

UNIT 7

Cell Division, Genetics, and Molecular Biology

General Outcomes

In this unit, you will

- describe the processes of mitosis and meiosis
- explain the basic rules and processes associated with the transmission of genetic characteristics
- explain classical genetics at the molecular level

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Focussing Questions

- 1 What processes contribute to genetic variation?
- 2 Why do you and other organisms inherit some characteristics and not others?
- 3 How did scientists discover the structure of DNA, and how do they use technology to change that structure to produce new varieties of organisms?



The peregrine falcon is one of the world's swiftest predators. Its curved wings allow it to maneuver quickly in flight. A band of dark feathers under each eye cuts the glare of the Sun. The falcon's vision is adapted to spot a small bird more than a kilometre away—and to keep this prey in precise focus during a dive that can reach a speed of more than 300 km/h. During the mating season, the male falcon shows off his hunting skill by offering gifts of food to the female. All of these characteristics are hereditary traits that the adult bird will pass on to its chicks. How can mating behaviour, or the colour of a feather, be programmed into an egg? What natural and human-induced means are there for changing that programming? What are the ramifications of these changes?

In this unit, you will examine the cellular processes that store, transmit, and express hereditary information. Beginning with a study of the life cycles of cells and organisms, you will learn to analyze and predict patterns of inheritance. You will become familiar with the range of events—from random mutations to careful genetic engineering—that can give rise to new traits, deadly diseases, or entirely new organisms. Perhaps more than any other scientific discipline, the fast-changing field of genetics promises to change human society. In this unit you will encounter some of the challenging social and ethical issues that accompany this promise.



Prerequisite Concepts

This unit draws and builds upon your understanding of biodiversity from Chapter 3 as well as from earlier studies.

The Chemical Codes of Cells

Nucleic acids are biological chemicals that direct the growth and development of every single-celled and multi-celled organism by means of a chemical code. These chemicals determine how the cell functions and what characteristics it has. The cell contains two types of nucleic acid: RNA (ribonucleic acid) and DNA (deoxyribonucleic acid). DNA is the main component of the genes (hereditary material) in all cells. Each gene contains instructions for making RNA, which contains the instructions for making proteins. These proteins make up much of the structure of a cell and control how it functions.

Prokaryotes and Eukaryotes

The smallest cells with the simplest type of internal

organization lack a nucleus. That is, they lack an enclosed region inside of the cell where the DNA is separated from the rest of the cell. Instead, the DNA in these cells is concentrated in one region inside the cell. Such cells are called prokaryotes (“pro” meaning before and “karyon” meaning nucleus). Prokaryotic organisms are divided into two domains—Bacteria and Archaea—as shown in Figure P7.1.

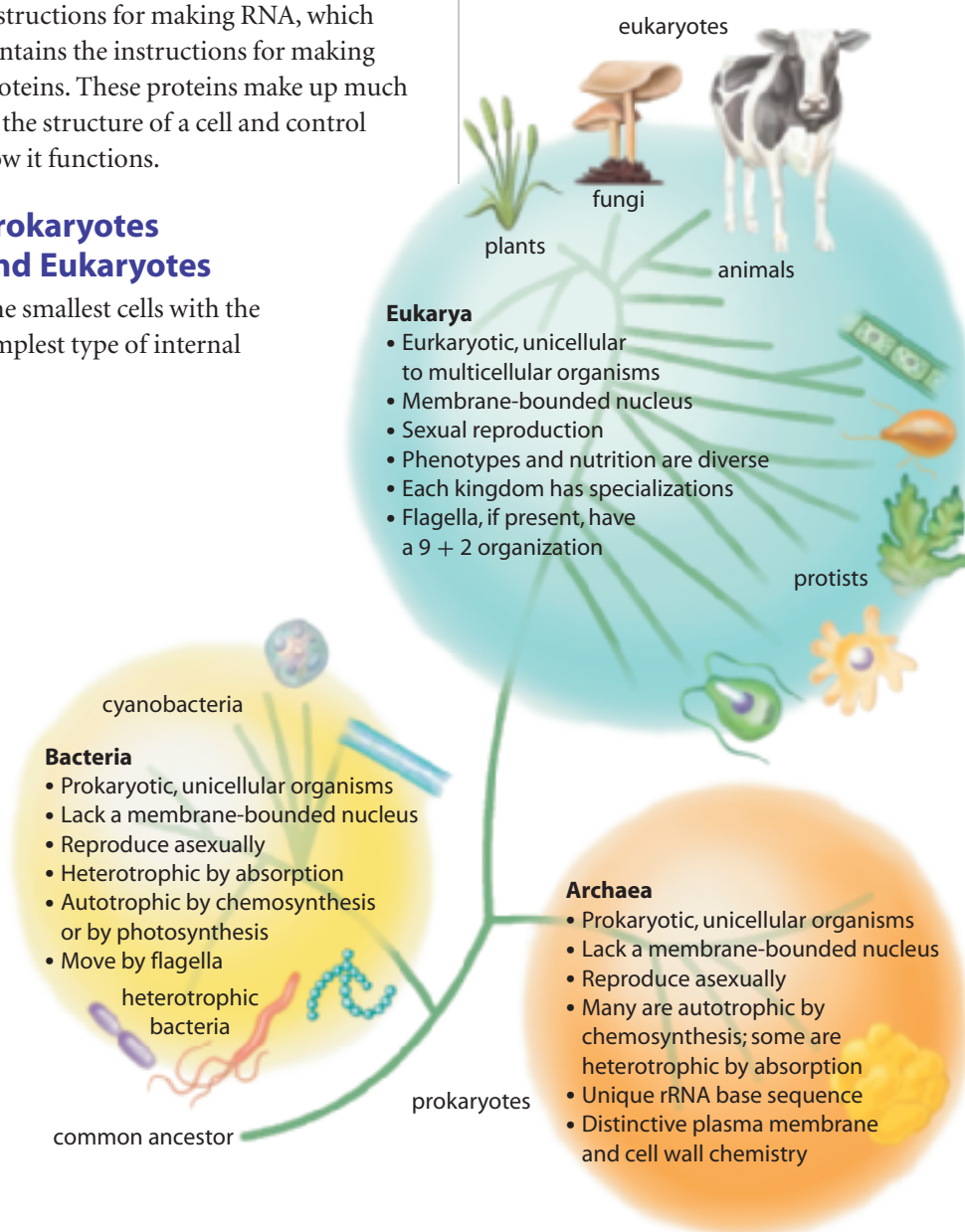


Figure P7.1 Two of the three domains of life contain prokaryotic organisms. The remaining domain contains eukaryotic organisms, including humans.

The cells of all other organisms are larger than prokaryotes and have a more complex structure that includes a nucleus. Such cells are called eukaryotes (“eu” meaning true, as in “true nucleus”).

The organelles of a eukaryotic cell divide its interior into compartments. This allows the many different chemical reactions constantly taking place within the cell to proceed at the same time without interfering with one another. Many organelles contain highly folded membranes that increase the surface area on which chemical reactions can be co-ordinated as well as the overall rate of reactions within the cell.

The Nucleus and Ribosomes

The genetic information stored in the DNA (Figure P7.2) determines the structural characteristics of the cell and how it functions. Unless a cell is in the process of dividing or preparing to

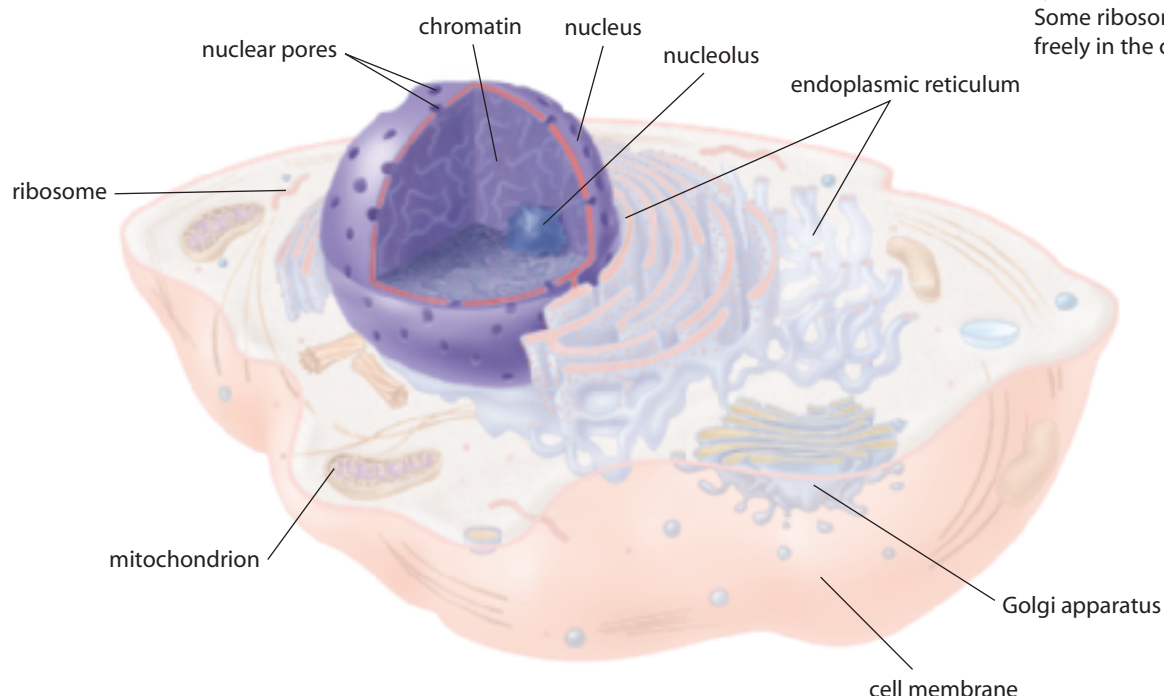
divide, the DNA exists in a network of strands called chromatin.

The nucleus has at least one area of chromatin, called a nucleolus, that is dedicated to producing a special type of RNA that is used to construct the many ribosomes required by the cell.

Ribosomes are tiny organelles that are the sites of protein synthesis in cells. Ribosomes are found in both eukaryotic and prokaryotic cells. In eukaryotes, ribosomes are 20 nm to 30 nm in diameter; they are slightly smaller in prokaryotes. In both types of cells, ribosomes are made up of two subunits, one large and one small, each with its own mix of proteins and RNA.

The nucleus is separated from the cytoplasm by a double membrane called the nuclear envelope. This membrane has nuclear pores about 100 nm in diameter that permit the passage of proteins into the nucleus and ribosomal subunits of the nucleus.

Figure P7.2 The cell nucleus and related structures. Continuous with the outer membrane of the nuclear envelope is a system of flattened membrane-bound sacs, the endoplasmic reticulum, studded with protein-synthesizing ribosomes. Some ribosomes also float freely in the cytoplasm.



CHAPTER 16

Cellular Reproduction

Chapter Concepts

16.1 The Cell Cycle

- Multicellular organisms grow by adding new cells through the process of cell division.
- The cell cycle is the continuous sequence of growth and division that gives rise to all cells.
- The cells of each species have a characteristic number and arrangement of chromosomes.

16.2 The Reproduction of Somatic Cells

- Mitosis involves a precise sequence of events, which can be grouped into four phases.
- The cell cycle is carefully regulated.

16.3 The Formation of Gametes

- Meiosis involves two nuclear divisions to create haploid gametes from diploid parent cells.
- Human gametes form by the processes of spermatogenesis and oogenesis.
- Meiosis contributes to genetic variation.

16.4 Reproductive Strategies

- Different species have life cycles that include different reproductive strategies.
- Many species are capable of both sexual and asexual reproduction.



In the late fall, the foothills of the Rocky Mountains ring with the clash of antlers as male elk challenge one another. An elk's antlers, which may span up to 2 m, take less than one year to grow. Antler tissue is one of the fastest-growing animal tissues. As each antler grows, millions of genetically identical antler cells are produced every day. When the elk breed, however, their offspring will have a variety of genetic characteristics. Some of these characteristics will be similar to those of their parents. Other characteristics will be quite different. In this chapter, you will investigate the cellular processes that allow for these different outcomes. You will also learn how an understanding of cell division helps scientists explore the important mechanisms of heredity.

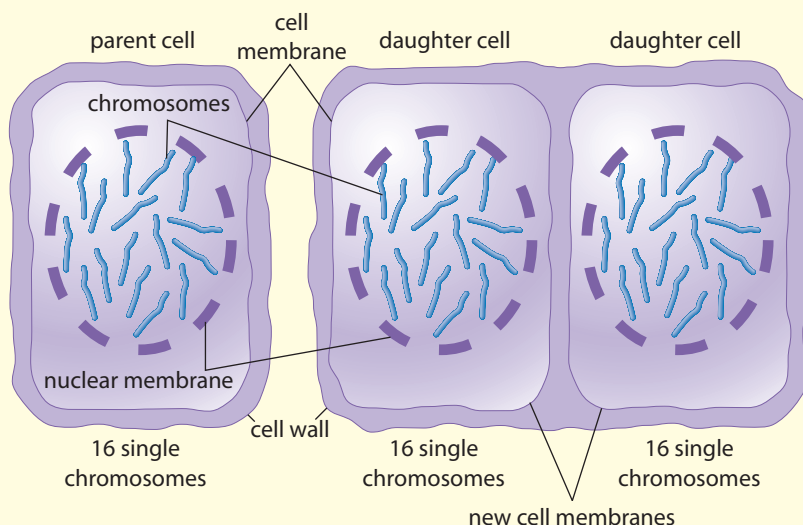
Launch Lab

Cell Division

In order for most organisms to grow, to repair damaged cells, and maintain their life functions, new cells are needed. Each new cell, or daughter cell, must contain the same genetic information as the original cell, or parent cell. How are these new, genetically identical cells produced?

Procedure

1. The diagrams show onion root-tip cells before and after the cells have divided to form new cells. The tip of an onion root-tip is an active growing region. The cells in this region are actively dividing to produce new cells.
2. Study the diagrams. Compare the number and characteristics of the chromosomes in the parent cell to the number of chromosomes in the two daughter cells.



Analysis

1. What do you notice about the number of chromosomes in the parent cell compared to the number of chromosomes in the two daughter cells?
2. What do you notice about the characteristics of each chromosome in the three cells?
3. How do you think it is possible to start with 16 chromosomes in the parent cell and end up with 16 chromosomes in each of the two daughter cells?
4. A somatic cell in humans contains 46 chromosomes. If this cell divides, how many chromosomes do you think will appear in the two new daughter cells?

This microscope image shows an animal cell dividing to produce two new somatic (body) cells. In what way would this image look different if the cell were dividing to produce sperm or egg cells instead of body cells?

SECTION 16.1

The Cell Cycle

Section Outcomes

In this section, you will

- **examine** the process of cell division and its significance
- **describe** the general stages of the cell cycle
- **describe** how genetic material is organized within eukaryotic cells
- **define and explain** the significance of chromosome number in somatic cells
- **prepare and interpret** a model of a human karyotype

Key Terms

cell cycle
somatic cells
parent cell
daughter cell
DNA
chromosome
histones
chromatin
centromere
homologous chromosomes
autosomes
sex chromosomes
genes
locus
alleles
diploid
haploid
gametes
polyploid
karyotype
interphase
G1 phase
S phase
sister chromatids
G2 phase
mitosis
cytokinesis

Imagine that you are a scientist who is studying plants and animals in the mid-1800s. Until the early 1800s, the best commonly available microscopes could reach a magnification of about $270\times$. By 1840, however, advances in lens technologies have led to the manufacture of microscopes that can magnify up to about $1200\times$. When you use one of these new microscopes to study plant and animal tissues, you are among the first scientists to observe that all living things are made up of cells. As well, you observe that cells of different tissues are different shapes and sizes, but almost all cells are microscopic in size. You conclude that as an organism grows, new cells are added. Perhaps you wonder why individual cells do not keep growing.

As a cell grows in size, the volume of its cytoplasm increases at a faster rate than the surface area of its plasma membrane. Recall that a cell absorbs nutrients and excretes wastes through its plasma membrane. As the volume of the cytoplasm increases, more materials must pass through this membrane. If a cell continued to grow, its plasma membrane would be too small to meet its metabolic needs (see Figure 16.1). Thus, a cell must stop growing once it reaches a certain size. New growth, therefore, must come from the addition of new cells.

Until the mid-1800s, most scientists accepted the theory of *spontaneous generation*. According to this theory, living organisms could arise from non-

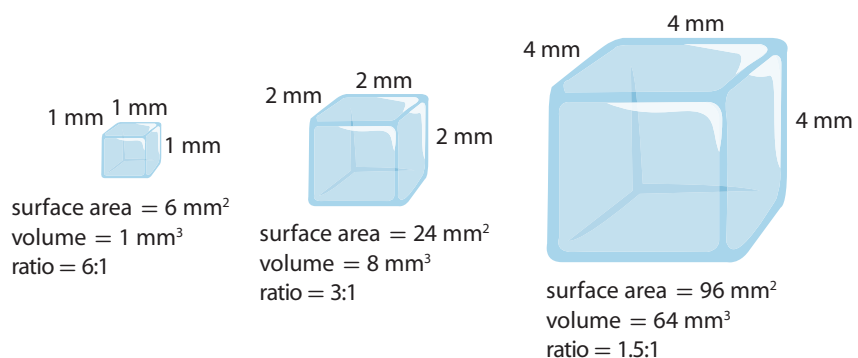
living matter. Observations of cell division led scientists to propose an alternative theory of how living cells originate. In 1855, Rudolph Virchow (1821–1902) became the first scientist to publish the conclusion that new cells arise *only* from the division of other cells. This conclusion became an important part of the argument against spontaneous generation, and it inspired many scientists to turn their attention to the study of cell division.

Cell Division and the Cell Cycle

The life cycle of the cell is called the **cell cycle**. The lives of **somatic cells** (body cells) vary, based on their type and their environment. For example, blood cells and skin cells are replaced frequently, so the cells that produce them divide frequently. Nerve cells, on the other hand, divide infrequently or not at all. For the many somatic cells that divide, the cell cycle consists of a maintenance period during which a cell seems to be resting and a period during which it divides. A single cell cycle is defined as the sequence of events from one cell division to the next. For a growing organism to develop properly, new cells that arise through cell division must be able to carry on the same function as the original cell.

While some scientists in the 1800s had begun to explore heredity, the mechanisms of heredity were not yet understood. Although researchers had begun to identify some cell structures,

Figure 16.1 The ratio of surface area to volume is a key factor that limits cell size. In these model cells, an increase in the length of the cell from 1 mm to 4 mm causes the ratio of surface area to volume to decrease from 6:1 to 1.5:1.



many others—including genetic material—appeared transparent under a microscope. These structures were impossible to differentiate, even at high magnifications. Although scientists could observe the division of cells, they could not infer how distinct cellular processes work.

A significant technological boost came from an unexpected source—the clothing industry. In the mid-1800s, the first synthetic dyes were produced. In 1879, the German biologist Walther Flemming (1843–1903) used one of these new dyes to stain a specimen of tissue. The stain was picked up by a substance in the nucleus, which Flemming called *chromatin* (meaning “coloured matter”). Within a few years, Flemming had observed that chromatin is made up of a set of individual coloured structures. As well, he had offered the first accurate description of the cell cycle and the process of cell division in plant and animal cells. Flemming coined the word *mitosis*—from Greek, meaning “thread”—to describe his observations of thread-like structures dividing in the cell nucleus. (You will learn about mitosis in Section 16.2.)

Flemming had no idea there was a connection between the coloured substance he was studying and the processes of heredity. Even so, the fact that this substance behaved in predictable ways during cell division, and that its behaviour was similar in both plant and animal cells, indicated that it was important to the life of all cells. The systematic study of cell division began in earnest in the late 1800s.

Today, scientists know that the structure and function of a cell are determined by its genetic material. Therefore, the central feature of the cell cycle is the way that genetic material is duplicated and then passed from the original cell, called the **parent cell**, to each new cell, called a **daughter cell**. This process is made possible by the highly organized arrangement of genetic material within a cell.

- 1 Explain why there is a limit to how large a cell can grow.
- 2 Define the term “cell cycle.”
- 3 Briefly summarize how advances in technology led to the new theories about the origin of cells.
- 4 What is the central feature of the cell cycle?

Organization of Genetic Information in the Eukaryotic Cell

The genetic information of a cell is contained in its **DNA** (deoxyribonucleic acid), a molecule of nucleic acid that governs processes of heredity in the cells of organisms. DNA is found in each **chromosome** of a cell. A chromosome is a length of DNA and its associated proteins.

In eukaryotic cells, the chromosomes are found in the nucleus. (Eukaryotic cells are those that make up protists, fungi, plants, and animals. These cells have a membrane-bound nucleus.) If you lined up all the DNA found in the nucleus of a single human cell, it would reach about 3 m. The diameter of a nucleus, however, is only about 5 μm . (As a comparison, imagine stuffing a piece of string about 150 km long into a lunch box.) A highly organized arrangement of proteins, known as **histones**, and DNA compacts this material within the cell.

For most of a cell’s life cycle, its genetic material appears as a mass of long, intertwined strands known as **chromatin**. As the genetic material is reorganized during the processes of cellular division, the threads of chromatin condense and become visible under a light microscope as distinct chromosomes. Figure 16.2 shows the levels of organization of genetic material within a eukaryotic cell. The constricted (pinched-in) region in the condensed chromosome is a specialized region called a **centromere**.

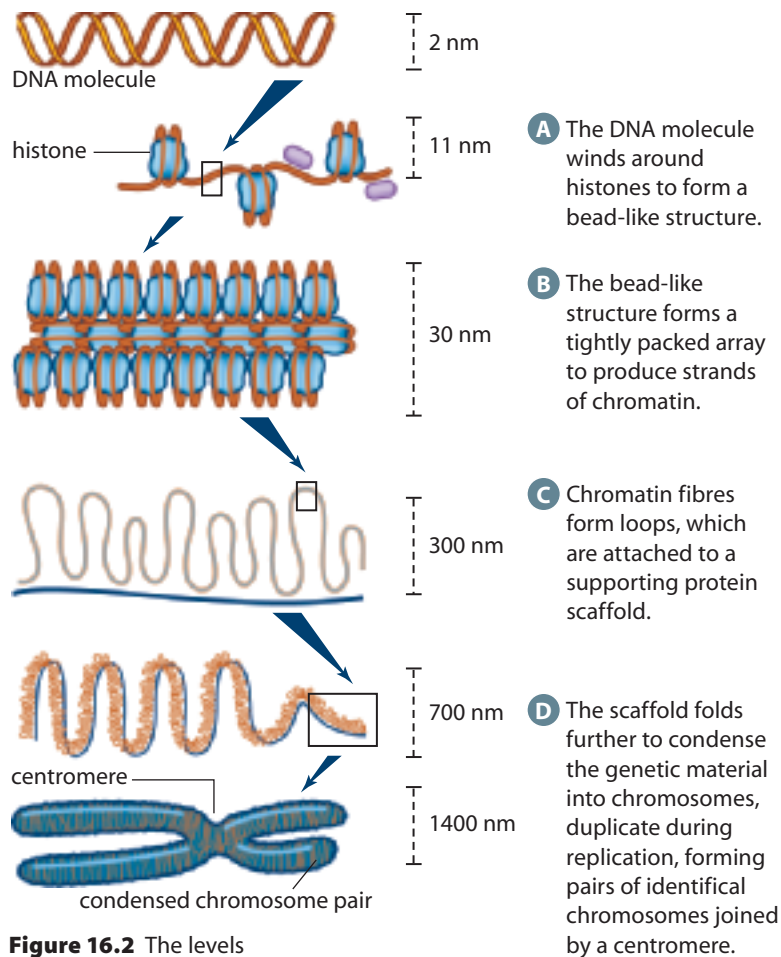


Figure 16.2 The levels of organization of genetic material in a eukaryotic cell

- 5 In what structures is the genetic information of a cell contained? Where are these structures located?
- 6 What is a centromere and where would you find it?

Chromosome Number

The levels of organization of genetic material shown in Figure 16.2 are much the same in all eukaryotic cells. However, the number of individual chromosomes each cell contains varies from one species to another. Human somatic cells have 46 chromosomes. These can be organized into 22 pairs of **homologous chromosomes** (similar-looking chromosomes) known as **autosomes**. Each somatic cell also has two **sex chromosomes** that may or may not be a homologous pair. The autosomes are numbered 1 through 22. The sex chromosomes are called X and Y.

The sex chromosomes determine the sex of an individual. A human female has two X chromosomes, and a human male has one X and one Y chromosome. By convention, the sex chromosomes are counted as a pair even though X and Y are not homologous.

Homologous chromosomes carry the same **genes**—areas of DNA that contain specific genetic information—at the same location, or **locus**. Despite appearing similar, homologous pairs are not identical to each other. Instead, they carry different forms, or **alleles**, of the same gene (Figure 16.3).

A cell that contains pairs of homologous chromosomes is said to be **diploid** (from a Greek word meaning “double”). The diploid number in humans is 46, or 23 pairs. A cell that contains unpaired chromosomes is said to be **haploid** (from a Greek word meaning “single”). Human **gametes**, or reproductive cells (egg and sperm cells), are haploid. The haploid number of chromosomes in a species is designated as n . In humans, $n = 23$, and a diploid cell has $2n$ chromosomes ($2n = 46$). n varies from species to species. In corn plants (*Zea mays*), $n = 10$. In fruit flies (*Drosophila* sp.), $n = 4$. Some organisms are **polyploid**, which means they have sets of more than two homologous chromosomes. For example, some plants are **tetraploid** ($4n$, or four homologous chromosomes of each type), **triploid** ($3n$), or even **octoploid** ($8n$).

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FYI

The total length of the DNA in all of your cells is about 2×10^{10} km—about twice the distance between Earth and the Sun.

- 7 How many chromosomes are there in the somatic cells of humans?
- 8 What are homologous chromosomes?
- 9 Why are the X and Y chromosomes known as the sex chromosomes?
- 10 Write a sentence that clearly differentiates these terms: diploid, haploid, polyploid.

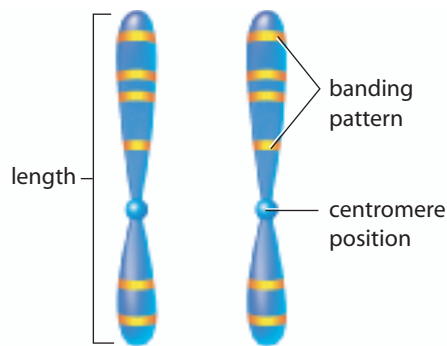


Figure 16.3 Homologous chromosomes are not identical to one another, because they carry different forms, or alleles, of the same genes. They have several other characteristics in common, such as their length, centromere location, and banding pattern.

Examining Chromosomes: The Karyotype

Autosomes 1 to 22 and chromosomes X and Y are distinct from one another in several ways. For example, they vary in their overall length, the location of their centromere, and their staining properties. (Each chromosome has a distinct pattern of banding when stained.) These three characteristics are the same in homologous chromosomes, however (see Figure 16.3). Therefore, scientists can use these characteristics to identify individual chromosomes and to match pairs of homologous chromosomes.

The particular set of chromosomes that an individual possesses is called the individual's **karyotype** (see Figure 16.4).

To prepare a karyotype, scientists collect a cell sample and use chemicals to stop the cell cycle when the condensed chromosomes are most clearly visible under a light microscope. Then they stain the cells to help them identify the individual chromosomes. Usually, they photograph the stained chromosomes and transfer the images onto a new background. They complete the karyotype by organizing the images into a series of homologous pairs. In the next investigation, you will model the process of preparing a karyotype by hand. (In the past, karyotypes were prepared by hand. Now this is usually done on a computer.)

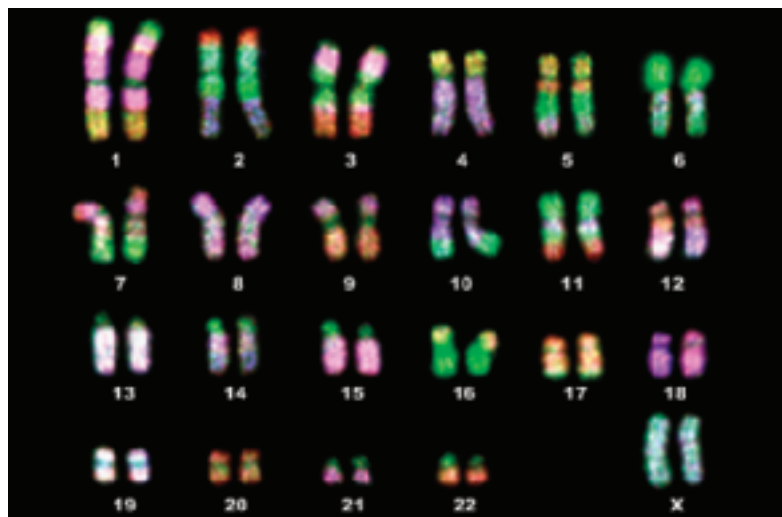


Figure 16.4

A human karyotype. The chromosome pairs are arranged and numbered in order of their length, from longest to shortest. The sex chromosomes appear last. Karyotypes are helpful in diagnosing conditions such as Turner syndrome, where one X chromosome is partly or totally missing, and Down syndrome, where there is an extra chromosome 21.



What is a karyotype?



Describe how the 22 autosomes and the sex chromosomes are distinct from one another.

Stages of the Cell Cycle

The cell cycle is made up of two main stages: a growth stage and a division stage. Each of these stages includes a series of distinct events, as shown in Figure 16.5.

Growth Stage

Most of the somatic cell's life is spent in the growth stage, which is called **interphase**. During interphase, the cell carries out its regular metabolic functions and prepares for its next division. There are three phases in interphase: G1, S, and G2.

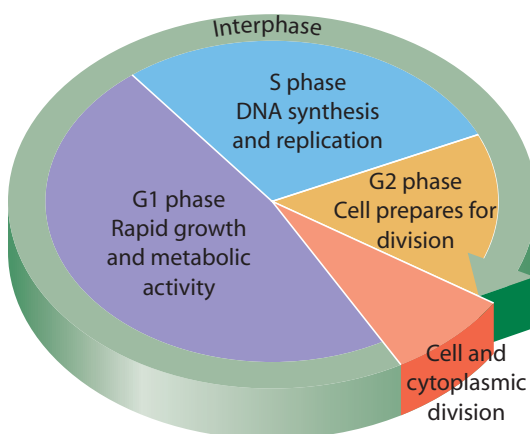


Figure 16.5

The cell cycle. Interphase, the stage of growth and metabolic activity, occupies most of the cell cycle. The division stage involves the reproduction of the nucleus and the division of the cell contents.

BiologyFile

FYI

Many people believe that the bands on a stained chromosome correspond to individual genes. In fact, a single band may include hundreds of genes.

- **G1 phase:** Early scientists could not identify any specific activities taking place during this phase, so they called it “Gap 1” or “G1.” Scientists now know that important growth processes are occurring, so more recent work usually refers to this phase as “Growth 1.” The cell grows quickly during the G1 phase.
- **S phase:** About midway through interphase, the cell’s DNA is copied exactly. That is, the DNA in the chromatin *replicates* to create a second identical set of DNA. (You will learn more about DNA replication in Chapter 18.) These two identical chromosomes, called **sister chromatids**,

are joined at the centromere, as shown in Figure 16.6. Because new genetic material is synthesized during this phase, it is known as the *synthesis* or S phase.

- **G2 phase:** Cells that have completed the S phase then enter the last segment of interphase, called “Gap 2” or “Growth 2.” DNA replication in the S phase has consumed a great deal of energy, so this second growth stage lets the cell rebuild its reserves of energy to prepare for division. As well, the cell manufactures proteins and other molecules to make structures required for division of the nucleus and cell.

INVESTIGATION

16.A

Target Skills

Preparing and interpreting models of a human karyotype

Modelling a Karyotype

A karyotype provides information about the number and organization of chromosomes in an individual. Karyotypes are used most often by geneticists to determine the presence of particular genetic conditions. In this investigation, you will simulate the preparation of a karyotype and analyze your results.

Question

How can you prepare and interpret a karyotype?



Safety Precautions

- Use care when handling scissors.

Materials

- image of the chromosomes in a human somatic cell
- blank karyotype form
- scissors
- tape

Procedure

1. Work with a partner. Your teacher will provide an image of chromosomes in a human somatic cell. Examine the chromosomes. How many chromosomes can you count? What similarities and differences can you see? Record your observations.
2. Carefully cut out each chromosome.

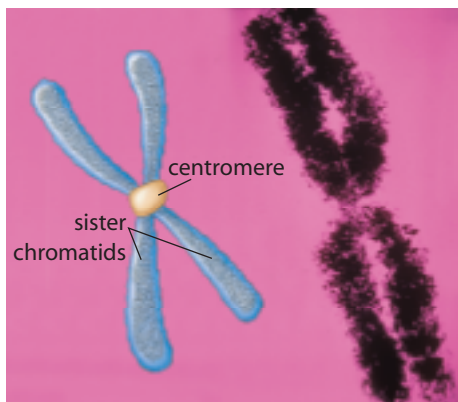
3. Match the homologous pairs of chromosomes. Remember to match the length, location of the centromere, and banding pattern of the chromosomes in each pair.
4. Tape the pairs of autosomes 1 to 22 on the karyotype form in order, from longest to shortest. Place the sex chromosomes with each other, at the end of the karyotype. **Note:** The X and Y chromosomes are not a homologous pair. The length of the X chromosome is between the lengths of chromosome 4 and chromosome 5. The Y chromosome is much shorter, about the same length as chromosome 14.
5. Examine your finished karyotype, and record your observations.

Analysis

1. How many chromosomes does this cell have? How would you write the chromosome number to show the haploid chromosome number?
2. How would the karyotype differ if this were a gamete? What would its chromosome number be?
3. Did these chromosomes come from a male or a female? How can you tell?

Conclusion

4. What kind of information can you infer from a karyotype?



Magnification: 67 534 x

Figure 16.6 During the S phase of the cell cycle, each chromosome is copied. The resulting sister chromatids are held together at the centromere.

Interphase ends when the cell begins the process of nuclear division: mitosis.

Cell Division

There are two main processes in cell division:

- **mitosis**, the division of the genetic material and the contents of the nucleus into two complete and separate sets
- **cytokinesis**, the division of the cytoplasm and the organelles into two separate cells

Together, mitosis and cytokinesis form two new daughter cells with the same genetic information as the parent cell. In the next section, you will examine these processes in more detail.

13 What are the main phases of the cell cycle?

14 Briefly describe each phase.

Section 16.1 Summary

- Multicellular organisms grow by adding new cells through the process of cell division.
- The cell cycle is the continuous sequence of growth and division that gives rise to all cells.
- A highly organized arrangement serves to compact genetic material within a eukaryotic cell.
- Each eukaryotic cell contains chromosomes. The number and arrangement of these chromosomes varies from species to species. For example, a human somatic cell contains 23 pairs of chromosomes.
- The cell cycle ensures that the diploid parent cell provides an identical set of chromosomes to each of its daughter cells.
- The cell cycle is made up of two main stages: interphase and division.
- These stages can be organized into five general phases or processes: a first growth stage, called the G1 phase; a period of DNA synthesis, called the S phase; a second growth stage, the G2 phase; the division of the nucleus (mitosis); the division of the cytoplasm (cytokinesis).

Section 16.1 Review

1. Give two reasons that cell division is necessary for a plant to grow from a seedling into a tree.
2. What two main technological advances enabled scientists to observe cell division?
3. What are the five general phases or processes of the cell cycle?
4. Contrast the two terms in each pair of terms.
 - a) haploid and diploid
 - b) chromatin and chromosome
 - c) XX and XY
5. What three characteristics are the same in each chromosome of a homologous pair?
6. During what phase of the cell cycle are chromosomes replicated?
7. Suppose that you are examining a human cell with 22 pairs of autosomes, one X chromosome, and one Y chromosome. Did this cell come from a male or a female? Is the cell somatic or a gamete? Diploid or haploid? Explain.

SECTION 16.2

The Reproduction of Somatic Cells

Section Outcomes

In this section, you will

- **identify** the phases of mitosis and describe their significance
- **assess** the similarities and differences between mitosis in plant cells and mitosis in animal cells
- **calculate** the duration of individual phases of the cell cycle

Key Terms

prophase
centrioles
spindle apparatus
metaphase
anaphase
telophase
cell plate
cancer



Figure 16.7 If a sea star (*Asterias vulgaris*) is attacked by a predator and loses one or more arms, new arms are regenerated through the processes of mitosis and cytokinesis. Four arms are regenerating here. What applications could the study of these processes have for humans?

Each cell that undergoes mitosis will divide to produce two new cells. The linked processes of mitosis and cytokinesis have three important functions:

- **Growth:** They enable organisms to grow from a single-celled zygote into a mature organism that may contain hundreds of trillions of cells.
- **Maintenance:** They produce new cells to replace worn out or dead cells.
- **Repair:** They can regenerate damaged tissues. If you cut your finger, skin cells reproduce so that new skin can grow over the injured area. Some organisms are able to regenerate entire body parts that have been lost (see Figure 16.7).

To accomplish each of these functions, each daughter cell must have the correct genetic information. This means that several cellular events must take place:

- The genetic material of the parent cell must be replicated.
- The replicated chromatin must be condensed and organized as chromosomes in the nucleus.
- One complete set of chromosomes must be divided into each of two new nuclei.

- The cell cytoplasm must divide to produce two complete and functional daughter cells.

In this section, you will study the cellular events that achieve these outcomes.

15 Name the three important functions of mitosis and cytokinesis.

16 Why must each daughter cell have the correct genetic information?

Phases of Mitosis

Recall, from Section 16.1, that DNA replication takes place during the S phase of interphase. In G₂, the cell begins manufacturing or assembling other materials it will require for mitosis and cytokinesis. At the end of interphase, the chromatin consists of two identical sets of DNA. The cell is ready to begin mitosis.

Mitosis consists of a precise sequence of events. In a living cell, this sequence is continuous. That is, there are no clear dividing lines between one event and the next. To facilitate description

and communication, cell biologists have grouped the events into four main phases. Each phase is identified by a characteristic arrangement of chromosomes and by the appearance or disappearance of other cell structures. Study Figure 16.8 as you read through the following description of the phases of mitosis in animal cells.

Prophase

Prophase is the first of the four phases of mitosis. During prophase, the chromatin condenses into tightly packed chromosomes.

Other structures in the cell also change during prophase. The nuclear membrane breaks down, releasing the

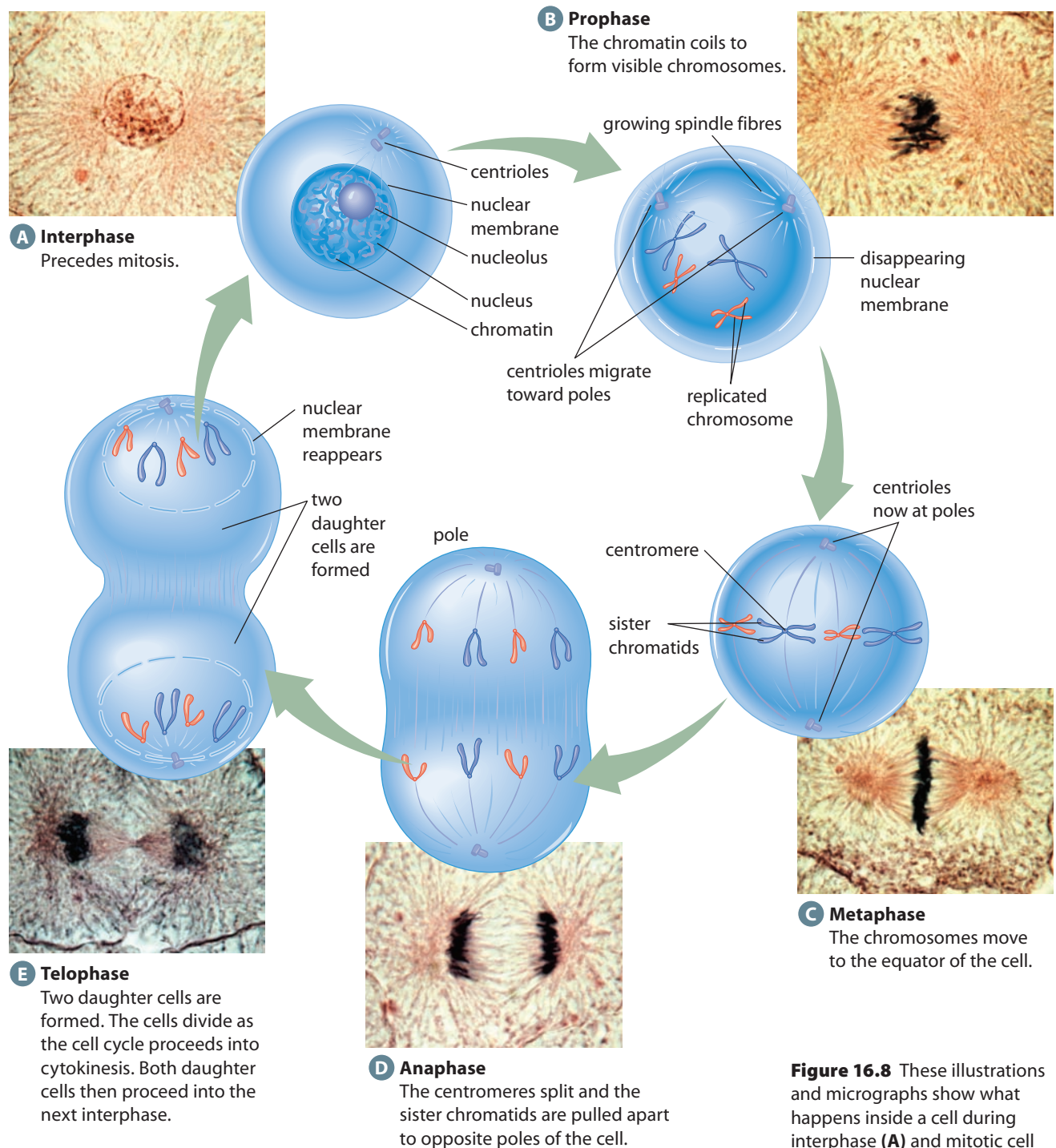


Figure 16.8 These illustrations and micrographs show what happens inside a cell during interphase (A) and mitotic cell division (B to E).

BiologyFile

Try This

Cells invest a great deal of energy and materials into condensing long chromatin strands into short chromosomes. Why do you think the genetic material does not simply stay in one form or the other throughout the cell cycle? Discuss your ideas with a partner.

chromosomes into the cytoplasm. The nucleolus disappears. One pair of cylindrical organelles, called **centrioles**, moves apart to opposite poles of the cell. As the centrioles move apart, a network of fibres called the **spindle apparatus** forms between them. Each *spindle fibre* is made of microtubules—hollow tubes of protein that facilitate movement of chromosomes within a cell. A spindle fibre lengthens with the addition of microtubule subunits. The removal of these subunits causes a spindle fibre to shorten.

Metaphase

The second phase of mitosis is called **metaphase**. During metaphase, the spindle fibres guide the chromosomes to the equator, or centre line, of the cell. The spindle fibres from opposite poles attach to the centromere of each chromosome. The spindle fibres attach in such a way that one sister chromatid faces one pole, while the other sister chromatid faces the opposite pole. (By convention, each pair of sister chromatids is considered to be a single chromosome as long as the chromatids remain joined at the centromere.)

Anaphase

The third phase of mitosis is called **anaphase**. During anaphase, each centromere splits apart and the sister chromatids separate from one another. The spindle fibres that link the centromeres to the poles of the cell shorten. As these fibres shorten, sister chromatids are pulled to opposite poles. At the same time, other microtubules in the spindle apparatus lengthen and force the poles of the cell away from one another. At the end of anaphase, one complete diploid set of chromosomes has been gathered at each pole of the elongated cell.

Telophase

The fourth and final phase of mitosis is called **telophase**. Telophase begins when the chromatids have reached the opposite poles of the cell. The chromatids begin to

unwind into the longer and less visible strands of chromatin. The spindle fibres break down. A nuclear membrane forms around each new set of chromosomes, and a nucleolus forms within each new nucleus.

Cytokinesis

Mitosis is the process of nuclear division. It is followed by cytokinesis, which is division of the cytoplasm to complete the creation of two new daughter cells. During cytokinesis in animal cells, an indentation forms in the cell membrane along the cell equator. This indentation deepens until the cell is pinched in two. The cytoplasm and organelles divide equally between the two halves of the cell. Cytokinesis ends with the separation of the two genetically identical daughter cells. The daughter cells are now in G1 of interphase.

- 17 What are the four phases of mitosis?
- 18 List the key events that happen to chromosomes in each phase.

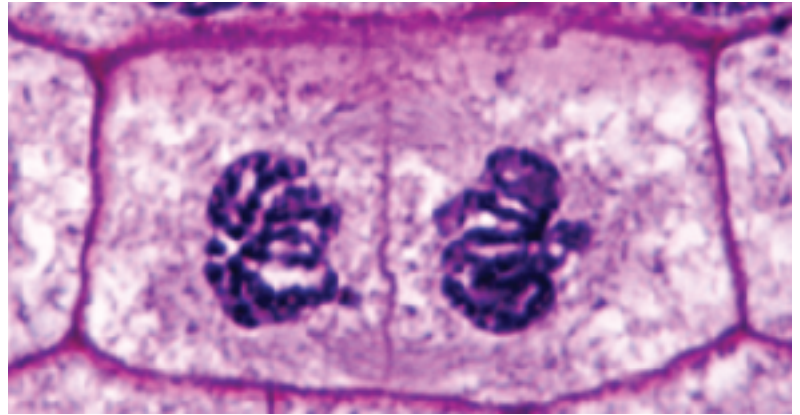
Mitosis and Cytokinesis in Plant Cells

In the mid-1800s, scientists observed that the phases of cell division are very similar in plants and animals. The observation that plants and animals share this basic process of life caused a philosophical shift toward recognizing the unity of living things. At the same time, however, scientists recognized that the structural differences between plant cells and animal cells lead to some differences in cell division:

- Plant cells do not have centrioles, but they do form a spindle apparatus.
- The rigid cell wall of a plant cell is much stronger than the membrane of an animal cell. The cell wall does not furrow and pinch in during cytokinesis. Instead, a membrane called a **cell plate** forms between the two daughter nuclei

(see Figure 16.9). This cell plate extends across the diameter of the cell, and it is then reinforced by the addition of cellulose and proteins to create a new cell wall.

19 How do mitosis and cytokinesis differ in plant cells and animal cells?



Magnification: 514 ×

Figure 16.9 Cytokinesis in a plant cell. A new cell wall is forming between the two daughter cells.

INVESTIGATION

16.B

Target Skills

Identifying the stages of the cell cycle in plant and animal cells

Calculating the duration of each stage of the cell cycle in a plant or animal cell

Analyzing the similarities and differences of cell division in plant and animal cells

Observing the Cell Cycle in Plant and Animal Cells

In this investigation, you will observe and compare the stages of the cell cycle in prepared slides of onion root tip cells and in whitefish embryo cells.

Question

What stages of the cell cycle can you recognize and identify in plant and animal cells?



Safety Precautions

- Be sure that the microscope is turned off and your hands are dry when you plug in or disconnect the cord.
- Handle the microscope slides with care.

Materials

- microscope
- prepared slide of onion root-tip cells
- prepared slide of whitefish embryo cells

Procedure

1. Place the onion root-tip slide on the microscope stage, and observe it under low power. Focus on the area just behind the tip of the root.
2. Carefully shift to medium power, focus, and then go to high power to observe the cells. Try to find cells in the different phases of mitosis, and draw a cell in each phase. Also find and draw a cell in interphase and a

cell undergoing cytokinesis. Label as many features as you can.

3. Move the slide to concentrate your attention on the root tip. Note any differences between the root tip and the area you observed in step 2.
4. Change back to lower power, and remove the onion root tip slide. Place the whitefish embryo slide on the stage, and observe it under low power.
5. Find an area of dividing cells. Change to medium power, focus, and then shift to high power. As you look at each cell, determine which phase of mitosis it is in.
6. Draw one cell in interphase, one cell in each phase of mitosis, and one cell in cytokinesis. Label as many parts as you can. Note any difference between mitosis in animal cells and mitosis in plant cells.
7. Copy the data table on the next page. Switch back to the onion slide and, working in pairs, observe every onion root-tip cell in one high power field of view and identify its phase of the cell cycle. Have one partner observe the slide and call out the phase of each cell while the other partner records the observations. After you do one full field of view, choose another

continued on next page

and switch roles. If you have not counted at least 200 cells, then count a third field of view.

8. Calculate the percentage of cells found in each stage by dividing the number of cells in a given stage by the total number of cells in the sample and then multiplying by 100:

$$\frac{\text{number in a stage}}{\text{total sample number}} \times 100$$

Enter your calculated values in the data table.

9. Assuming that it takes about 24 h (1440 min) for onion root-tip cells to go through one full cell cycle, you can calculate the amount of time the cells spend in each phase from the percentage of the cells in that stage: percent of cells in a stage $\times$ 1440 min. Enter your calculated values in the data table.
10. Change back to lower power, and remove the slide. Turn off and unplug the microscope.

Analysis

1. What differences did you notice between the cells in the onion root tip and the cells farther away from the root tip? Consider
 - a) the size of the cells
 - b) the shape of the cells
 - c) the number of dividing cells
2. What differences did you notice between the onion root-tip cells and the whitefish embryo cells? Consider
 - a) the size of the cells
 - b) the shape of the cells
 - c) the arrangement of chromosomes in the cells
3. Draw a pie graph using the data you collected in steps 8 and 9.
4. Do you think that your observations and calculations in steps 7–9 are representative of the cell division taking place in the entire root? Explain your answer.

Conclusion

5. Prepare a table that compares and contrasts the events of the cell cycle in plant cells and animal cells.

Data table for determining timing of cell division

	Number of Cells				Percent of total counted	Time in each stage
	Field 1	Field 2	Field 3 (optional)	Total		
Interphase						
Prophase						
Metaphase						
Anaphase						
Telophase						
Total cells						

Regulation of the Cell Cycle

You know that mitosis and cell division govern the growth, repair, and maintenance of plant and animal tissues. In your own body, about 150 billion cell divisions take place each day. What would happen if the wrong cells were dividing?

For any organism to develop properly and to remain healthy, its cells must divide only at certain times and they must stop dividing at the correct time. This requires a delicate balance among many different regulatory signals. Within a cell, specific protein interactions serve as “start” or

“stop” signals for cell division. External factors such as the presence of particular hormones, the availability of nutrients, and contact with other cells also play a role.

Anything that interferes with regulatory signals can cause the cell cycle to proceed at an uncontrolled rate. The group of diseases that are associated with uncontrolled, rapid cell division are known as **cancer**. Rather than spending much of their cell cycle as functioning tissue cells in interphase, cancerous cells move quickly from one cell division to the next. The result is a fast-growing

mass of non-functional cells, called a *tumour*. In Chapter 18, you will learn more about some of the specific genetic events that can lead to cancer.

Applying Knowledge of Mitosis

Many of the studies of cell division have used tissues from non-human organisms, such as yeasts, frogs, and fruit flies. Because the processes of cell division are similar in all eukaryotes, these studies have applications for human cells as well. Many non-human tissues offer important advantages for laboratory investigations. The embryo cells of some species of frog, for example, are large enough that researchers can micro-inject proteins and other substances directly into the dividing cells to study the effects. In more recent years, the study of cell division has shifted to the roles of individual genes in triggering specific events. The fruit fly, *Drosophila melanogaster*, has proven to be a useful model organism for these studies because its genetic material contains counterparts to many of the human genes involved in regulating the cell cycle.

Since the first observations of dividing cells in the late 1800s, new

microscopes and staining techniques have advanced our understanding of the cell cycle. For example, scientists can now tag individual protein molecules with fluorescent dyes to track the movements and reactions of proteins at different stages of the cell cycle. New types of light microscopes provide improved live images of cell division at work. These technologies have helped researchers learn more about the complex interactions of signals and processes that are involved in the cell cycle.

Section 16.2 Summary

- Mitosis involves a precise sequence of events.
- These events are grouped into four phases: prophase, metaphase, anaphase, and telophase.
- Each phase is defined by a particular arrangement of chromosomes within the dividing cell. Telophase is followed by cytokinesis.
- The cell cycle is carefully regulated by specific regulatory signals. Interference with these signals can result in uncontrolled cell division and the development of cancer.

Section 16.2 Review

1. What three functions does mitosis serve in your body?
2. In which phase of mitosis does each of the following events occur?
 - a) migration of sister chromatids to opposite poles
 - b) condensation of chromatin into compact chromosomes
 - c) formation of a nuclear membrane
 - d) alignment of chromosomes along the cell equator
3. Sketch the four phases of mitosis. Include labels to explain what is happening in each phase.
4. What role does the spindle apparatus play in cell division?
5. Briefly explain the link between cell cycle regulation and cancer.
6. The scientists in a lab have isolated a substance that prevents cells from synthesizing microtubules. What impact would this substance have on cell division? Explain.
7. A scientist studying a group of somatic cells notices that upon the completion of the cell cycle half of the daughter cells have no chromosomes and the other half have 92 chromosomes. In what phase of mitosis did an error most likely occur? Explain your reasoning.

Regenerating the Sense of Hearing?

Nerve deafness, the most common form of hearing loss, is caused by damage or loss of hair cells in the inner ear. Until recently, scientists assumed that hearing loss due to nerve deafness was irreversible. Treatments to aid the hearing impaired, such as hearing aids and cochlear implants, are not designed to re-grow hair cells.

The discovery in 1986 that birds could regenerate hair cells in their ears after trauma—and thus could regain hearing—gives hope that deafness in humans can be reversed.

The organ of Corti is located in the cochlea of the inner ear and contains two types of cells: hair cells, and supporting cells, which nourish hair cells. Outer organ of Corti hair cells detect sound. In the innermost part of the organ of Corti, hair cells turn auditory input into an electrical signal, which is then sent to the brain via the auditory nerve.

In birds, remaining support cells receive a signal to divide into daughter cells by mitosis and cytokinesis after hair cells die. Brain-derived neurotrophic factor (BDNF) molecules that encourage the survival of nervous tissue are understood to promote this process in birds. After cell division, support daughter cells receive a signal to change into hair cells by transdifferentiation—a process whereby a non-stem cell develops into another kind of cell.

Initially, scientists doubted this kind of regeneration could occur in mammals. However, laboratory studies on pigs, mice, rats, guinea pigs, and humans have shown that when hair cells are destroyed, a small amount of support cells grew in the tissue of the inner ear. This offers hope that human hearing loss can one day be reversed, if the mechanism that causes support cells to grow into hair cells can be further manipulated.

One method that has been used to support cell regeneration involves the use of growth factors. These are hormone-like chemicals that control the growth of cells. Another method of support cell regeneration is gene therapy, which introduces specialized growth genes into the support cell through a specially made virus. The reasoning is that if a growth factor or gene therapy is successful, it will trigger cell division. Then, support cells will regenerate into hair cells and potentially restore hearing.

While progress so far is encouraging, barriers remain. Scientists are only beginning to identify and test growth factors that may play a role in regeneration. Furthermore, hair cells must “know” where and how much to grow. Cell growth must be controlled, since uncontrolled

growth could result in tumors. Finally, for a hair cell to be useful, it must connect with the auditory nerve.

...

1. Research and describe three common causes of non-congenital (not present at birth) hearing impairment. What steps can you take to prevent hearing loss?
2. Retinoblastoma (Rb) is a protein that prevents cells from multiplying. Research with Rb with respect to support cell regeneration. How could an understanding of retinoblastoma contribute to a cure for nerve deafness?



Magnification: 2905 ×

This colorized scanning electron micrograph of a healthy human inner ear shows hair cells (brownish-pink) and the feathery projections, called stereocilia (pink) at their ends. Unlike hair cells in some other animals, human hair cells are unable to regenerate naturally if they are damaged.

SECTION 16.3

The Formation of Gametes

Section Outcomes

In this section, you will

- **define** and **explain** the significance of chromosome number in gametes
- **examine** how meiosis results in the production of gametes
- **describe** the ways in which meiosis contributes to genetic variation
- **compare** the processes of oogenesis and spermatogenesis
- **design** a model to simulate the processes of meiosis and mitosis
- **model** the processes of crossing over between chromosomes
- **compare** the formation of fraternal and identical twins

Key Terms

meiosis
reduction division
recombination
meiosis I
meiosis II
germ cells
synapsis
tetrad
non-sister chromatids
crossing over
nondisjunction
spermatogenesis
oogenesis
spermatogonium
primary spermatocyte
secondary spermatocyte
spermatids
oogonium
primary oocyte
secondary oocyte
first polar body
second polar body

Figure 16.10 The union of two haploid gametes forms a diploid zygote. The zygote contains chromosomes from each parent. The chromosomes that are donated from the ovum are of *maternal origin* and those from the sperm cell are of *paternal origin*.

Each species has a unique set of genetic information in its chromosomes. When the somatic cells reproduce, the new cells have the same genetic information and the same number of chromosomes as the parent cells. During sexual reproduction, however, a gamete from the male organism and a gamete from the female organism fuse to create a new cell (see Figure 16.10). The resulting zygote has genetic information from both parents and the same number of chromosomes as its parents. For this to be possible, the gametes of an organism must contain half the number of chromosomes as the somatic cells of the organism.

The process that produces haploid gametes from diploid cells in the ovaries and testes is called **meiosis**. Meiosis has two key outcomes:

- **Reduction division:** Meiosis is sometimes referred to as a reduction division because it is a form of cell division that produces daughter cells with fewer chromosomes than the parent cells.
- **Recombination:** The products of meiosis have different combinations of genes. Genetic recombination gives rise to offspring that are genetically distinct from one another and their parents.

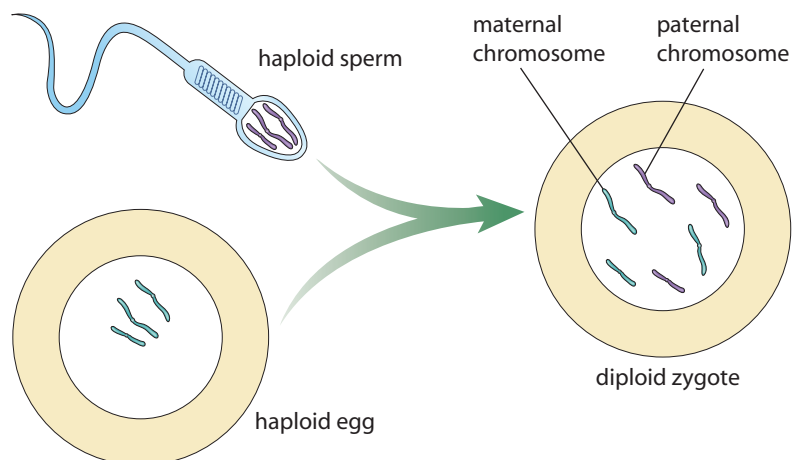
- 20 Describe the two key outcomes of meiosis.
- 21 In what ways does meiosis serve a different function than mitosis?
- 22 Where does meiosis take place?

Phases of Meiosis

Like mitosis, meiosis involves a precise sequence of events that can be grouped into four distinct phases: prophase, metaphase, anaphase, and telophase. Meiosis, however, involves two complete rounds of these phases, called **meiosis I** and **meiosis II**. Refer to Figure 16.11 on page 564 as you read through the following descriptions of the phases.

Interphase

Like somatic cells, **germ cells** (gamete-producing cells) proceed through the growth and synthesis phases of interphase before dividing. Recall, from Section 16.1, that chromosomes are replicated during the S phase of interphase. This also occurs before a germ cell begins meiosis. At the start of meiosis, therefore, a germ cell contains duplicated chromosomes. Each chromosome is made up of a pair of identical sister chromatids held together at the centromere.



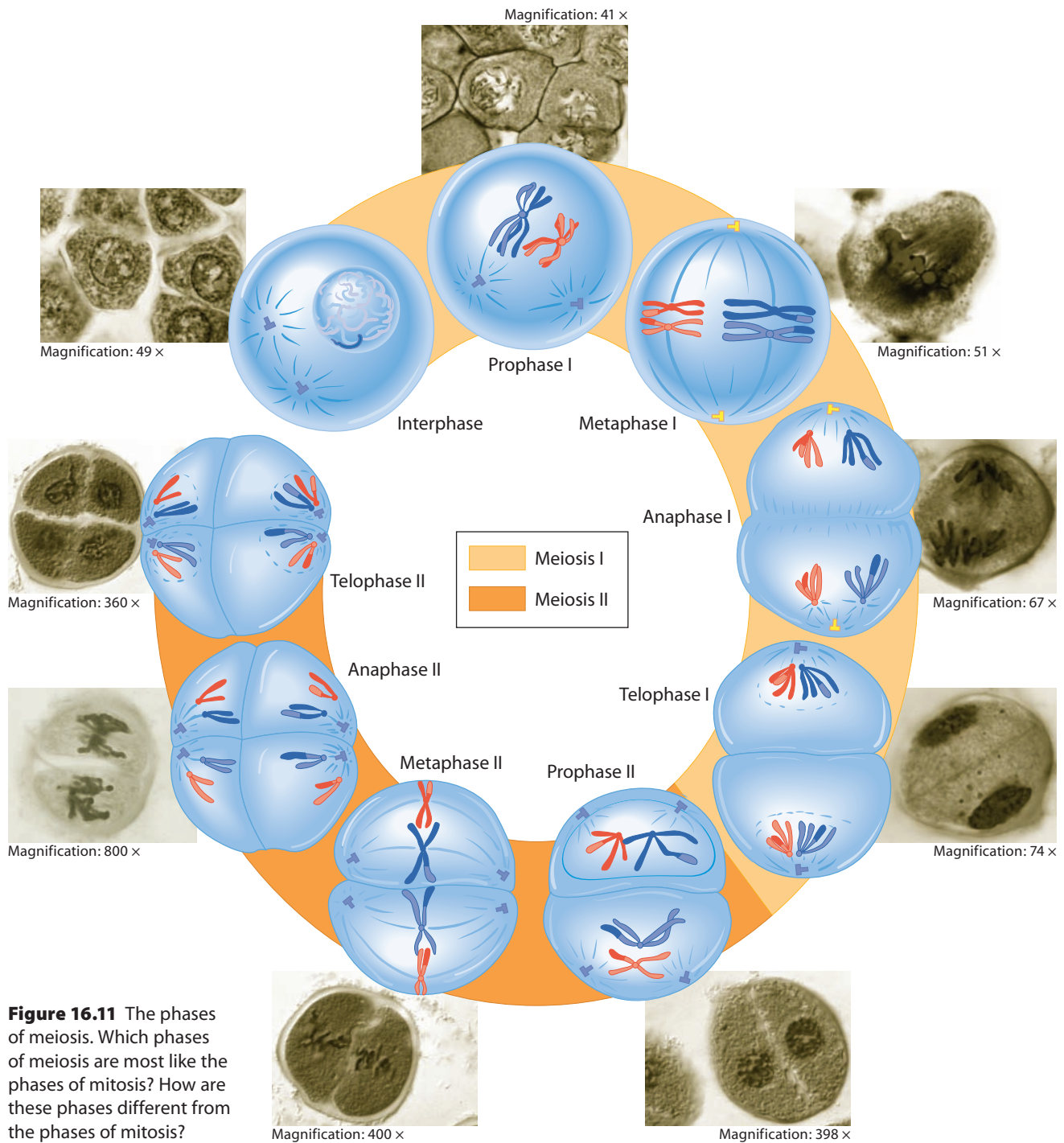


Figure 16.11 The phases of meiosis. Which phases of meiosis are most like the phases of mitosis? How are these phases different from the phases of mitosis?

Prophase I

In prophase I, each pair of homologous chromosomes align side by side. This aligning of homologous chromosomes is called **synapsis**. Recall that homologous chromosomes are not identical. Although they contain the same genes, the homologues carry different alleles of these genes. (You will learn more about alleles in Chapter 17.) At synapsis, homologous

chromosomes pair up. Because each consists of two chromatids, a pair of homologous chromosomes is made up of four chromatids and is called a **tetrad**.

As shown in Figure 16.12, each tetrad is made up of a pair of sister chromatids synapsed with another pair of sister chromatids. In the middle of a tetrad, two homologous but non-identical chromatids, which are called

non-sister chromatids, lie side by side. As you will find out later, this alignment of non-sister chromatids plays an important role in genetic recombination.

Metaphase I

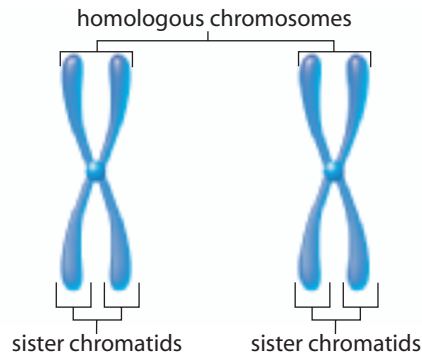
Following prophase I, a spindle fibre attaches to the centromere of each chromosome. A spindle fibre from one pole attaches to one pair of sister chromatids in the tetrad, and a spindle fibre from the opposite pole attaches to the other pair of sister chromatids. The spindle fibres guide each tetrad to the equator of the cell. The chromosomes, however, do not line up in single file as they do in mitosis. Instead, they line up as homologous pairs. In each pair, one homologous chromosome is positioned on one side of the cell's equator, and the other homologous chromosome is positioned on the other side of the cell's equator.

Anaphase I

During anaphase I, the spindle fibres shorten. This causes the homologous chromosomes to separate from one another. The homologues move to opposite poles of the cell. Because the sister chromatids are still held together, the centromeres do not split as they do in mitosis. The result is that a single chromosome (made up of two sister chromatids) from each homologous pair moves to each pole of the cell.

Telophase I

Some cells move directly from anaphase I to meiosis II (described below). Other cells go through telophase I following anaphase I. In telophase I, the homologous chromosomes begin to uncoil and the spindle fibres disappear. The cytoplasm is divided, the nuclear membrane forms around each group of homologous chromosomes, and two cells are formed. Each of these new cells contains one set of sister chromatids and is now haploid. Chromosome replication *does not* take place before the next phase of meiosis.



Meiosis II

The phases of meiosis II are similar to the phases of mitosis. Each cell proceeds through prophase II, metaphase II, anaphase II, and telophase II. Each cell that enters meiosis II is haploid but consists of replicated chromosomes. At the end of meiosis II, the daughter cells are still haploid, but they contain single unreplicated chromosomes.

Sources of Genetic Recombination

Mitosis results in the creation of daughter cells that are precise genetic copies of their parent cells. In contrast, the outcome of meiosis is the formation of genetically distinct haploid gametes. What processes create new combinations of genetic material in meiosis?

Remember that each diploid germ cell has two copies of each chromosome. One copy of this homologous pair was contributed by the female gamete (egg), so it is of maternal origin. The other chromosome was contributed by the male gamete (sperm), so it is of paternal origin. During meiosis, genetic variation is ensured in two ways: by the creation of gametes that carry different combinations of maternal and paternal chromosomes, and by the exchange of genetic material between maternal and paternal chromosomes.

Independent Assortment

During metaphase I, chromosomes are arranged in homologous pairs along the equator of the cell. In each pair, the chromosome of maternal origin is

Figure 16.12 A chromosome tetrad is made up of two pairs of non-sister chromatids arranged side by side. Homologous chromosomes carry the same genes at the same locations, but may carry different alleles of these genes. Sister chromatids, in contrast, are identical to each other.

BiologyFile

FYI

In early studies of meiosis, crossing over during meiosis was considered to be an "error." Scientists now know that it is a common event and an important contributor to genetic diversity.

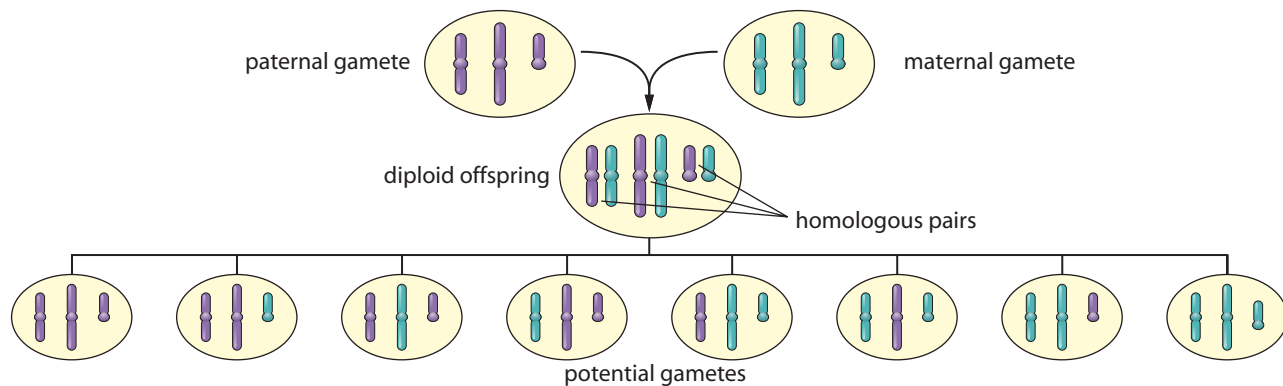


Figure 16.13 The diploid offspring has three chromosome pairs. The potential combinations of chromosomes produce eight genetically different gametes. A cell that has seven chromosome pairs can give rise to 2^7 or 128 different gametes.

oriented toward one pole of the cell while the chromosome of paternal origin is oriented toward the other pole. This orientation of each pair of homologous chromosomes is independent of the orientation of the other pairs. Therefore, some maternal homologues and some paternal homologues face each pole of the cell. As shown in Figure 16.13, the resulting gametes have different combinations of parental chromosomes.

Crossing Over

You have seen that homologous chromosomes synapse, or pair up, during prophase I. While they are lined up side by side, non-sister chromatids may exchange pieces of chromosome in a process known as **crossing over**. The process of crossing over is illustrated in Figure 16.14.

A section of chromosome that is crossed over may contain hundreds or even thousands of genes. As a result of crossing over, individual chromosomes contain some genes of maternal origin and some genes of paternal origin. Although only one example of crossing over is shown in Figure 16.14A, crossing over can occur at several points along non-sister chromatids, as shown in Figure 16.14B.

- 23 Describe the phases of meiosis I and meiosis II.
- 24 How is the outcome of meiosis different from the outcome of mitosis?
- 25 Distinguish independent assortment from crossing over.

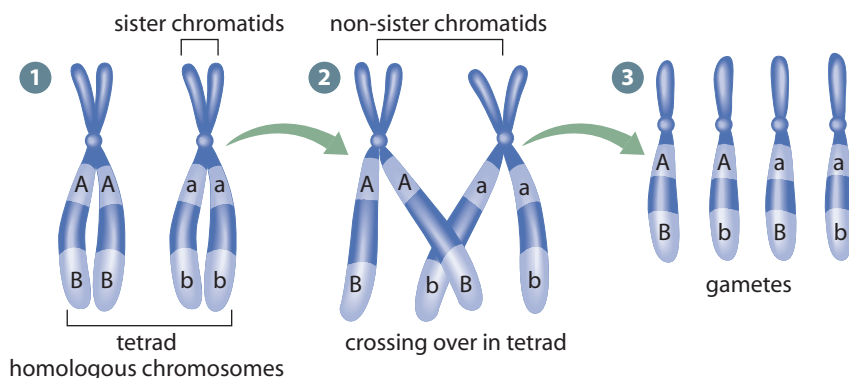
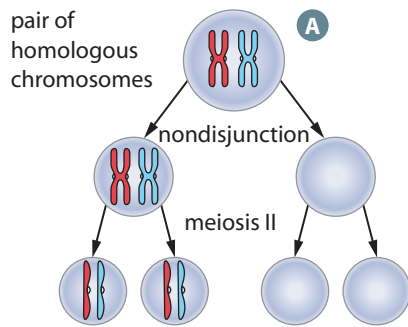


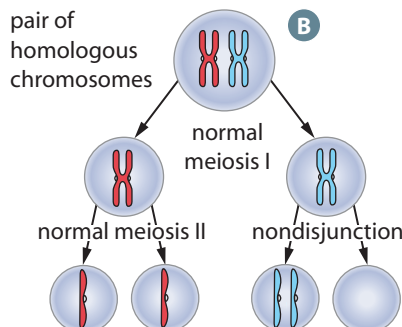
Figure 16.14 (A) Crossing over occurs at random between pairs of homologous chromosomes. In these chromosomes, upper-case and lower-case letters denote different alleles, or different versions of the same gene. (1) During prophase, homologous chromosomes form pairs. (2) Non-sister chromatids cross over each other and exchange segments of chromosomes. As a result, chromosomes in the gametes (3) contain new combinations of genetic material.



Figure 16.14 (B) Crossing over between non-sister chromatids can occur at several points simultaneously.



Abnormal gametes: two gametes have one extra and two gametes have one fewer chromosome than normal.



Gametes have usual number of chromosomes.

One gamete has one extra and the other has one fewer chromosome.

Figure 16.15 Nondisjunction results in gametes with too many or too few chromosomes. Nondisjunction may take place during anaphase I (A) or anaphase II (B).

Nondisjunction

Sometimes chromosomes or chromatids do not separate as they should during meiosis. This phenomenon is called **nondisjunction**. Nondisjunction occurs in anaphase I and II of meiosis.

- In anaphase I, nondisjunction occurs when homologous chromosome pairs do not separate to opposite poles; instead, one entire pair is pulled toward the same pole together.
- In anaphase II, nondisjunction occurs when sister chromatids do not separate to opposite poles; instead, both sister chromatids are pulled toward the same pole together.

As a result, nondisjunction produces gametes that have either too few or too many chromosomes (see Figure 16.15).

When one chromosome is lost due to nondisjunction, it is called *monosomy*. In this case, the gamete is missing one

chromosome of a homologous pair.

For example, individuals with Turner syndrome are missing an X chromosome. Individuals who have this disorder have female sexual characteristics which are underdeveloped.

Conversely, nondisjunction can also result in *trisomy*—the gain of an extra chromosome. Trisomy occurs in Down syndrome, a condition in which individuals are born with an extra chromosome 21. The characteristics of Down syndrome include impairment of physical growth, below-average cognitive ability, and the development of certain physical features such as almond-shaped eyes and an enlarged tongue. Infants with Down syndrome are also more likely to have congenital (present at birth) heart defects. The incidence of nondisjunction increases with age. For example, the chance of conceiving a child

BiologyFile

Try This

Down syndrome results from nondisjunction of chromosome 21. Use Figure 16.15 to determine the ways in which trisomy could occur in a zygote.

Thought Lab 16.1 Nondisjunction Syndromes

The table shows the chromosomal basis for various syndromes (disorders) involving nondisjunction. Most of these are rare in the human population. Choose one syndrome that you have not read about and conduct research about it using the library or the Internet. Present your findings in a print or electronic multimedia format. **ICT**

Analysis

1. What is the frequency of the syndrome you studied?
2. How does the syndrome occur?
3. Describe the technologies that are used to diagnose the syndrome. What, if any, treatments are there? What is involved in the treatment?

Target Skills

Working co-operatively for a presentation of nondisjunction syndromes

Syndrome	Sex	Chromosomes
Down	M or F	trisomy 21
Patau	M or F	trisomy 13
Edward	M or F	trisomy 18
Turner	F	XO
Triplo-X	F	XXX (or XXXX)
Klinefelter	M	XXY (or XXXY)
Jacobs	M	XYY

with Down syndrome is 1 in 1490 between ages 20 to 24 and increases to 1 in 106 at age 40. At age 49, the chance increases to about 1 in 11.

26 Describe nondisjunction, and outline the difference between monosomy and trisomy.

Gamete Formation in Animals

The products of meiosis are haploid gametes. In many organisms, the gametes are sperm and eggs. The process of sperm production is called **spermatogenesis**, and the process of egg production is called **oogenesis**. While both of these processes involve meiosis, they take place in slightly different ways, as illustrated in Figure 16.16.

INVESTIGATION

16.C

Target Skills

Designing a model to simulate the behaviour of chromosomes during mitosis and meiosis

Comparing mitosis and meiosis

Modelling to Compare Meiosis and Mitosis

You have seen that meiosis and mitosis have many similarities. They also have important differences. In this investigation, you will create a model of a cell that undergoes mitosis and meiosis. Then you will use your model to describe the different phases of each type of cell division.

Problem

How can you design a model to show a cell that is undergoing mitosis and meiosis?

Design Specifications

1. Work in a small group. With your group, examine the following design specifications:
 - You are modelling a germ cell from the testes of a male diploid organism. The haploid number of chromosomes in this organism is 4 (that is, $2n = 8$).
 - Your model must be able represent the changes that take place in the germ cell and in its chromosomes as it divides to produce two identical germ cells, one of which then divides to produce four non-identical gametes.
 - Your model must be able to represent at least one mechanism that ensures genetic variation among the gametes.

Plan and Construct

1. Brainstorm options for a model that meets the design specifications. Be creative—for example, your group could build a clay model, create a computer simulation, or perform a play. Make a list of your ideas, and decide on the model you will use.

2. Design your model.
3. Prepare an assessment plan for your model. That is, how will you know if your model is successful at meeting the design specifications? What features will make it a useful model for explaining cell division?
4. Review your model design and assessment plan with your teacher. Then assemble the materials you will need, and create your model.
5. Present your model to your class.

Evaluate and Communicate

1. Using the assessment plan you prepared, evaluate your model and presentation. How effectively do you think your model and presentation described mitosis and meiosis?
2. Evaluate the presentations by other groups in your class. What are the features of the most effective models?
3. After seeing all the presentations, what changes (if any) would you make to your own model? Explain your reasons.
4. In what ways are the outcomes of meiosis suited to the production of gametes, but not to the purposes of the cell cycle? Explain your answer using your model as a reference. How is mitosis better suited for these purposes?

Spermatogenesis

In most male animals, meiosis takes place in the testes. As you can see from Figure 16.16, the process of spermatogenesis starts with a diploid germ cell called a **spermatogonium**. Beginning at puberty, spermatogonia are stimulated to divide by mitosis to form two daughter cells. One of these cells replenishes the spermatogonia cell population, and the other develops into a **primary spermatocyte**. The primary spermatocyte undergoes meiosis I to form two **secondary spermatocytes**. The secondary spermatocytes then undergo meiosis II to form four **spermatids**.

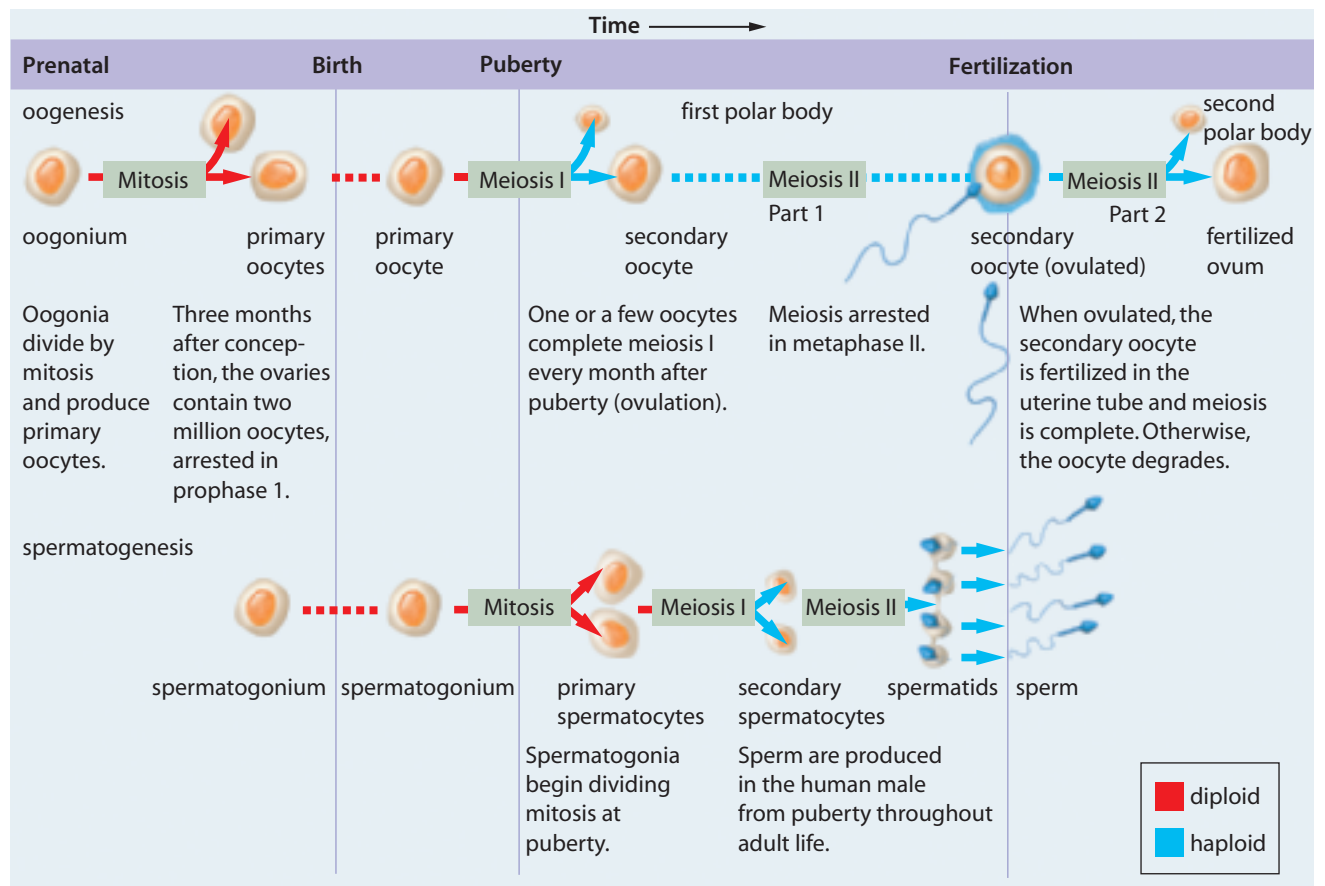
Following meiosis II, the spermatids go through a final set of developmental stages in order to develop into mature sperm. The nucleus and certain enzymes are organized into a “head” region. The midsection holds many mitochondria, which serve as an energy resource for the cell. Finally, a long tail-like flagellum develops for locomotion.

Some animals, including most mammals, produce sperm throughout the year. Other animals produce sperm only during a specific breeding season. Hundreds of millions of sperm are released in a single ejaculation, so meiosis is constantly occurring. Mitosis is also occurring regularly to keep a supply of germ cells for gamete production.

Oogenesis

In female animals, meiosis takes place in the ovaries. As shown in Figure 16.16, oogenesis starts with a diploid germ cell called an **oogonium**. Each oogonium undergoes mitosis to form two primary oocytes. About three months after conception, two million primary oocytes can be found in the ovaries. They are arrested in prophase I and remain that way until puberty. Every month after puberty, one **primary oocyte** undergoes meiosis. In contrast to spermatogenesis, however, oogenesis involves an unequal division of cytoplasm, known as

Figure 16.16 The processes of spermatogenesis and oogenesis in mammals. This illustration is not drawn to scale. In reality, the diameter of the egg is about 20 times greater than the length of the sperm head.



asymmetrical cytokinesis. At the end of meiosis I, the cytoplasm is not equally divided between the two daughter cells. The cell that receives most of the cytoplasm is called the **secondary oocyte**. The other cell is called the **first polar body**. The first polar body may or may not go through a second division to produce a pair of second polar bodies. In either case, the polar bodies are not functional and soon degenerate.

When the secondary oocyte undergoes meiosis II, the cytoplasm is again unequally divided. The cell that contains most of the cytoplasm will eventually become a mature egg, or ovum. The other cell, another **second polar body**, is not a viable gamete.

The unequal division of cytoplasm means that only one egg cell is produced from the division of the secondary oocyte. This egg cell, however, contains a large quantity of nutrients that the zygote can use prior to implantation.

The processes of meiosis I and meiosis II are not always continuous. In human females, more than a decade separates the events of meiosis I and meiosis II. The primary oocytes begin meiosis I before birth, but cell division stalls in prophase I. The cells remain in this suspended state until puberty. At puberty, a hormone signal triggers a single primary oocyte to resume meiosis. The primary oocyte completes meiosis I. The secondary oocyte is then released from the ovary and travels down the Fallopian tube.

The secondary oocyte is arrested at metaphase II until fertilization occurs. If the secondary oocyte does not come into contact with a sperm cell, it will not complete a second meiotic division. If it does come into contact with a sperm cell and fertilization occurs, it will complete meiosis II. The product of this second meiotic division is the ovum, or egg cell, and a second polar body. The haploid nucleus of the egg cell then fuses with the haploid nucleus of the sperm cell to

complete fertilization and create a diploid zygote.

As you know from your study of the menstrual cycle (see Chapter 14), in most cases only one primary oocyte undergoes this process each month. The production of egg cells continues at a rate of about one per month from the start of puberty until menopause, which usually occurs between 40 and 50 years of age. Thus, a human female will produce about 400 gametes in her lifetime.

27 Identify key similarities and differences between spermatogenesis and oogenesis.

28 How does the process of asymmetrical cytokinesis help to ensure a healthy zygote?

29 How does the timing of spermatogenesis differ from the timing of oogenesis? In what way is the timing of these processes suited to their functions?

Cell Division and the Conception of Twins

As you know, the fusion of one ovum and one sperm creates a single zygote. Sometimes, however, a woman gives birth to more than one baby at once. In humans, twins occur in slightly more than one percent of all births. As you can see in Figure 16.17, *fraternal twins* are no more alike than any other siblings, while *identical twins* are genetically identical to one another (but not to either parent).

While most women release only a single secondary oocyte at each ovulation, occasionally more than one secondary oocyte may be released. If both of these oocytes are fertilized and successfully implant in the uterus, fraternal twins may be born. On the other hand, if a single zygote or blastocyst divides into two separate bodies in the first few days of embryonic development, identical twins may be



Figure 16.17 Fraternal twins (A) and identical twins (B)

born. About 30 percent of all human twins are identical.

30 Explain how the development of fraternal twins is different from the development of identical twins.

Applying Knowledge of Meiosis

An understanding of meiosis is clearly important to the study of reproduction and development. As shown in Figure 16.18, cell biologists can put their understanding of meiosis to work in the field—literally.

Animal cells do not usually survive if they contain extra chromosomes. In contrast, polyploidy is common in plants. Polyploid plants often produce larger flowers or fruit than their diploid counterparts do. As well, they may have other commercially valuable features, such as the “seedless” fruit of the watermelon shown in Figure 16.18.

An ordinary watermelon (*Citrullis lanatus*) is diploid ($2n$), and its gametes are haploid (n). Using chemicals that cause nondisjunction, biologists can create tetraploid ($4n$) watermelons, which produce diploid ($2n$) gametes. A cross between a $4n$ watermelon and a $2n$ watermelon produces a triploid ($3n$)

watermelon zygote. This zygote divides by mitosis to form an adult watermelon plant. The $3n$ plant develops fruit, but the extra pair of homologous chromosomes means that the required synapsis of homologous chromosomes cannot take place at metaphase I. Meiosis does not proceed, so the watermelon does not create viable seeds.

Section 16.3 Summary

- The process of meiosis involves two nuclear divisions, which create haploid gametes from diploid parent cells.



Figure 16.18 If a watermelon plant does not complete meiosis, it will produce only rudimentary seeds. “Seedless” fruit, such as this watermelon, are popular consumer products. In what other ways could scientists apply their understanding of meiosis?

- Two key features of meiosis contribute to genetic variation: (1) The pairing of homologous chromosomes allows for crossing over, which results in the exchange of chromosome sections between non-sister chromatids. (2) The independent assortment of homologous chromosomes during metaphase I results in gametes that have different combinations of parental chromosomes.
- Nondisjunction occurs when chromosomes fail to separate correctly during one of the anaphase divisions of meiosis.
- Different meiotic processes result in the production of human sperm and eggs.
- An understanding of meiosis can be applied to develop modified forms of living organisms with useful attributes.

Section 16.3 Review

1. What two main functions does meiosis accomplish?
2. Where does meiosis take place?
3. At the end of meiosis II, how many haploid cells have been formed from the original parent cell?
4. A diploid organism has four pairs of chromosomes in each somatic cell. Assuming that no crossing over occurs, how many genetically distinct gametes can this organism produce?
5. Explain what you think is happening in the following image. Why is this significant?
6. Compare and contrast the two terms in each pair of terms.
 - a) nondisjunction and crossing over
 - b) primary oocyte and secondary oocyte
 - c) spermatid and sperm cell
 - d) oocyte and polar body
7. A human germ cell in interphase has 23 pairs of chromosomes. If this cell undergoes cell division, how many chromosomes are found in each of the following phases? Indicate whether the chromosomes are found as linked sister chromatids, single chromatids, or homologous pairs.
 - a) metaphase (mitosis)
 - b) metaphase I (meiosis)
 - c) metaphase II (meiosis)
8. Is it possible for identical twins to be different sexes? Explain in terms of the cellular processes that result in identical twins.
9. In what stage of meiosis do chromosome tetrads align at the cell equator? What feature of this alignment contributes to genetic diversity?
10. The karyotype of a young woman shows that she is missing one X chromosome. Draw or describe the sequence of events that made this occur.



Magnification: 5187 ×

SECTION 16.4

Reproductive Strategies

Section Outcomes

In this section, you will

- **describe** the diversity of reproductive strategies among living organisms
- **evaluate** the advantages and disadvantages of sexual and asexual reproduction
- **research** and **present** information about contrasting reproductive strategies
- **assess** how research on plant and animal reproduction has affected the development of new reproductive technologies

Key Terms

asexual reproduction
sexual reproduction
binary fission
conjugation
pilus
budding
vegetative reproduction
fragmentation
parthenogenesis
spore
alternation of generations
sporophyte
gametophyte

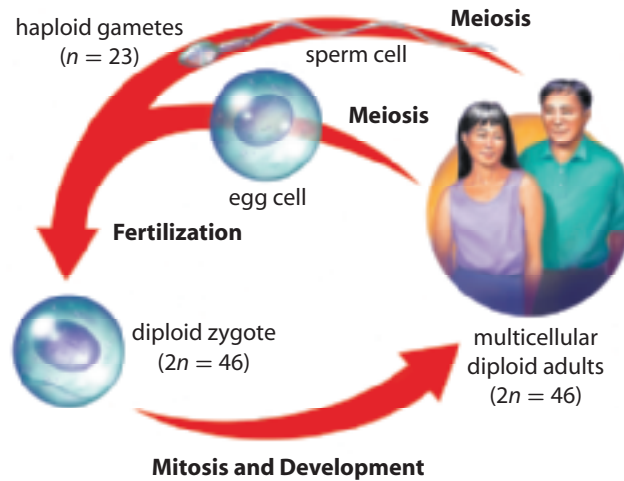


Figure 16.19 The human life cycle is based on a regular pattern of meiosis and mitosis.

In the preceding sections, you learned how mitosis and meiosis work as separate processes in individual cells. In this section, you will learn how these two forms of cell division operate within the life cycle of different organisms. In general, mitosis is the key mechanism involved in **asexual reproduction**, the reproductive process in which a parent organism produces genetically identical offspring. **Sexual reproduction** involves the production of gametes by meiosis, followed by fertilization between genetically distinct parental gametes to produce genetically distinct offspring.

The life cycle of many organisms includes a regular sequence of both forms of cell division. Figure 16.19 illustrates how mitosis and meiosis alternate in the human life cycle. Humans can only reproduce sexually, and the diploid individual is the only life stage that has the capacity for independent existence. While most animals have a similar life cycle, other organisms have a wide variety of life cycles.



31 Distinguish asexual reproduction from sexual reproduction.

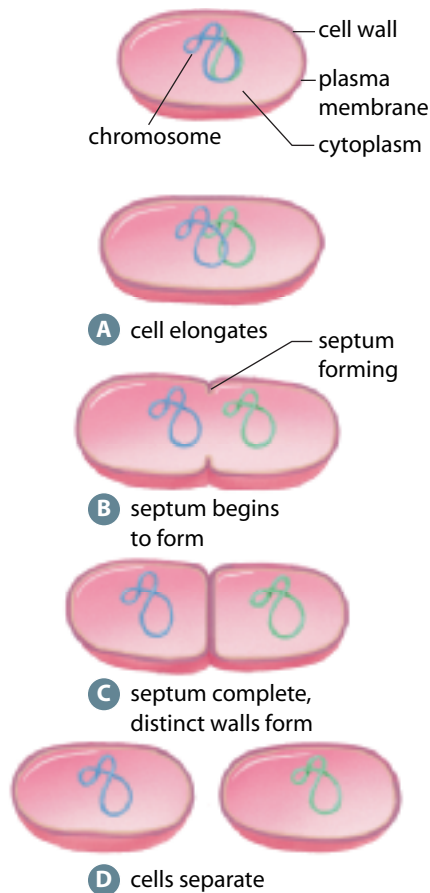
Reproduction in Prokaryotes

Like a human somatic cell, a bacterial cell reproduces by replicating its DNA and then distributing one complete copy of its DNA into each of two identical daughter cells. Bacteria and other prokaryotes, however, have a single, circular chromosome and no nucleus. Therefore, a bacterial cell does not undergo mitosis. Instead, it reproduces through a form of cell division called **binary fission**. The stages of binary fission are illustrated in Figure 16.20.

In favourable conditions, a bacterial cell can divide in as little as 20 min. Each new cell can then grow and produce two more cells 20 min later. This sequence of repeated doubling is called *exponential growth*. It allows bacteria to produce huge populations in a fairly short time. However, these populations are genetically identical. If one cell is vulnerable to a particular toxin or virus, then every cell in the colony will also be vulnerable to the same toxin or virus.

Some bacteria are able to reproduce by a process called **conjugation**. Conjugation involves the transfer of genetic material from one cell to another by cell-to-cell contact through a bridging structure called a **pilus** (plural: pili), as shown in Figure 16.21.

Figure 16.20 Binary fission in a bacterial cell. Binary fission begins with the attachment of the circular bacterial chromosome to the cell wall. As the chromosome replicates, the new chromosome also attaches to the cell wall. The elongation of the cell and the formation of a septum then separates the two chromosomes. Cell division results in two genetically identical daughter cells.



Conjugation creates cells with new genetic combinations, and thereby provides a chance that some cells may be better adapted to changing conditions. It can only take place between non-identical bacterial cells, however. It creates only a single genetically unique daughter cell, but this new cell can undergo binary fission to create a colony of cells. Later, you will see how the processes of genetic recombination and reproduction in bacteria can be used as a tool in genetic engineering.

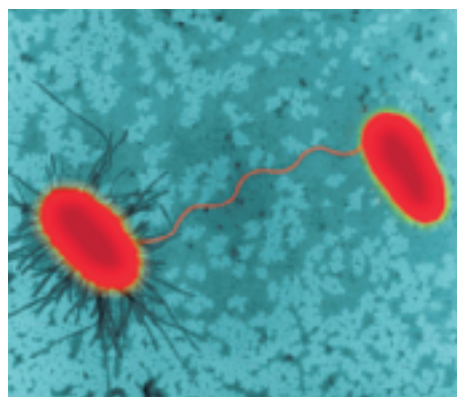


Figure 16.21 During conjugation, one bacterium transfers all or part of its chromosome to another bacterium. The receiving bacterium then undergoes binary fission. Some eukaryotes, including certain algae and fungi, are also capable of conjugation.



Figure 16.22 This *Hydra* is reproducing by budding. The species can also reproduce sexually.

- 32 In what ways does the asexual reproduction of prokaryotic cells differ from mitosis?
- 33 In what ways does conjugation differ from sexual reproduction?

Asexual Reproduction

Some organisms can reproduce asexually by budding. **Budding** is a form of asexual reproduction in which a complete but miniature version of the parent grows out from the parent's body. The new organism then separates to become an independent organism. Figure 16.22 shows an example of budding in *Hydra*.

A similar form of asexual reproduction, called **vegetative reproduction**, takes place in many plants. For example, strawberry plants can spread across a garden by extending thin creeping stems. A new strawberry plant develops at the end of each stem. Once the new plant has taken root, the stem disintegrates, separating the new plant from its parent.

Another form of asexual reproduction involves the creation of new plants from a fragment (portion) of a parent plant. This process is called **fragmentation**. In the cultivation of potatoes, for example, entire new plants are grown from a fragment, or tuber, of a parent plant. Gardeners rely on fragmentation to propagate new garden plants from cuttings (see Figure 16.23).

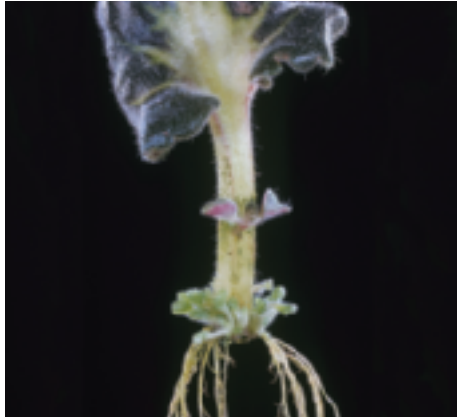


Figure 16.23 In many plant species, even a small fragment of a leaf can develop roots and grow into a complete new plant.

34 Describe two ways that plants can reproduce asexually.

Parthenogenesis

Asexual reproduction is less common in animals than in plants. Many animals, however, are capable of some forms of asexual reproduction. Some animals, such as sea stars, can reproduce by fragmentation. Other animals can reproduce through **parthenogenesis**, a form of asexual reproduction in which an unfertilized egg develops into an adult. In honeybees, for example, the queen bee lays both fertilized and unfertilized eggs. The fertilized eggs develop into female worker bees, while the unfertilized eggs develop into male drones. The whiptail lizard (*Cnemidophorus neomexicanus*), is another animal that reproduces by parthenogenesis.

35 Why is parthenogenesis a form of asexual reproduction?

Spores

Many forms of asexual reproduction require that the offspring develop close to or in contact with the parent. While this enables the offspring to take advantage of a favourable environment, it limits the organism's ability to spread

quickly to more distant environments. Several different species have evolved a mechanism to reproduce asexually and disperse their offspring long distances. A **spore** is a structure that contains genetic material and cytoplasm surrounded by a protective sheath or wall. The wall protects the contents until conditions are favourable, at which point the spore wall opens and the organism begins to develop. Because spores tend to be very small, they are readily dispersed in water and by the wind (see Figure 16.24).

Spores may be haploid or diploid, and not all spores are the product of asexual reproduction. Some organisms produce spores by meiosis, resulting in an alternation of generations.

36 What are spores?

Alternation of Generations

Imagine what the world might be like if humans gave birth to sperm and eggs, which then grew up and had lives of their own before mating to create a new diploid baby. Something much like this is happening in fields, forests, and gardens all around you. The life cycle of plants consists of two generations: a haploid generation and a diploid generation that alternate. This is called **alternation of generations**. Figure 16.25 illustrates the



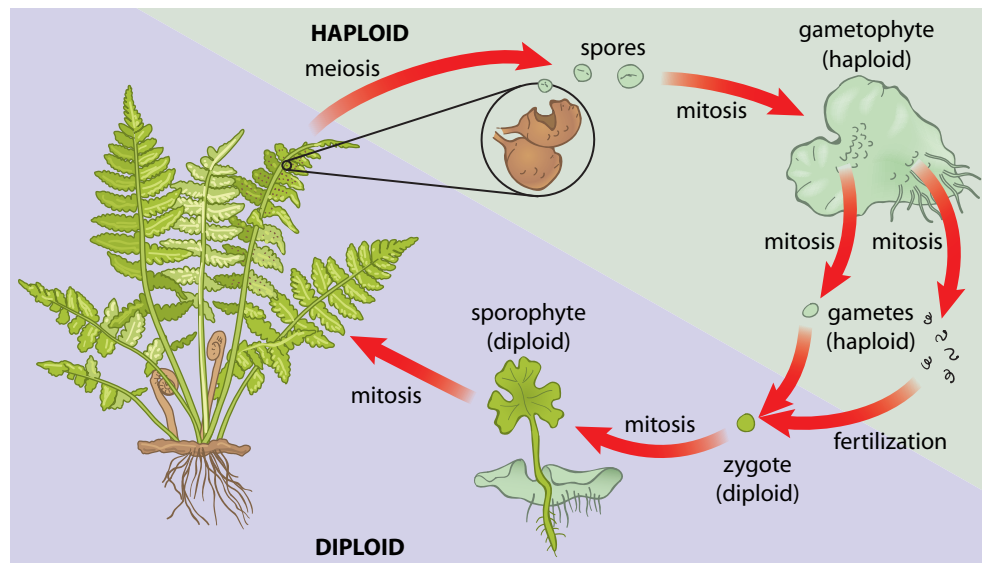
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Some species of reptiles, amphibians, and fish are able to reproduce naturally by parthenogenesis. As well, biologists can induce parthenogenesis in some species, including some mammals. What new fields of research have opened up as a result of research on parthenogenesis? Which field do you think is the most interesting?

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Figure 16.25 The life cycle of a fern, like all plants, consists of the alternation of generations of diploid sporophytes and haploid gametophytes.



basic components of the alternation of generations.

The diploid generation of a plant is called the **sporophyte** (spore-making body). Through the process of meiosis, the sporophyte produces one or more haploid spores. These spores develop without fertilization. Each haploid spore grows into a plant body called the **gametophyte** (gamete-making body). Gametophytes produce male and female gametes, which fuse at fertilization and develop into another sporophyte. The cycle then repeats.

Although all plant life cycles include a sporophyte generation and a gametophyte generation, one generation or the other is characteristically dominant in different plant groups. The non-dominant generation is often either a temporary structure or a much smaller component attached to the dominant generation. As described below, the dominant generation in vascular plants (plants that have a transport system of conducting tubes) is the diploid sporophyte. The dominant generation in non-vascular plants, such as mosses, is the haploid gametophyte.

Mosses

The alternation of generations is easy to observe in mosses (Figure 16.26). The leafy green mat that is characteristic of mosses is the gametophyte. At certain

times of the year, a stalk grows up from this mat. This stalk is the sporophyte, and spores are cast from its cap. These spores fall on the ground and develop into the leafy gametophyte. Special structures within the gametophyte produce sperm and eggs. The sperm swim to the eggs and fertilize them. Each fertilized egg then develops into a new stalk. Because the sperm must swim to the eggs, mosses can only grow in environments that are moist for at least part of the year.

Conifers

In conifers, such as a pine tree (*Pinus* sp.), the tree itself is the diploid sporophyte (Figure 16.27 on page 578). The haploid gametophytes are microscopic structures within the male and female cones that are produced by the tree. The single-celled female gametophyte develops from a spore that is produced by a specialized structure at the top of each scale of the female cone. (The female cone is the larger, woody cone that most people think of as the pine cone.) The female gametophyte remains inside the spore-producing structure.

The male gametophyte is produced by a structure that is found on the male cone. (The male cone is much smaller than the female cone.) The male gametophyte is released in the pollen

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Conjugation is sometimes described as a form of sexual reproduction. It differs from sexual reproduction, however, because there is no formation or fertilization of gametes. As well, conjugation does not produce any new cells. Instead, it adds new genetic information to an existing cell.

that is cast by the male cones. The pollen is dispersed by the wind. If the pollen reaches a female cone, sperm from the gametophyte will grow and fertilize the egg within the female gametophyte. The fertilized zygote forms a seed that is attached to the scale of the female cone.

Alternation in Sexual Cycles

Strictly speaking, the term “alternation of generations” refers to the alternation of diploid and haploid generations. This reproductive strategy is found only in plants. Some animal life cycles, however, alternate between asexually-reproducing and sexually-reproducing phases. For example, the phylum Cnidaria includes jellyfish, sea anemones, and corals. Most of the animals in this phylum alternate reproductive phases. The life cycle of

these organisms is characterized by two distinct adult forms: a non-motile *polyp* and a free-swimming *medusa*. The characteristic cnidarian life cycle is illustrated in Figure 16.28.

The cnidarian life cycle varies from species to species within this class. In jellyfish, the medusa stage is dominant or exclusive. In sea anemones, the polyp stage is dominant or exclusive. The species *Obelia* alternates regularly between an asexual polyp form and a sexual medusa form.



What is the difference between the alternation of generations and the alternation of reproductive cycles?

Figure 16.26 The life cycle of moss. The moss gametophyte produces gametes that join to form a zygote. The zygote develops into the sporophyte that produces spores. Spores can germinate and grow into a gametophyte, completing the life cycle.

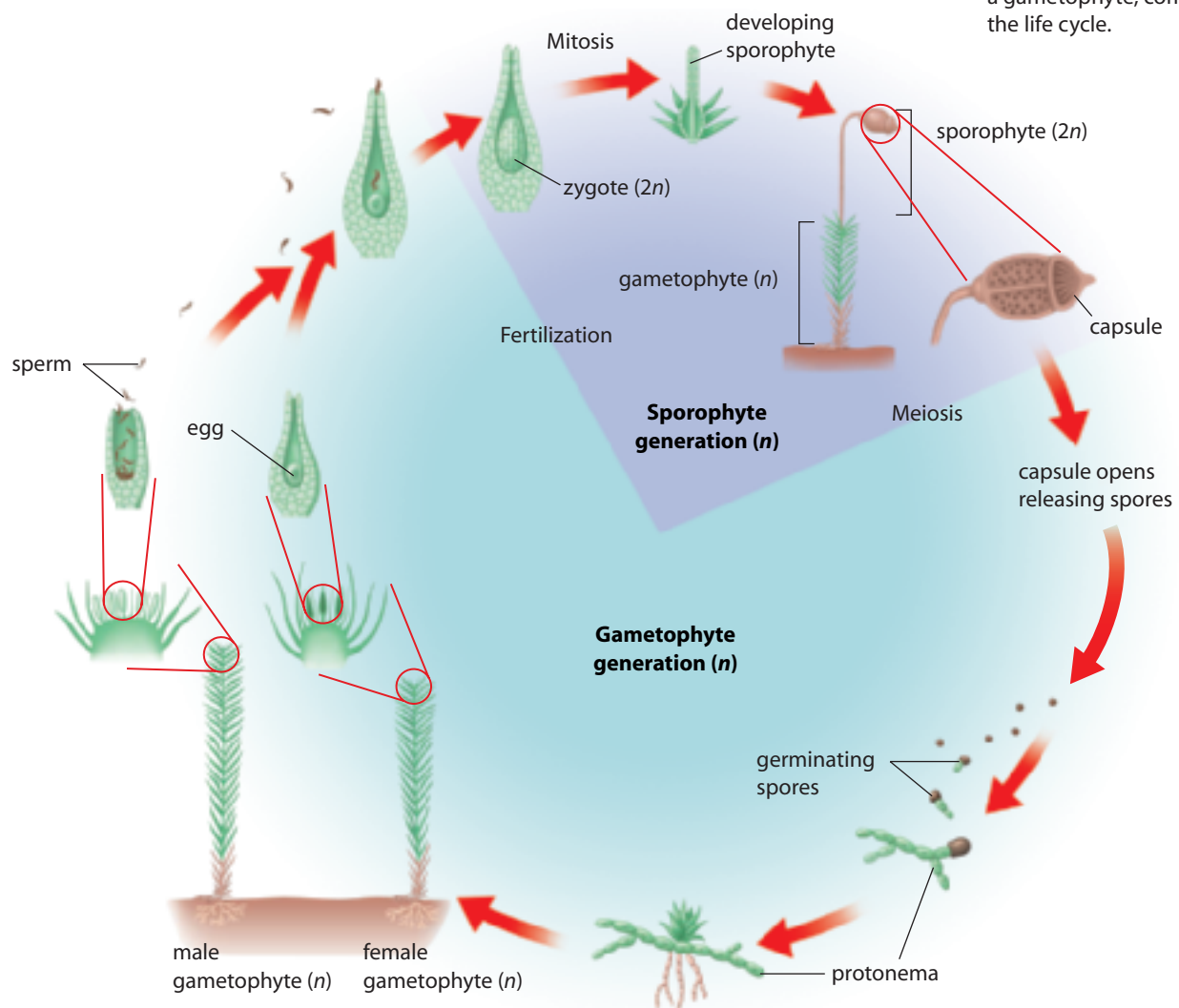
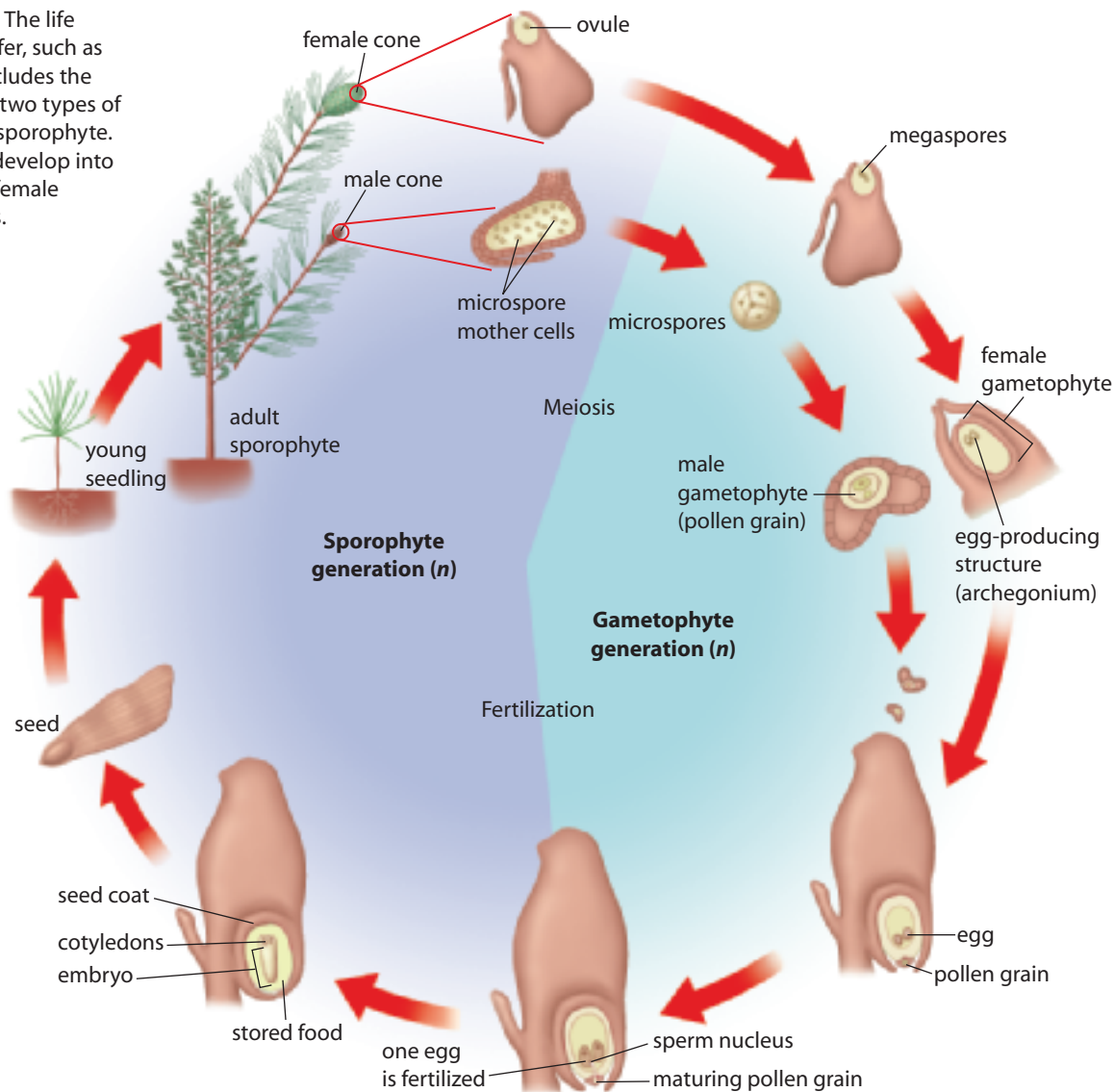


Figure 16.27 The life cycle of a conifer, such as a pine tree, includes the production of two types of spores by the sporophyte. These spores develop into the male and female gametophytes.



Advantages and Disadvantages of Reproductive Strategies

Almost all organisms are capable of some form of sexual reproduction. There is no consensus among evolutionary biologists, however, on how sexual reproduction first arose. While sexual reproduction offers an opportunity for genetic variation, this variation may not always be helpful to a well-adapted organism. If an organism is well-suited to its environment, there is always the possibility that offspring with new characteristics may, in fact, be less well-adapted to this environment than its parents are.

There are three potential advantages of sexual reproduction:

- Sexual reproduction offers a population a way to adapt to a changing environment. At least some offspring, for example, may have a greater ability to resist parasites or toxins in the environment or to take advantage of new food sources.
- Competition among siblings may be reduced if they are genetically diverse.
- Pairing of homologous chromosomes and crossing over offer opportunities to replace or repair damaged chromosomes.

Asexual reproduction also offers certain advantages:

- Asexual reproduction often proceeds more quickly than sexual reproduction, and it does not require the presence of a second parent organism.

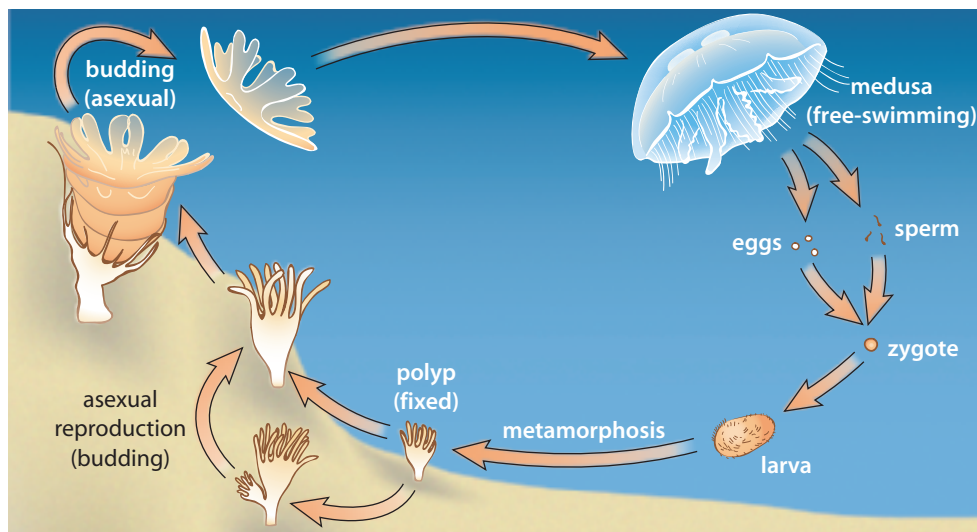


Figure 16.28 A generalized representation of the cnidarian life cycle. Not all cnidarians alternate adult forms like this, but most cnidarians can reproduce both sexually and asexually.

- Asexual reproduction usually requires less energy than sexual reproduction.
- Many forms of asexual reproduction, such as vegetative reproduction and budding, help to maximize the chances that individual offspring will survive. In these forms of asexual reproduction, the daughter organism does not fully separate from the parent until it is capable of independent survival.

Do organisms that alternate generations or reproductive phases have the best of both worlds? Some biologists think so. Asexual reproduction offers an opportunity to make the most of favourable conditions, while sexual reproduction offers a way to adapt to change.

Whether sexual or asexual, all forms of reproduction share a common purpose: the addition of new individuals to a

Thought Lab 16.2 Comparing Reproductive Strategies

Target Skills

Researching reproductive strategies in a variety of organisms

Presenting research results in a suitable form (such as a chart, table, or diagrams)

As you have seen, there are many different forms of reproduction. In this Thought Lab, you will create a table or another form of concept organizer to describe, analyze, and communicate the advantages and disadvantages of two different strategies.

Procedure

1. In small groups, select two organisms that have different forms of reproduction. You can select two organisms described in this textbook, or use a library or the Internet to select two organisms.
2. Write brief descriptions or draw simple diagrams to illustrate the life cycles of these organisms. Then brainstorm a list of potential advantages and disadvantages of each strategy. Try to think of the advantages and disadvantages for an individual organism and for the population as a whole.
3. Prepare a table or another form of concept organizer to present your findings.
4. Summarize your findings in a brief concluding statement. Then present your concluding statement to the class.

Analysis

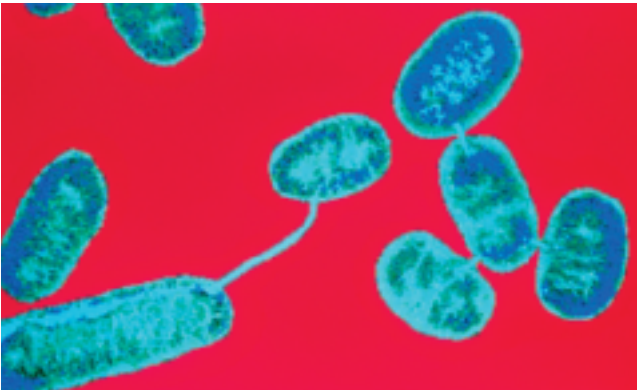
1. Did all groups come to similar conclusions? How could you account for any differences?
2. Is there one reproductive strategy that is clearly better than the others? Explain your answer.
3. Suppose that you wanted to create a new species (plant or animal) that would live in your classroom.
 - a) What form of reproduction would you choose for your species?
 - b) Prepare a description or illustration that shows how the life cycle of your species works. Make sure that this life cycle can carry on over time.
 - c) Explain how the form of reproduction you chose would benefit your organism, given the environment in which it will exist.

population. Each of these new individuals carries a set of genetic instructions that determines how members of the species will grow and develop. This set of instructions is passed from one generation to the next in an unbroken line that extends back to the origins of life on Earth. In the next chapter, you will study the patterns of inheritance that maintain the continuity of life.

Section 16.4 Summary

- Prokaryotes reproduce through a form of cell division called binary fission.
- Asexual reproduction is the creation of offspring through the mitosis. Examples of asexual reproduction include budding, fragmentation, and parthenogenesis.
- Offspring that arise from asexual reproduction are genetically identical to the parent organism.
- Conjugation in bacteria produces organisms with new genetic combinations.
- Sexual reproduction involves meiosis to create haploid gametes, followed by fertilization to produce a new and genetically unique diploid organism.
- Many organisms are capable of both sexual and asexual reproduction.
- Plants reproduce vegetatively and have a sexual life cycle that features the alternation of haploid and diploid generations.
- Some animals are capable of both asexual and sexual reproduction, and may shift strategies in response to changing environmental conditions.
- Sexual reproduction and asexual reproduction have different advantages and disadvantages. One of the key advantages of sexual reproduction is the creation of genetic variation.

Section 16.4 Review

1. Give two examples of different forms of asexual reproduction.
 2. What form of reproduction is shown in the following image? In what kind of organism would you expect to see this form of reproduction?
- 
- Magnification: 14700 ×
3. In what way is fragmentation similar to budding? In what way are the two forms of reproduction different?
 4. In one species of fish, the females lay eggs that are not fertilized. The eggs hatch and develop into adult fish.
 - a) What is the name of this form of reproduction?
 - b) What proportion of the offspring are likely to be male? Explain.
 5. Draw a diagram that illustrates the life cycle of a mammal. Use the following terms to label your diagram: haploid phase, diploid phase, meiosis, mitosis, fertilization, zygote. (You may need to use some of these terms more than once.)
 6. How are the life cycle of a moss and the life cycle of a pine tree similar? How are they different?
 7. What reproductive advantage does a spore offer over vegetative reproduction?
 8. Briefly explain two advantages and two disadvantages of a life cycle that requires sexual reproduction.
 9. Sea anemones can reproduce asexually by budding and sexually by means of fertilized eggs, which hatch into larvae. Adult sea anemones exist only as polyps, which remain fixed in one location. Their larvae, however, are free-swimming. Explain how sexual reproduction could help a population of sea anemones overcome a toxic-waste spill.

Many somatic cells go through a continuous sequence of growth and division: the cell cycle. New cells have the same structure and function as their parent cells. Cell structure and function are determined by genetic information carried on the chromosomes in the cell nucleus.

Each species has a characteristic number and arrangement of chromosomes: the karyotype. Each diploid human somatic cell contains 22 pairs of autosomes and a pair of sex chromosomes. Human females have two X chromosomes; human males have one X and one Y chromosome.

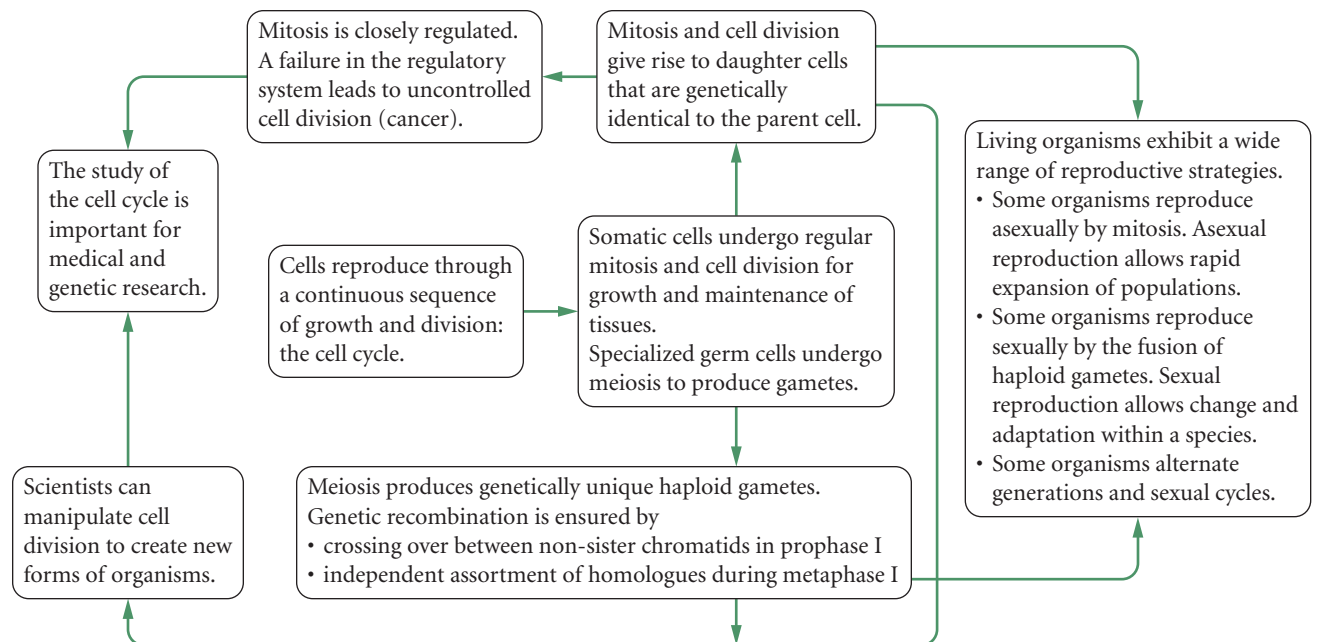
The cell cycle can be broken into a phase of growth and metabolic activity called interphase and a phase of division. The reproduction of somatic cells takes place through mitosis: a single parent cell gives rise to two new daughter cells that are genetically identical to the parent cell. Before a cell begins mitosis, all its genetic information is duplicated. Each chromosome replicates to form a pair of identical sister chromatids joined at the centromere. The process of mitosis can be broken into four general phases: prophase, metaphase, anaphase, and telophase. Mitosis is followed by

cytokinesis, the division of the cytoplasm to produce two separate cells.

Meiosis is the cellular process that produces haploid gametes from diploid somatic cells. Meiosis proceeds through two complete rounds of nuclear division. Meiosis provides for two different sources of genetic recombination: crossing over between non-sister chromatids and the independent assortment of maternal and paternal chromosomes. Meiosis takes place only in specialized germ tissues within the gonads. In the ovaries, each complete meiotic sequence produces one haploid secondary oocyte and two or more non-functional polar bodies. In the testes, each complete meiotic sequence produces four haploid spermatids.

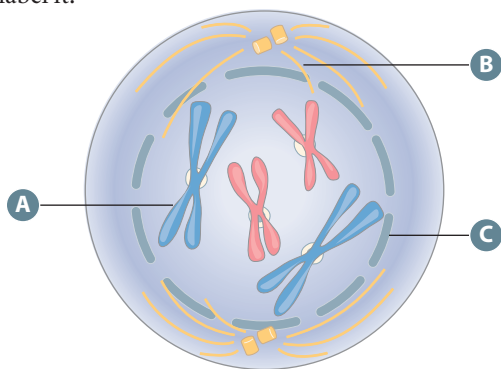
Some organisms reproduce asexually, and other organisms reproduce sexually. Some plants and animals can reproduce both sexually and asexually. The life cycle of plants includes a regular alternation of haploid and diploid generations. Sexual reproduction and asexual reproduction each have advantages and disadvantages. One characteristic of sexual reproduction is genetic variation among offspring.

Chapter 16 Graphic Organizer

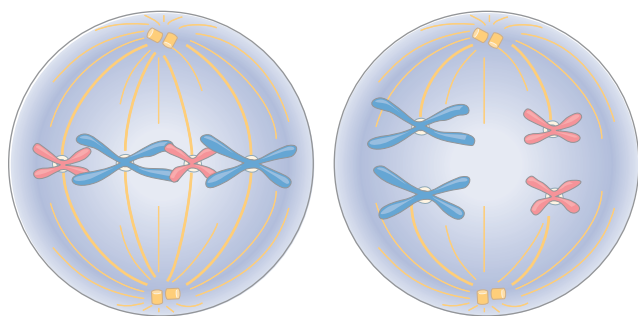


Understanding Concepts

- Describe one advance in technology between 1800 and 1900 that helped biologists understand the process of cell division.
- Define and distinguish among chromatin, chromatids, and chromosomes.
- Describe the three stages of interphase, and explain their importance.
- The following diagram shows a cell in early prophase of mitosis. Copy this diagram into your notebook, and label it.



- Why does the number of chromosomes in gametes need to be less than the number of chromosomes in somatic cells?
- Which kind of cell division, mitosis or meiosis, is involved in each of the following functions?
 - tissue renewal
 - growth of an embryo
 - production of gametes
- Which plant tissue would be best to use for studying each of the following processes? Explain your answer.
 - mitosis
 - meiosis
- At which point in the cell cycle does the replication of chromosomes take place?
- One of the following diagrams represents metaphase I of meiosis. Which diagram is it? How do you know?



- Copy the following diagram into your notebook, and complete the labels.
 - What is the significance of the arrangement shown?



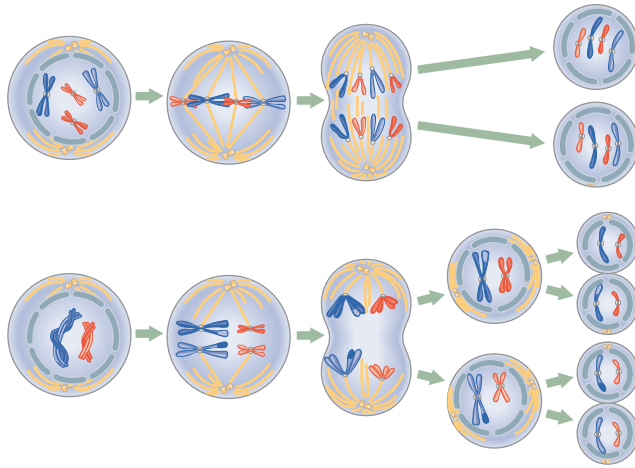
- A diploid germ cell is undergoing meiosis. Is the product of telophase I haploid or diploid? Explain.
- Describe two means of asexual reproduction, and identify one organism that can reproduce by each.
- Explain why crossing over between non-sister chromatids does not occur during mitosis. Why is this important?
- Use the chromosome numbers in the first table to complete the second table. (Do not write in this book.)

Chromosome Numbers of Some Common Organisms

Organism	Diploid body cell ($2n$)
fruit fly	8
garden pea	14
leopard frog	26
pine tree	24

Cell type and phase	Number of chromosomes	State of chromosomes (duplicated or unduplicated)
fruit fly germ cell after telophase I of meiosis		
garden pea germ cell after telophase II of meiosis		
leopard frog somatic cell in interphase		
pine tree gametophyte cell in prophase of mitosis		

- 15.** Describe what is occurring in the two processes shown below. Copy the diagrams into your notebook and use proper labels to explain your answer.



Applying Concepts

- 16.** Which individual is more likely to be seriously affected by the same exposure to radiation: an embryo in the first four weeks of development or a 10-year-old child? Explain.
- 17.** The cell cycle of a cancerous skin cell takes place at a faster rate than the cell cycle of a normal skin cell.
- Which phase(s) of the cell cycle is (are) likely to be most shortened in the cancerous skin cell? Explain.
 - Design a procedure you could use to test your hypothesis. Write the steps in your procedure and a list of the materials you will need.
- 18.** What would happen if a chromosome synapsed with a non-homologous chromosome during meiosis, rather than with its homologue?
- 19.** Create a table or diagram that compares and contrasts the processes and timing of spermatogenesis and oogenesis in humans.
- 20.** How many different gametes could a human germ cell produce? If a man and a woman already have one child, what is the possibility that their second child will be genetically identical to their first child? (Assume that no crossing over takes place.)
- 21.** Draw a labelled diagram to illustrate a life cycle that includes the alternation of generations. Write a brief description to communicate three important features of this life cycle.
- 22.** Create a table that clearly outlines the advantages and disadvantages of asexual reproduction.
- 23.** Your orchard has become infested by a species of insect that devours the blossoms before any fruit can develop. The insects are damaging the trees as well, and some trees appear to be dying.
- How could an understanding of the insects' life cycle help you combat the infestation? Give examples.
 - Your neighbour tells you, "I hope this species of insect reproduces asexually. That would help to keep the insects from spreading to my orchard." Is your neighbour's assumption correct?
 - What can you do to make sure that you do not lose your fruit trees while you are developing your strategy to deal with the insects?

Making Connections

- 24. a)** Does mitosis occur more frequently in a 5-year-old or a 40-year-old human? Explain your answer.
- b)** Many scientists are working on ways to slow the effects of aging. Given your answer to the first part of the question, suggest an area for further research. List three ways that this research could be applied.
- 25.** Imagine that you have been asked to explain cell division to a junior class. You know that many people learn best when they can use their bodies as well as their minds, so you decide to have the class put on a 15 min "mitosis play." Create a list of characters and the dialogue for this play. Include a props list and production directions.
- 26.** Geneticists can use the frequency of crossing over as a way to map the relative locations of genes on chromosomes. Describe, in general terms, how you think this could be done. In what ways could mapping the relative locations of genes be useful?
- 27.** You have discovered a new species of insect that reproduces both sexually and asexually. Design an experiment to test the effects of two different environmental factors on this insect's reproduction. Be sure to include a control.
- 28.** Some genetic researchers are developing artificial chromosomes. What features would these chromosomes need to have for them to behave appropriately during cell division?