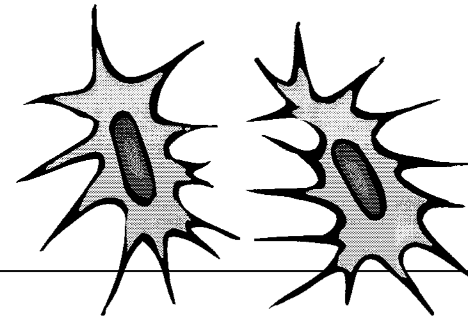
Cellular Reproduction

Section 9.1
The Cell Cycle and Mitosis



Pre-View 9.1

- **Somatic cells** – all the cells in the body except the sex cells (gametes); the cells that make up tissues and organs
- **Cell cycle** – the process that somatic cells go through in order to grow and to reproduce
- **Interphase** – the longest part of a cell cycle when the cell grows and develops, replicates its DNA, and makes proteins and RNA to prepare for cell division
- **Mitosis** – the part of the cell cycle when the nucleus divides
- **Prophase** – the first stage of mitosis when chromatin condenses and can be seen
- **Metaphase** – the second stage of mitosis when the chromatids line up along the midline of the nucleus
- **Anaphase** – the third stage of mitosis when the centromeres divide and the sister chromatids separate
- **Telophase** – the last phase of mitosis when new nuclear membranes are formed around each set of chromosomes
- **Cytokinesis** – the last part of the cell cycle when the entire cell divides
- **Replicate** – to make an exact copy of; for example, chromosomes *replicate* in the nucleus before a cell divides
- **Centromere** – a structure that holds sister chromatids (pairs of replicated chromosomes) together
- **Chromatin** – the threadlike material made of DNA and proteins found in chromosomes (or will condense to form chromosomes)

Like all living things, cells must be able to grow and to reproduce. The cells in your body, for example, do not live forever. They die and must be replaced by new cells. The cells that make up the tissues and organs of your body are called **somatic cells**. The only cells in your body that are not somatic cells are the sex cells (called gametes). Examples of somatic cells would be blood cells, liver cells, nerve cells, skin cells, etc. New somatic cells are made when one "parent" cell divides into two identical "daughter" cells. For example, to repair a skin cut, the skin cells around the cut divide until the cut is repaired. But think about it for a minute. In order for one cell to produce two identical cells, some things must duplicate. After all, daughter cells with only half a nucleus and half the original DNA would NOT be identical to the parent cell. Let's take a closer look at how somatic cells grow and reproduce.

The Cell Cycle

Somatic cells grow and reproduce during a process called the **cell cycle** (figure 9-1 on the next page). By undergoing the stages of the cell cycle, one cell divides into two genetically identical daughter cells. The cell cycle is divided into two main parts: one part for cell growth and one part for cell division. Certain processes occur during each of these parts of the cell cycle.

The Cell Cycle

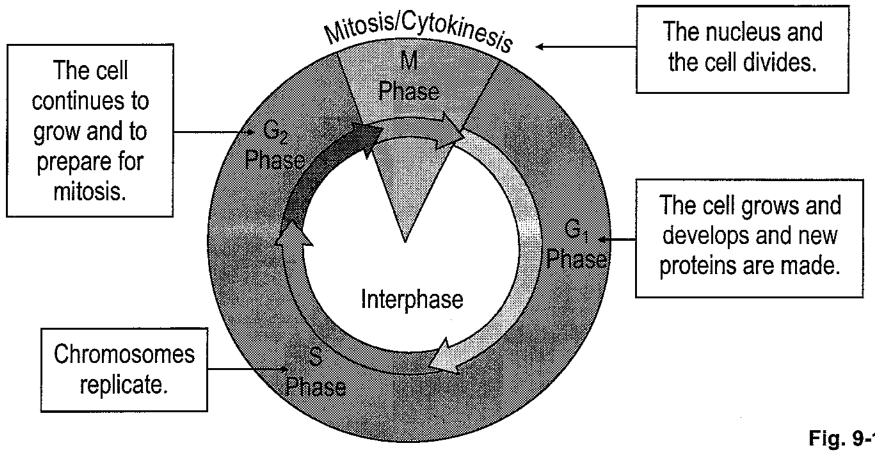


Fig. 9-1

Interphase

The longest part of the cell cycle is called **interphase**, and it is divided into three main parts.

G_1 Phase: The first part is called the *G_1 phase* when the cell grows and develops and new proteins are made.
Hint: Remember <u>G</u>rowth <u>1</u>st since that's when the cell grows and develops.

S Phase: The next stage is called the *S phase*. During the S phase, the DNA **replicates** in the nucleus to form a new set of identical chromosomes. When the cell divides, each new cell will have the correct number of chromosomes.
Hint: Remember that ***S*** is for <u>S</u>ynthesize, which means to make. In the S phase, new chromosomes are synthesized.

G_2 Phase: The last part of interphase is the *G_2 phase*. During the G_2 phase, the cell is getting ready for mitosis and continues to grow.

The M Phase

The second part of the cell cycle is the M phase, which includes **mitosis** (when the nucleus divides) and **cytokinesis** (when the entire cell divides). Mitosis is the process that divides the nucleus. It is only a small part of the cell cycle, but it is an important part. Mitosis is the part of the cell cycle most directly responsible for passing genetic information to the cells. It has four main stages.

Stages of Mitosis

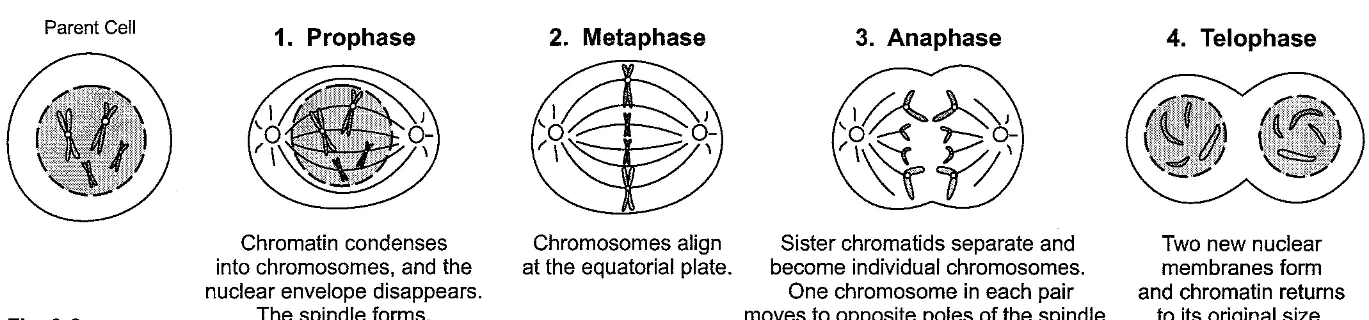


Fig. 9-2

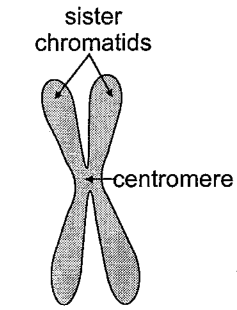


Fig. 9-3

Figure 9-2 on the previous page diagrams each stage of mitosis and gives a summary. Now let's look at each stage more closely.

Prophase: During **prophase**, the chromatin (material that makes up chromosomes) coils up, shortens, and thickens. Before this time, the chromatin is too thin to be seen. During prophase the chromatin becomes visible as sister chromatids that are held together by a structure called the **centromere** (figure 9-3). The sister chromatids are the result of DNA replication that occurred during the S phase. In prophase, the nuclear membrane also disintegrates, and the spindle starts to form. The spindle will help move the chromosomes to the new cells.

Metaphase: The second stage is **metaphase**. The chromatids attach to the spindle fibers by the centromere. The chromatids also line up at the middle of the nucleus (called the equator). This alignment allows each new cell to receive an identical set of chromosomes.
Hint: Remember that in <u>m</u>etaphase, chromosomes line up in the <u>m</u>iddle.

Anaphase: During anaphase, the chromosomes, which were in pairs called chromatids, are pulled apart by the spindle fibers. (Once the sister chromatids separate, they are called chromosomes.)

Telophase: The last stage is **telophase.** The chromosomes have reached opposite ends of the cell, and they start to unwind. The spindle disappears, and a new nuclear membrane forms around each set of chromosomes to form two new nuclei.

Hint: To help you remember the stages of mitosis and their order, remember the sentence *Paul Meets Anna Tonight.* The *P* in *Paul* stands for *prophase*, the first stage of mitosis. *M* in *meets* is for *metaphase. A* in *Anna* is for *anaphase*, and *T* in *tonight* is for *telophase*. Once you can remember the names and order of the stages, then be sure you remember what happens in each of those stages. Let's summarize. In prophase, chromatin condenses so that it can be seen. The chromatids line up in metaphase. In anaphase, they separate. In telophase, new nuclear membranes form.

Cytokinesis

After mitosis is complete, the cytoplasm divides during the process of **cytokinesis**.

Plant Cell Cytokinesis

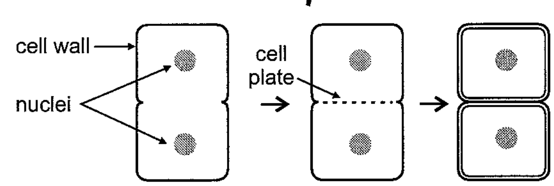


Fig. 9-4

Plant Cells

In plant cells, a structure called a **cell plate** forms midway between the two new nuclei and grows out to the edges of the cell. Once formed, the cell plate divides the cell in half. A cell membrane then forms around each new cell, and a cell wall forms on each side of the cell plate.

Animal Cell Cytokinesis

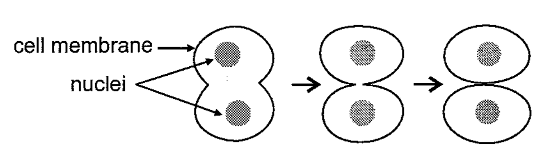


Fig. 9-5

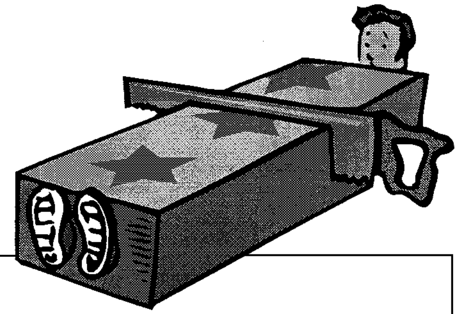
Animal Cells

In animal cells, the cell membrane begins to pinch in at the end of telophase and gradually separates the cytoplasm.

When the two new identical cells are separated, the cell cycle is complete and will begin again with interphase.

Cellular Reproduction

Section 9.2
Sexual Reproduction and Meiosis



Pre-View 9.2

- **Somatic cells** – all cells except sex cells; for example: blood cells, liver cells, skin cells
- **Sex cells** (or **gametes**) – the cells other than somatic cells that are formed through a process called meiosis
- **Meiosis** – the process that forms the sex cells called gametes (ova and sperm cells)
- **Haploid cells** – sex cells produced through the process of meiosis that contain half the number of chromosomes for that organism; have an *n* number of chromosomes
- **Diploid cells** – somatic cells produced through the process of mitosis that contain the full number of chromosomes for that organism; have a 2*n* number of chromosomes
- **Homologous chromosomes** (or **homologues**) – the two chromosomes that make up each pair of human somatic cells (23 pairs for a total of 46 chromosomes in humans)
- **Sex chromosomes** – the pair of chromosomes that determines gender (male or female)
- **Autosomes** – the pairs of chromosomes that do not include the one pair of sex chromosomes and that do not determine gender
- **Tetrad** – homologous chromosomes paired together side by side during meiosis
- **Crossing over** – the exchange of DNA between paired homologous chromosomes during meiosis

Gametes (Sex Cells)

Organisms that reproduce sexually have two types of cells. As we reviewed in Section 9.1, the cells that make up the body of the organism are called **somatic cells,** and they reproduce through the process of mitosis. The other cells are called **sex cells** or **gametes,** and they are formed using a process called **meiosis**.

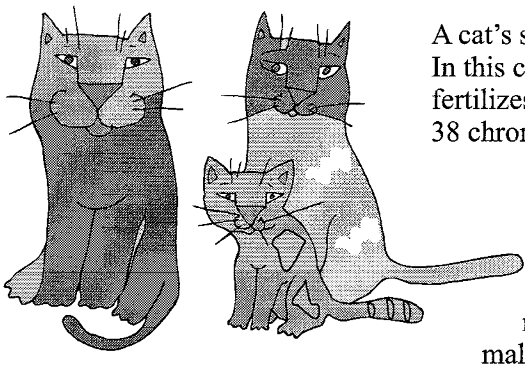
Meiosis occurs only in reproductive cells to form egg cells and sperm cells. Unlike mitosis, meiosis does *not* produce two new genetically identical cells. Instead, the cells produced by meiosis are called **haploid cells**. Haploid cells have only half the usual number of chromosomes that other cells have. These cells are said to have an *n* number of chromosomes. Somatic cells are said to be **diploid** and contain the full number of chromosomes for any given organism. Somatic cells are said to have a 2*n* number of chromosomes. For example, human somatic cells have 23 pairs of chromosomes for a total of 46 chromosomes. The diploid number of chromosomes for humans is 46.

Human egg and sperm cells are haploid, which means they have only 23 chromosomes, not 23 pairs. When one egg with 23 chromosomes is fertilized by one sperm with 23 chromosomes, the offspring will have 46 chromosomes (23 pairs), the correct number for humans. If gametes were produced by mitosis, then each gamete would have 46 chromosomes, and the first set of offspring would have 92 chromosomes — twice as many as normal!

Somatic cells in an organism contain pairs of chromosomes that carry similar genetic information. The two chromosomes that make up each pair are called **homologous chromosomes** or **homologues**. One chromosome from each pair came from the mother's egg cell, and the other chromosome for each pair came from the father's sperm cell. Each pair of homologues contains similar information. For example, one pair of homologues will contain genes that determine eye color. One of the chromosomes may have information for blue eyes from the mother, and the other may have information for brown eyes from the father.

Twenty-two (22) pairs of human chromosomes are called **autosomes**. The other pair is referred to as the **sex chromosomes** because they determine if a child will be male or female.

Example: Cats have 19 pairs of chromosomes (38 chromosomes total) in their somatic cells. How many chromosomes would be found in a male cat's sperm cells? How many chromosomes would be found in a female cat's egg cells?



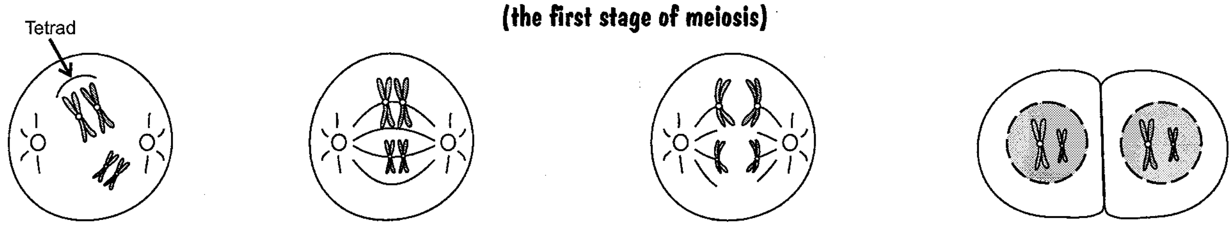
A cat's sperm cells or egg cells would contain a haploid number of chromosomes. In this case, they would contain 19 chromosomes. When a male's sperm cell fertilizes a female's egg cell, the kitten offspring will have a total of 38 chromosomes, or 19 pairs, like its parents.

Keeping the correct chromosome number is not the only reason that meiosis is important. It is also important because it allows **genetic variation** in a species. When the chromosomes separate during meiosis, the new cells are *not* identical. Then, when the sperm cell of a male parent combines with an egg cell of a female parent, the resulting offspring has a combination of genetic material from each parent. This variation is the reason you may see a mother cat that is gray and white, a father cat that is red and cream colored, but the kitten is gray and cream.

Meiosis

The process of meiosis can be seen in figures 9-6 and 9-7, which show only two sets of chromosomes. By following what happens in each stage, you should be able to see why meiosis results in genetic variation.

Meiosis I
(the first stage of meiosis)



Prophase I

Homologous chromosomes pair with one another to form tetrads. "Crossing over" may occur.

This arrangement of chromosomes does NOT occur in mitosis.

Metaphase I

Tetrads line up at the equator.

(In mitosis, each chromosome lines up instead.)

Anaphase I

Disjunction (separation) occurs, and one of each homologous chromosomes goes to opposite poles.

(In mitosis, the chromatids separate at the centromere, but the separation of chromatids does not happen at this stage of meiosis.)

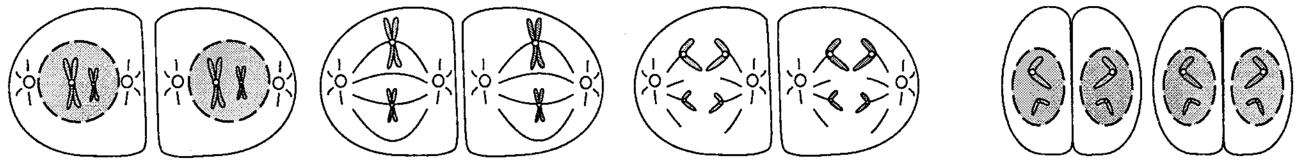
Telophase I and Cytokinesis

Original cell divides into two cells, each cell having one of the homologous chromosomes.

(In mitosis, each replicated chromosome separates at the centromere so that each new cell has one of each chromosome.)

Fig. 9-6

Meiosis II
(the second stage of meiosis)



Prophase II	Metaphase II	Anaphase II	Telophase II and Cytokinesis
The nuclear membrane disappears.	Chromosomes align at the equatorial plate.	Disjunction occurs again. This time, sister chromatids separate at the centromere and are pulled to opposite poles of each cell.	Original cell is divided into four haploid cells, each containing half the number of the original chromosomes. In males, this results in four sperm cells. In females, the cell divisions are unequal in size, and only one out of the four cells becomes an egg cell.

Fig. 9-7

Here's a summary of what happens in the cell cycle of gametes during meiosis.

Meiosis I

- **Interphase**
  During interphase, the DNA is replicated. The DNA and proteins make up chromatin, which will form the chromosomes.

- **Prophase I**
  The first division of meiosis begins with prophase I, which has some important differences from prophase in mitosis. In prophase I, the chromatin shortens and thickens into chromosomes. Each chromosome is made of a pair of chromatids connected by a centromere. The chromosomes pair with their homologous chromosomes to form a **tetrad**. (Two chromosomes that are made of two chromatids each equal 4 chromatids, or a tetrad.) Because these homologous chromosomes are so closely aligned, **crossing over** may occur. (See figure 9-8). In crossing over, a piece of DNA from one homologous chromosome may change places with the same section of DNA on the other homologous chromosome. This exchange of DNA that occurs in crossing over leads to even more genetic variation as it causes new combinations of genes.

Crossing Over

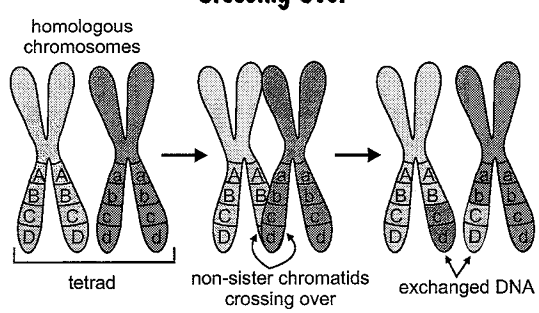


Fig. 9-8

- **Metaphase I**
  In metaphase I, the nuclear membrane has disappeared and the spindle has formed. The chromosomes are still in homologous pairs as they line up on the equator.

- **Anaphase I**
  During anaphase I, the homologues are pulled apart so that each group of chromosomes at the poles can have a different "mix" of homologues.

- **Telophase I**
  By the time telophase I begins, there is a cluster of chromosomes at each pole, and a new nuclear membrane starts to form around each cluster. Because of crossing over, the sister chromatids are not identical anymore. Now, the two new cells that have been formed have only one chromosome of each homologous pair.

Meiosis II

Meiosis II begins after a short interphase that is different because the *DNA does not copy itself.* The stages of meiosis II are very similar to mitosis except in anaphase II, the number of chromosomes in each cell is half of the number in mitotic anaphase. After the new nuclear membranes form in telophase II, cytokinesis occurs, and the result is four new cells with each having a haploid number of chromosomes.

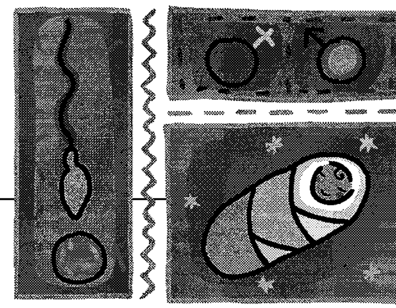
Comparing Mitosis and Meiosis

The chart below summarizes the differences between similar stages of mitosis, meiosis I, and meiosis II.

	Mitosis	Meiosis I	Meiosis II
Prophase	Chromosomes become visible. They are diploid, $2n$.	Homologous chromosomes pair together closely. Crossing over may occur.	The DNA has not replicated, so the cells are haploid, n.
Metaphase	Individual chromosomes line up at the equator.	The tetrads (4 chromatids) become visible and line up along the equator.	Individual chromosomes line up at the equator.
Anaphase	Chromosomes split and sister chromatids are pulled to opposite poles.	Homologous chromosomes separate, and one of each pair is pulled to each pole.	Chromosomes split and one of each pair of sister chromatids is pulled to opposite poles.
Telophase and Cytokinesis	Two new nuclei are formed, and the cell divides to form two genetically identical diploid cells.	Two new nuclei are formed, and the cell divides to form two haploid cells that are not genetically identical.	Two new nuclei are formed from each of the two daughter cells, and the cells divide and form four haploid cells.

Cellular Reproduction

Section 9.3
Gamete Production



Pre-View 9.3

- **Spermatozoa** – sperm cells (or male gametes)
- **Ova** – egg cells (or female gametes)
- **Spermatogenesis** – the production of sperm cells
- **Oogenesis** – the production of ova (or eggs)
- **Polar bodies** – the cells produced during oogenesis that do not form a mature egg cell

Although meiosis explains how the new cells produced are haploid (half the usual number of chromosomes), it doesn't explain how the cytoplasm divides to produce egg cells and sperm cells. The production of **ova** (egg cells) is called oogenesis, and the production of **spermatozoa** (sperm cells) is spermatogenesis.

Spermatogenesis

In **spermatogenesis**, the immature diploid sperm cell divides equally after the first phase of meiosis to produce two cells that are equal in size. Each of these two cells divides again after the second phase of meiosis so that four spermatozoa, all equal in size, are produced. See figure 9-9.

Spermatogenesis

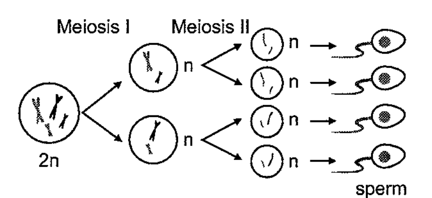


Fig. 9-9

Oogenesis

Oogenesis is a little different. After the first phase of meiosis, the immature diploid egg cell divides, but almost all of the cytoplasm and cell organelles go to one cell. As a result, one of the new cells is larger than the other. The smaller cell is called a polar body. It may or may not go through the rest of meiosis to produce two more polar bodies. After the second phase of meiosis, the larger cell again receives most of the cytoplasm and cell organelles, and it becomes the ovum, or egg cell. See figure 9-10. The very small polar bodies disintegrate.

Oogenesis

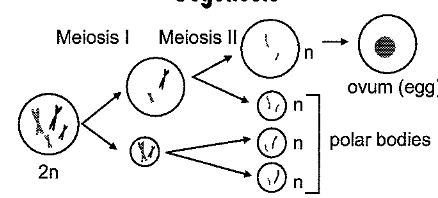
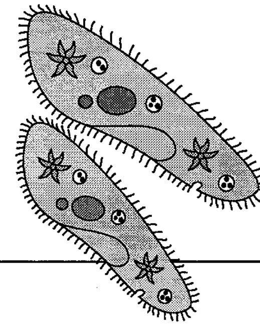


Fig. 9-10

Cellular Reproduction

Section 9.4
Asexual Reproduction



Pre-View 9.4

- **Asexual reproduction** – type of reproduction that occurs when only one parent organism reproduces itself to form a genetically identical offspring
- **Binary fission** – a type of asexual reproduction that occurs when a single-celled organism reproduces itself by replicating its DNA and then dividing
- **Budding** – a type of asexual reproduction that occurs when a group of cells grows on a parent organism and eventually detaches to become a separate organism
- **Vegetative propagation** – a type of asexual reproduction that occurs when a new plant grows from a part of the parent plant
- **Regeneration** – the regrowing of a missing body part
- **Fragmentation** – a type of asexual reproduction in which a small or broken piece from an organism develops into a new adult organism
- **Spore formation** – a type of asexual reproduction in which an organism creates either haploid or diploid spores, either of which can grow into an adult organism under favorable conditions
- **Parthenogenesis** – a type of asexual reproduction sometimes seen in more complex organisms, such as certain insects, in which an unfertilized egg develops into an adult

Reproduction is one of the basic characteristics of living things. Reproduction is not necessary for the survival of a single organism, but it is essential in order for a species to survive. By reproducing successfully, each species passes its genetic information down to future organisms. There are two types of reproduction: sexual reproduction and asexual reproduction. First, let's look at the different types of asexual reproduction.

Asexual reproduction uses only one organism as a parent. One or more cells from the parent organism form an offspring that is genetically identical to the parent. This type of reproduction is sometimes called **cloning**. There are several different types of asexual reproduction, and all of them involve a single parent. Most types of asexual reproduction take place by the process of mitosis. However, certain types of asexual reproduction can occur in haploid cells, cells formed from meiosis. Asexual reproduction usually results in a larger number of organisms that are genetically identical.

Binary Fission

Binary fission is one of the most simple types of asexual reproduction, and it occurs in many one-celled organisms like bacteria and the paramecium. The single-celled organism grows, replicates its DNA, and then splits in half. All prokaryotes reproduce by binary fission, and the single-celled offspring is genetically identical to its parent.

Budding and Vegetative Propagation

Some multi-celled organisms reproduce asexually by budding. In **budding**, a small area of cells attached to the parent starts to grow and then detaches when it is a separate organism. Many fungi and simple animals, such as hydra, sea anemones, and yeast, reproduce by budding.

Asexual Reproduction

Fig. 9-11
Strawberry plants reproducing by vegetative propagation

Some plants also reproduce in this manner, but for plants, this type of asexual reproduction is called **vegetative propagation**. In vegetative propagation, a parent plant might form a creeping stem that roots and forms a new plant. Grasses and strawberry plants often reproduce new plants in this way. Or an underground bulb or tuber, such as a tulip bulb or a potato, may form smaller additional bulbs or tubers that can grow into new plants. Even a cutting taken from a leaf or a stem of a plant can sometimes be rooted to form a new plant.

Both budding and vegetative propagation occur by mitosis, and the offspring is genetically identical to the parent organism. Parent and offspring will have the same number of chromosomes.

Regeneration and Fragmentation

Some simple animals, such as sponges, starfish, and planaria, can repair their bodies if a piece gets broken off or damaged. The process of growing a new body part is called **regeneration**. If enough genetic material is present in the broken piece, it can also form a new organism. Forming a new organism from a broken piece is called **fragmentation**. For example, by regeneration, a starfish can regrow an arm that becomes detached. By fragmentation, the broken arm of a starfish can grow into a completely new starfish. The new starfish is genetically identical to the parent.

Spore Formation

A spore is a reproductive cell that is protected by a tough outer wall. Several types of organisms, including algae, some protozoans, and many types of fungi and plants, produce spores. The outer wall of the spore protects it against harsh conditions so that when an organism releases spores into the environment, they can survive until the conditions are favorable for them to grow into new organisms. Some spores are produced by mitosis so that the offspring are genetically identical to the parent. Other spores are produced by meiosis, and the offspring have half the number of chromosomes as the parent. The haploid offspring usually produce sex cells by mitosis instead of by meiosis and undergo a type of sexual reproduction so that their offspring have a diploid number of chromosomes.

Parthenogenesis

Asexual reproduction is normally seen in simple organisms, but some complex organisms, such as certain types of insects, can reproduce asexually. **Parthenogenesis** is a type of asexual reproduction that occurs when an unfertilized egg develops into an adult organism. Most eggs are formed by meiosis and are haploid, so the new organism has only half the number of chromosomes as the parent organism. Parthenogenesis can be seen in honey bees. Unfertilized eggs can develop into male honey bees called drones.

Advantages of Asexual Reproduction

When conditions are favorable, organisms that reproduce asexually can produce a large number of offspring in a short time period. These genetically identical organisms may survive quite well in an environment that doesn't change much because genetic variation isn't as important in a stable environment.

Cellular Reproduction

Section 9.5
Sexual Reproduction

Pre-View 9.5

- **Sexual reproduction** – type of reproduction that usually requires two parents to produce offspring that are not genetically identical to either parent
- **Fertilization** – the union of a male and a female gamete during sexual reproduction
- **Pollination** – in plants, the transfer of pollen from the male reproductive organ to the female reproductive organ
- **Conjugation** – a primitive type of sexual reproduction in which two parent organisms, usually bacteria, exchange genetic material
- **Alternation of generations** – a process of reproduction in which one generation is produced by an asexual stage and the next generation is produced by a sexual stage

In Section 9.3, you reviewed how male and female gametes are formed by the process of meiosis. In many cases, a male organism produces male gametes (sperm), and a female organism produces female gametes (eggs or ova). **Sexual reproduction** occurs whenever a haploid sperm fuses to a haploid egg to form a diploid cell. This union of male and female gametes is called **fertilization**. Sexual reproduction allows two parents to contribute genetic information to an offspring. Frogs are an example of animals that reproduce sexually. Sexual reproduction occurs when a female frog lays eggs in water, and a male frog releases sperm cells into the water around them.

In plants, sexual reproduction occurs when the sperm in a grain of pollen fertilizes an egg cell and results in seeds. You'll learn more about plant reproduction later, but the transfer of pollen from the male reproductive organ to the female reproductive organ in plants is called **pollination**.

You saw in Section 9.4 that bacteria primarily reproduce asexually by binary fission, but bacteria and some other unicellular organisms can exchange genetic material with one another. This type of primitive sexual reproduction is called **conjugation**.

Advantages of Sexual Reproduction

Since sexual reproduction involves the union of haploid sex cells, it allows a lot of variation in a species. Genetic variation may help a species to adapt and survive since different organisms within the species will have different strengths and weaknesses. When an environment changes, genetically different organisms may have a better chance of surviving. For example, let's say that some tree frogs are able to survive colder temperatures and others are not. If the temperature in their environment changes, the frogs that can survive the colder temperatures will continue to live and reproduce, but the others will die. If, on the other hand, all of the frogs are genetically identical, they may all die when the temperature drops. In this example, sexual reproduction that produces genetically different offspring has an advantage over asexual reproduction that produces genetically identical offspring.

Alternation of Generations

How can you tell if an organism reproduces sexually or asexually? You can tell by looking at the number of chromosomes. If the number of chromosomes always stays the same and is not halved, then the organism reproduces asexually. If cells are produced with half the usual number of chromosomes, then the organism reproduces sexually. Some organisms, such as ferns, even use both in a process called **alternation of generations** — one stage will reproduce asexually, and then the next will reproduce sexually.

Advantages and Disadvantages of Sexual and Asexual Reproduction

	Advantages	Disadvantages
Asexual Reproduction	It produces a large number of offspring quickly, which may increase chances of survival in a favorable and stable environment. It requires only one parent organism.	Offspring are genetically identical to parent organism, which may limit their ability to survive a changing environment.
Sexual Reproduction	Offspring are genetically different from either parent, which may help the organism to adapt and survive a changing environment.	It produces a smaller number of offspring more slowly, so fewer offspring may survive. It usually requires two parents, one male and one female.