking

9. How would sexual reproduction in a lizard be different than in a fish?
10. What is the advantage of sexual reproduction over asexual reproduction?
11. If an organism has 12 chromosomes in its cells, how many chromosomes will be in its gametes?

Points to Consider

- What must be replicated prior to mitosis?
- How do you think DNA might be replicated?
- What might happen if there is a mistake during DNA replication?

5.3 DNA, RNA, and Protein Synthesis

Lesson Objectives

- Explain the chemical composition of DNA.
- Explain how DNA synthesis works.
- Explain how proteins are coded for and synthesized.
- Describe the three types of RNA and the functions of each.

Check Your Understanding

- What is the purpose of DNA?
- When is DNA replicated?

Vocabulary

- amino acid
- DNA
- DNA replication
- double helix
- gene
- mutagen
- mutation
- nucleotide
- RNA
- semiconservative replication
- transcription
- translation

What is DNA?

DNA, is the material that makes up our chromosomes and stores our genetic information. When you build a house, you need a blueprint, a set of instructions that tells you how to build. The DNA is like the blueprint for living organisms. The genetic information is a set of instructions that tell your cells what to do. DNA is an abbreviation for deoxyribonucleic acid. As you may recall, nucleic acids are a type of macromolecule that store information. The *deoxyribo* part of the name refers to the name of the sugar that is contained in DNA, deoxyribose. DNA may provide the instructions to make up all

living things, but it is actually a very simple molecule. DNA is made of a long chain of nucleotides.

Nucleotides are composed of 3 main parts:

1. Phosphate group
2. 5-carbon sugar
3. Nitrogen-containing base

The only difference between each nucleotide is the identity of the base. There are only four possible bases that make up each DNA nucleotide: adenine (A), guanine (G), thymine (T), and cytosine (C).

The various sequences of these four bases make up the genetic code of your cells. It may seem strange that there are only four letters in the “alphabet” of DNA. But since your chromosomes contain millions of nucleotides, there are many, many different combinations possible with those four letters.

But how do all these pieces fit together? James Watson and Francis Crick won the Nobel Prize in 1962 for piecing together the structure of DNA. Together with the work of Rosalind Franklin and Maurice Wilkins, they determined that DNA is made of two strands of nucleotides formed into a **double helix**, or a two-stranded spiral, with the sugar and phosphate groups on the outside, and the paired bases connecting the two strands on the inside of the helix (Figure 5.14 and Figure 5.15).

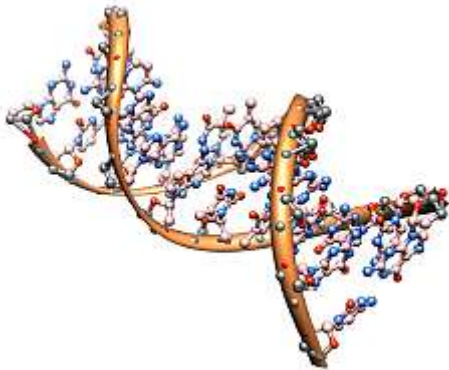


FIGURE 5.14

DNA's three-dimensional structure is a double helix. The hydrogen bonds between the bases at the center of the helix hold the helix together.

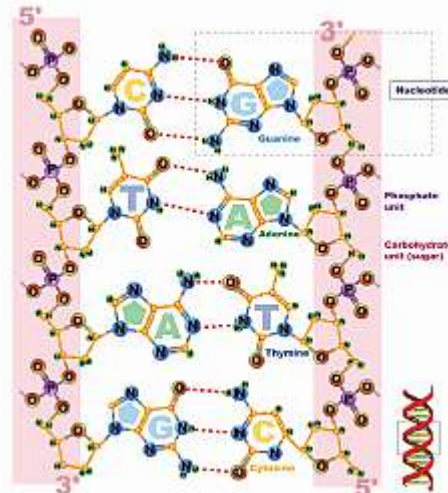


FIGURE 5.15

The chemical structure of DNA includes a chain of nucleotides consisting of a 5-carbon sugar, a phosphate group, and a nitrogen base. Notice how the sugar and phosphate form the backbone of DNA (one strand in blue), with the hydrogen bonds between the bases joining the two strands.

Base-Pairing

The bases in DNA do not pair randomly. When Erwin Chargaff looked closely at the bases in DNA, he noticed that the percentage of adenine (A) in the DNA always equaled the percentage of thymine (T), and the percentage of guanine (G) always equaled the percentage of cytosine (C). Watson and Crick's model explained this result by suggesting that A always pairs with T and G always pairs with C in the DNA helix. Therefore A and T, and G and C, are "complementary bases," or bases that always pair together. For example, if one DNA strand reads ATGCCAGT, the other strand will be made up of the complementary bases: TACGGTCA.

DNA Replication

The base pairing rules are crucial for the process of replication. **DNA replication** occurs when DNA is copied to form an identical molecule of DNA. DNA replication happens before cell division. Below are the steps involved in DNA replication:

1. The DNA helix unwinds like a zipper, as the bonds between the base pairs are broken.
2. The two single strands of DNA then each serve as a template for a new strand to be created. Using DNA as a template means that the bases are placed in the right order because of the base pairing rules. If ATG is on the "template strand," then TAC will be on the new DNA strand.
3. The new set of nucleotides then join together to form a new strand of DNA. The process results in two DNA molecules, each with one old strand and one new strand of DNA.

This process is known as **semiconservative replication** because one strand is conserved (kept the same) in each new DNA molecule (Figure 5.16).



FIGURE 5.16

DNA replication occurs when the DNA strands "unzip", and the original strands of DNA serve as a template for new nucleotides to join and form a new strand.

Protein Synthesis

The DNA sequence contains the instructions to make units called amino acids, which are assembled in a specific order to make proteins. In short, DNA contains the instructions to create proteins. Each strand of DNA has many separate sequences that code for a specific protein. Units of DNA that contain code for the creation of one protein are called genes.

Cells Can Turn Genes On or Off

There are about 22,000 genes in every human cell. Does every human cell have the same genes? Yes. Does every human cell use the same genes to make the same proteins? No. In a multicellular organism, such as us, cells have specific functions because they have different proteins. They have different proteins because different genes are expressed in different cell types.

Imagine that all of your genes are "turned off." Each cell type only "turns on" (or expresses) the genes that have the code for the proteins it needs to use. So different cell types "turn on" different genes, allowing different proteins to be made, giving different cell types different functions.

Three Types of RNA

DNA contains the instructions to create proteins, but it does not make proteins itself. DNA is located in the nucleus, while proteins are made on ribosomes in the cytoplasm. So DNA needs a messenger to bring its instructions to a ribosome located outside of the nucleus. DNA sends out a message, in the form of **RNA** (ribonucleic acid), describing how to make the protein.

There are three types of RNA directly involved in protein synthesis:

- Messenger RNA (mRNA) carries the instructions from the nucleus to the cytoplasm.
- The other two forms of RNA, ribosomal RNA (rRNA) and transfer RNA (tRNA) are involved in the process of ordering the amino acids to make the protein.

All three RNAs are nucleic acids, made of nucleotides, similar to DNA. The RNA nucleotide is different from the DNA nucleotide in the following ways:

- RNA contains a different kind of sugar, called ribose.
- In RNA, the base uracil (U) replaces the thymine (T) found in DNA.
- RNA is a single strand.

Transcription

mRNA is created by using DNA as a template. The process of constructing an mRNA molecule from DNA is known as **transcription** (Figure 5.17 and Figure 5.18). The double helix of DNA unwinds and the nucleotides follow basically the same base pairing rules to form the correct sequence in the mRNA. This time, however, U pairs with each A in the DNA. In this manner, the genetic code is passed on to the mRNA.

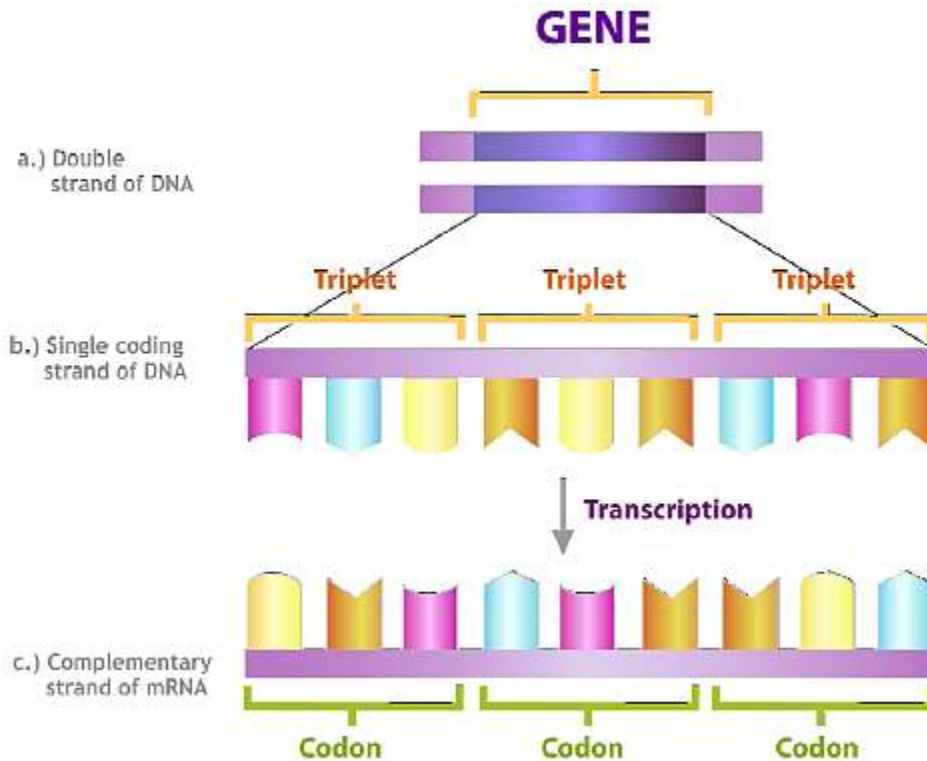


FIGURE 5.17

*Each gene (a) contains triplets of bases (b) that are transcribed into RNA (c).
Every triplet, or codon, encodes for a unique amino acid.*

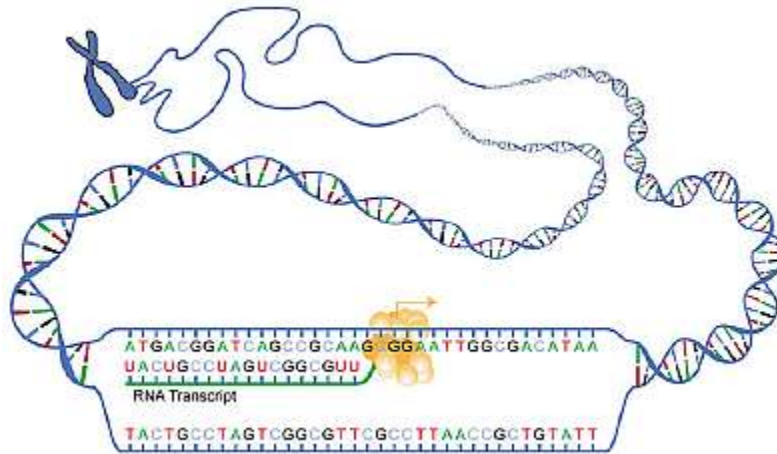
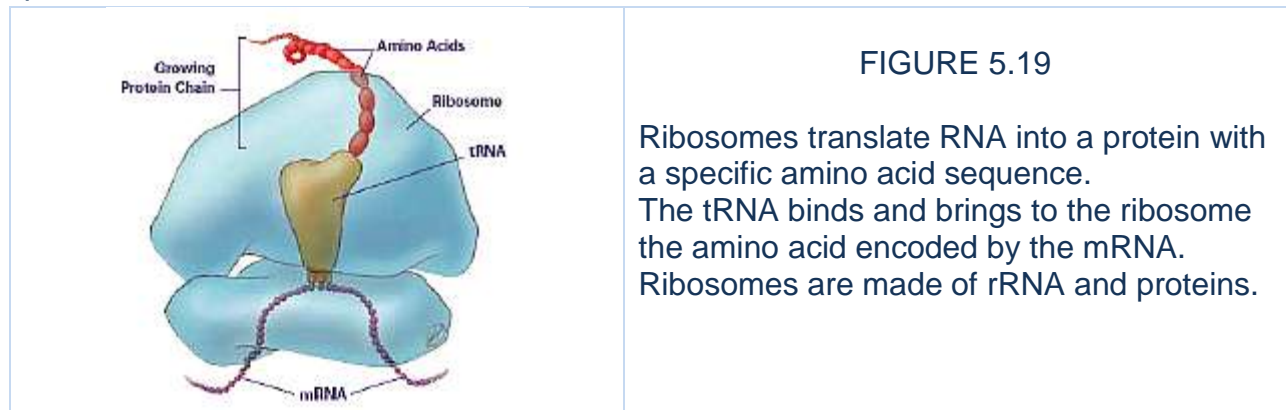


FIGURE 5.18

*Base-pairing ensures the accuracy of transcription.
Notice how the helix must unwind for transcription to take place.*

Translation

The mRNA is directly involved in the protein-making process. mRNA tells the ribosome (Figure 5.19) how to create a protein. The process of reading the mRNA code in the ribosome to make a protein is called **translation** (Figure 5.20). Sets of three bases, called codons, are read in the ribosome, the organelle responsible for making proteins.



The following are the steps involved in translation:

1. mRNA travels to the ribosome from the nucleus.
2. The base code in the mRNA determines the order of the amino acids in the protein. The genetic code in mRNA is read in “words” of three letters (triplets), called codons. There are 20 amino acids and different codons code for different ones. For example, GGU codes for the amino acid glycine, while GUC codes for valine.
3. tRNA reads the mRNA code and brings a specific amino acid to attach to the growing chain of amino acids.
Each tRNA carries only one type of amino acid and only recognizes one specific codon.
4. tRNA is released from the amino acid.
5. Three codons, UGA, UAA, and UAG, indicate that the protein should stop adding amino acids. They are called "stop codons" and do not code for an amino acid.
Once tRNA comes to a stop codon, the protein is set free from the ribosome.

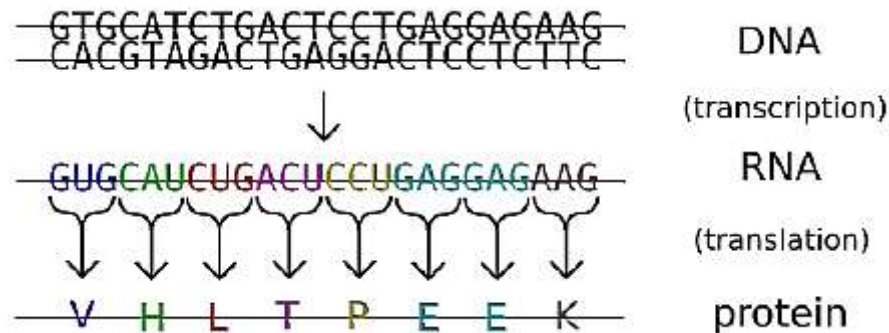


FIGURE 5.20

This summary of how genes are expressed shows that DNA is transcribed into RNA, which is translated in turn to protein

The chart in Figure 5.21 is used to determine which amino acids correspond to which codons.

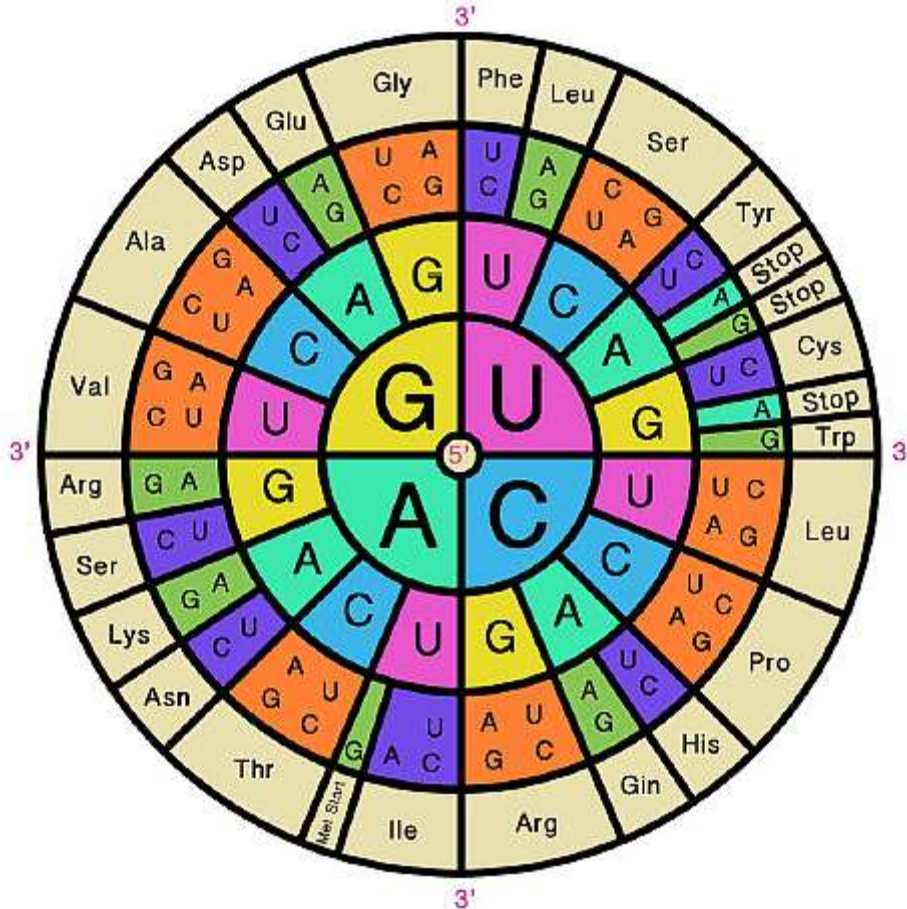


FIGURE 5.21

This chart shows the genetic code used by all organisms. For example, an RNA codon reading GUU would encode for a valine (Val) according to this chart. Start at the center for the first base of the three base codon, and work your way out. Notice for valine, the second base is a U and the third base of the codon may be either a G, C, A, or U. Similarly, glycine (Gly) is encoded by a GGG, GGA, GGC, and GGU.

Mutations

The process of DNA replication is not always 100% accurate, and sometimes the wrong base is inserted in the new strand of DNA. A permanent change in the sequence of DNA is known as a mutation. Small changes in the DNA sequence are usually point mutations, which is a change in a single nucleotide. A mutation may have no effect. Sometimes, a mutation can cause the protein to be made incorrectly, which can affect how well the protein works, or whether it works at all. Usually the loss of a protein function is detrimental to the organism.

However, in rare circumstances, the mutation can be beneficial. For example, suppose a mutation in an animal's DNA causes the loss of an enzyme that makes a dark pigment in the animal's skin. If the population of animals has moved to a light colored environment, the animals with the mutant gene would have a lighter skin color and be better camouflaged. So in this case, the mutation is beneficial.

Mutations may also occur in chromosomes. Possible types of mutations in chromosomes (Figure 5.22) include:

1. **Deletion:** When a segment of DNA is lost, so there is a missing segment in the chromosome.
2. **Duplication:** When a segment of DNA is repeated, creating a longer chromosome.
3. **Inversion:** When a segment of DNA is flipped and then reattached to the chromosome.
4. **Insertion:** When a segment of DNA from one chromosome is added to another, unrelated chromosome.
5. **Translocation:** When two segments from different chromosomes change positions.

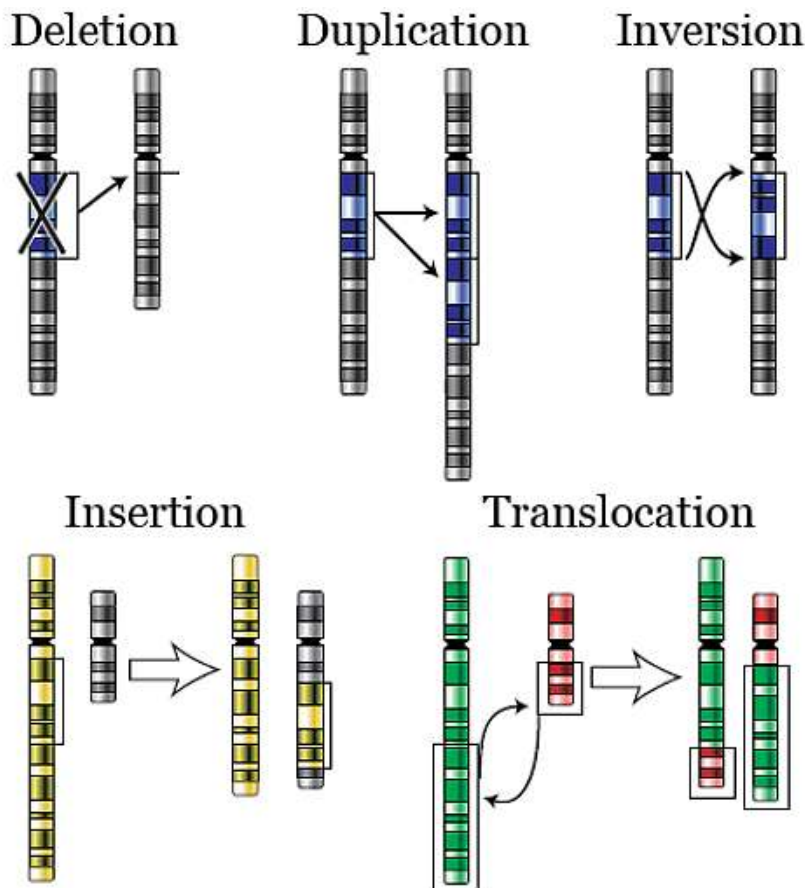


Figure 5.22

If a single base is deleted (called a point mutation), there can be huge effects on the organism because this may cause a "frameshift mutation." Remember that the bases are read in groups of three by the tRNA. If the reading frame gets off by one base, the resulting sequence will consist of an entirely different set of codons. The reading of an mRNA is like reading three letter words of a sentence. Imagine you wrote "the big dog ate the red cat". If you take out the second letter from "big", the frame will be shifted so now it will read " the bgd oga tet her edc at." One single deletion makes the whole "sentence" impossible to read.

Many mutations are not caused by errors in replication. Mutations can happen spontaneously and they can be caused by mutagens in the environment. Some chemicals, such as those found in tobacco smoke, can be mutagens. Sometimes mutagens can also cause cancer. Tobacco smoke, for example, is often linked to lung cancer.

Lesson Summary

- DNA stores the genetic information of the cell in the sequence of its 4 bases: adenine, thymine, guanine, and cytosine.
- The information in a small segment of DNA, a gene, is sent by mRNA to the ribosome to synthesize a protein.
- Within the ribosome, tRNA reads the mRNA in sets of three bases (triplets), called codons, which encode for the specific amino acids that make up the protein.
- A mutation is a permanent change in the sequence of bases in DNA.

Review Questions

Recall

1. What is a nucleotide made out of?
2. Describe the process of DNA replication.
3. What is made in the process of transcription?
4. What is made in the process of translation?
5. Name a mutagen.

Apply Concepts

6. Translate the following segment of DNA into RNA: AGTTC
7. Write the complimentary DNA nucleotides to this strand of DNA: GGTCCA
8. Nucleotides are subunits of which two macromolecules?
9. Amino acids are subunits that make up what macromolecule?
10. How does RNA encode for proteins?

Critical Thinking

11. How does a mutation in a strand of DNA affect translation and transcription?
12. Given the DNA sequence, ATGTTAGCCTTA, what is the mRNA sequence?
What is the amino acid sequence?

Points to Consider

- Your cells have “proofreaders” that replace mismatched pairs that occurred during DNA synthesis. How would that affect the rate of mutation in your body?
- There are many diseases due to mutations in the DNA. These are known as genetic diseases, and many can be passed onto the next generation. Think about how a single base change cause a huge medical problem.
- Your DNA contains the instructions to make you. So is everyone’s DNA different? Can it be used to distinguish individuals, like a fingerprint?