

5.2 Mitosis and Cytokinesis

VOCABULARY

chromosome
histone
chromatin
chromatid
centromere
telomere
prophase
metaphase
anaphase
telophase

KEY CONCEPT Cells divide during mitosis and cytokinesis.

MAIN IDEAS

- ▶ Chromosomes condense at the start of mitosis.
- ▶ Mitosis and cytokinesis produce two genetically identical daughter cells.

✦ Connect to Your World

When you were a child, perhaps you attended a birthday party where goody bags were handed out. Whoever stuffed the bags had to make sure that each bag had exactly the same number of erasers, candies, and stickers. Otherwise, some ill-mannered child (not you, of course) might have raised a fuss if an item was missing. In a similar way, your cells must receive a full set of DNA—no more, no less—to work properly. Dividing DNA is a complicated task because the DNA is so long and stringy. Mitosis is an amazing process that efficiently sorts two sets of DNA and divides them between two nuclei.

▶ MAIN IDEA

Chromosomes condense at the start of mitosis.

DNA is a double-stranded molecule made of four different subunits called nucleotides. A **chromosome** is one long continuous thread of DNA that consists of numerous genes along with regulatory information. Your body cells have 46 chromosomes each. If stretched out straight and laid end to end, the DNA in just one of your cells would be about 3 meters (10 feet) long. How does it fit inside the nucleus of a microscopic cell?

DNA wraps around proteins that help organize and condense it. During interphase, or when a cell is not dividing, DNA is loosely organized—it looks a bit like spaghetti. During mitosis, however, your chromosomes are tightly condensed, as shown in **FIGURE 2.1**. These changes in DNA's organization allow a cell to carry out its necessary functions. During all of interphase, proteins must access specific genes for a cell to make specific proteins or to copy the entire DNA sequence. During mitosis, the duplicated chromosomes must condense to be divided between two nuclei.

If chromosomes remained stringy during mitosis, they could become entangled. Perhaps a cell would get two copies of one chromosome and no copies of a different one. **FIGURE 2.2** shows the process that converts a chromosome from a linear strand of DNA to its highly condensed form. The key to this process is the association between DNA and proteins.

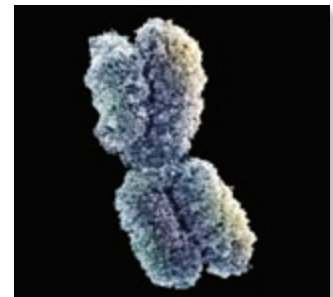


FIGURE 2.1 This duplicated chromosome is tightly condensed. (colored SEM; magnification unknown)

✦ CONNECT TO

BIOCHEMISTRY

As you will learn in **From DNA to Proteins**, a nucleotide is made of three parts: a sugar, a phosphate group, and a nitrogen-containing molecule called a base. When the sugars and phosphate groups bond, they form the backbones of the long chains called nucleic acids.

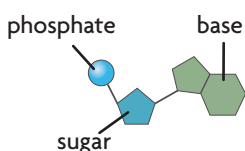
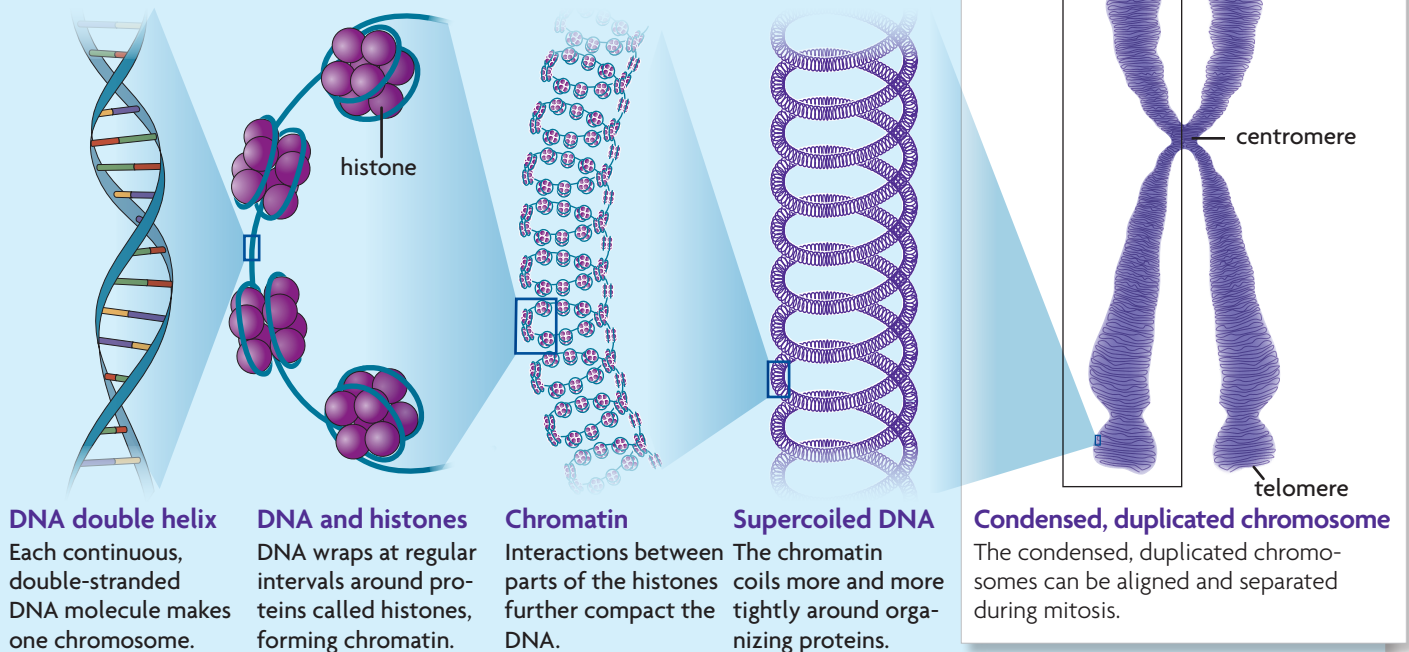


FIGURE 2.2 Chromosome Structure

DNA condenses tightly during the early stages of mitosis.



DNA double helix

Each continuous, double-stranded DNA molecule makes one chromosome.

DNA and histones

DNA wraps at regular intervals around proteins called histones, forming chromatin.

Chromatin

Interactions between parts of the histones further compact the DNA.

Supercoiled DNA

The chromatin coils more and more tightly around organizing proteins.

Condensed, duplicated chromosome

The condensed, duplicated chromosomes can be aligned and separated during mitosis.

Infer Overall, DNA has a negative charge. Look at the histone proteins in the figure. What type of overall charge do you think they have? Explain.

At almost all times during the cell cycle, each of your chromosomes is associated with a group of proteins called **histones**. DNA wraps around histones at regular intervals, similar to beads on a string. Parts of the histones interact with each other, further compacting the DNA. At this stage—the “spaghetti” stage—the loose combination of DNA and proteins is called **chromatin**. The word “loose” describes how much the DNA strand folds back on itself; it does not mean the DNA is loosely wrapped around the histones.

As a cell progresses into mitosis, chromatin further condenses. It continues to coil more and more tightly around organizing proteins, finally forming small thick rods. Recall that each chromosome has already been copied during the previous S stage. Thus, the chromosome looks similar to an “X” in which the left and right halves are two identical DNA double helices. One half of a duplicated chromosome is called a **chromatid** (KROH-muh-tihd). Together, the two identical chromatids are called sister chromatids. Sister chromatids are held together at the **centromere** (SEHN-truh-MEER), a region of the condensed chromosome that looks pinched.

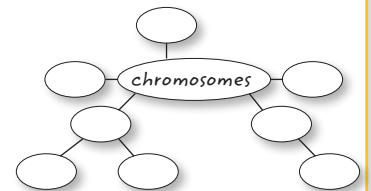
In addition, the ends of DNA molecules form structures called **telomeres** (TEHL-uh-MEERS), which are made of repeating nucleotides that do not form genes. They prevent the ends of chromosomes from accidentally attaching to each other, and they help prevent the loss of genes. A short section of nucleotides is lost from a new DNA molecule each time it is copied. It is important that these nucleotides are lost from telomeres, not from the genes themselves.

Apply What is the relationship between a molecule of DNA and a chromosome?

READING TOOLBOX

TAKING NOTES

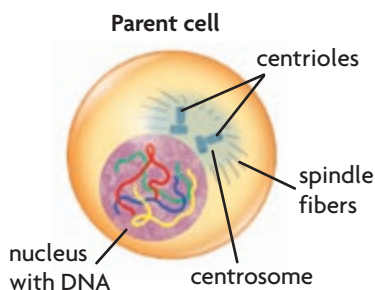
Use a main idea web to help you study the makeup and organization of chromosomes.



▶ **MAIN IDEA**

Mitosis and cytokinesis produce two genetically identical daughter cells.

FIGURE 2.3 The nucleus and chromosomes go through dramatic changes in a dividing cell.



✦ **CONNECT TO**

CELLS

As you will learn in **Meiosis and Mendel**, your body has two major cell types. Germ cells develop into eggs or sperm. Somatic cells make up the rest of your body.

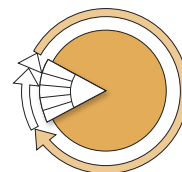
Animated
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PREMIUM CONTENT
Mitosis Stage Matching

The combined processes of mitosis and cytokinesis produce two genetically identical daughter cells. Follow along in **FIGURE 2.4** as you read about the process in more detail below.

Interphase

Interphase plays an important role in preparing the cell to divide. It provides critical time for the duplication of organelles and for DNA replication. By the end of interphase, an individual cell has two full sets of DNA, or chromosomes, and is large enough to divide.

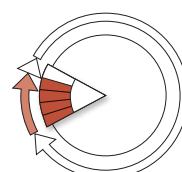
INTERPHASE



Mitosis

Mitosis divides a cell's nucleus into two genetically identical nuclei, each with its own single, full set of DNA. This process occurs in all of your body cells—except those that form eggs or sperm—and prepares them for cytokinesis. Although mitosis and cytokinesis are continuous processes, scientists have divided them into phases to make them easier to understand and discuss. The four main phases of mitosis are prophase, metaphase, anaphase, and telophase. Cytokinesis begins during late anaphase or telophase.

MITOSIS



- 1 During **prophase**, chromatin condenses into tightly coiled chromosomes. Each consists of two identical sister chromatids. The nuclear envelope breaks down, the nucleolus disappears, and the centrosomes and centrioles begin to migrate to opposite sides of the cell. Organized microtubules called spindle fibers grow from the centrioles and radiate toward the center of the cell.
- 2 In **metaphase**, the spindle fibers attach to a protein structure on the centromere of each chromosome and align the chromosomes along the cell equator, around the middle of the cell.
- 3 During **anaphase**, sister chromatids separate from each other. The spindle fibers begin to shorten, pulling the sister chromatids away from each other and toward opposite sides of the cell.
- 4 In **telophase**, a complete set of identical chromosomes is positioned at each pole of the cell. The nuclear membranes start to form, the chromosomes begin to uncoil, and the spindle fibers fall apart.

Cytokinesis

Cytokinesis divides the cytoplasm into two cells and completes a full stage of the cell cycle. Cytokinesis differs in animal and plant cells. In animal cells, the membrane forms a furrow, or trench, that is pulled inward by tiny filaments, like a drawstring. Gradually, the membrane pinches closed, forming a separate cell around each nucleus.

CYTOKINESIS

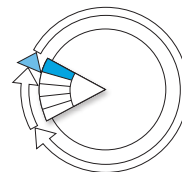


FIGURE 2.4 The Cell Cycle in Detail

Following interphase, mitosis divides duplicated chromosomes between two nuclei. Cytokinesis divides the cytoplasm. In this diagram, the mitosis stage is greatly expanded to highlight its four major phases. (micrographs; magnification about 100 \times)

INTERPHASE

The cell copies its DNA and grows in preparation for division. The DNA is loosely organized during interphase.

MITOSIS

Mitosis divides a cell's nucleus into two nuclei, each with an identical set of DNA.

CYTOKINESIS

Cytokinesis divides cytoplasm between two daughter cells, each with a genetically identical nucleus. The cells enter interphase and begin the cycle again.

1 Prophase DNA and proteins condense into tightly coiled chromosomes. The nuclear envelope breaks down, centrioles begin to move to opposite poles, and spindle fibers form.

2 Metaphase Spindle fibers attach to each chromosome. They align the chromosomes along the cell equator.

3 Anaphase Chromatids separate to opposite sides of the cell. Cytokinesis usually begins in late anaphase or telophase.

4 Telophase Nuclear membranes start to form, chromosomes begin to uncoil, and the spindle fibers fall apart.

CRITICAL VIEWING How many chromosomes does the cell have at the start of mitosis? How many does it have after cytokinesis?

DATA ANALYSIS

CONSTRUCTING DATA TABLES

Scientists use data tables to record their data. Data tables are organized by the independent and dependent variables. Usually the independent variable is listed in the left column, and the other columns list the dependent variables. Each separate observation is listed in its own row. When measurements are taken using units, they are listed in the column headings in parentheses. All tables should have numbers and titles.

Table 1 shows data from a hypothetical experiment in which growth hormones were added to clumps of cells in a laboratory, and the growth of the cell clumps was measured.

TABLE 1. EFFECT OF HORMONES ON CELL DIVISION

Concentration of Hormone Solution (%)	Size of Cell Clump After 24 Hours (mm)
0	3
25	4
50	8
75	9
100	9

Labels in the diagram:
- **independent variable** points to the first column.
- **dependent variable** points to the second column.
- **observations** points to the rows of data.

- 1. Display Data** Suppose a scientist decided to measure the effect of temperature on cell division in *chlorella*, a type of green algae. Set up a table that could be used to record the results for the number of daily doublings of the cells: 20°C, 3 doublings; 30°C, 7 doublings; 40°C, 12 doublings; 50°C, 0 doublings.
- 2. Apply** Label the independent and dependent variables on your table.



During cytokinesis in plant cells, the membrane cannot pinch inward because of the cell wall. Instead, a cell plate forms between the two nuclei. It is made by the Golgi apparatus, which supplies the new plasma membrane. A new wall then grows as cellulose and other materials are laid down. Typically, cytoplasm is divided evenly between daughter cells in both plant and animal cells.

The formation of new cells is critical in both multicellular and single-celled organisms. Single-celled organisms use cell division to reproduce, whereas multicellular organisms use it for growth, development, and repair.

Contrast How does cytokinesis differ in animal and plant cells?



5.2 Formative Assessment

REVIEWING ► MAIN IDEAS

1. Draw what a **chromosome** looks like during **metaphase**. Identify the **chromatids** and the **centromere**.
2. Briefly explain why the daughter cells resulting from mitosis are genetically identical to each other and to the original cell.

CRITICAL THINKING

3. **Contrast** How do **prophase** and **telophase** differ?
4. **Apply** Using a light microscope, you observe a cell that has no nucleus. What features would you look for to determine whether it is a eukaryotic cell undergoing mitosis or a prokaryotic cell?

CONNECT TO

PROTEIN SYNTHESIS

5. For a cell to make proteins, enzymes must access its genes. When **histones** are modified with acetyl groups (-COCH₃), their positive charge is neutralized, so they wrap DNA less tightly. How might this affect the rate of protein synthesis?