# **The Cell Cycle**

**Textbook Reference: 14.1**

The continuation of life greatly depends upon the body’s ability to replace old cells with new cells. The functioning of all cells is dependent upon the instructions provided by the genetic material found within cells. This genetic material must be duplicated and passed on to new cells.

The **cell cycle** is composed of the following processes:

1. Interphase:
* G1 Phase: Cell growth and metabolic activity
* S Phase: DNA synthesis and replication
* G2 Phase: Centrioles replicate and cell prepares for division
1. Mitosis: Division of nucleus
2. Cytokinesis: Division of cytoplasm

**Diagram of Cell Cycle**

**Interphase**

Interphase is a period of cell growth, maintenance and differentiation. The duplication of chromosomes and centrioles will occur prior to the beginning of mitosis.

Normally, the DNA material exists as a mass of thin, twisted threads called **chromatin**. Chromatin is DNA wound around small groups of proteins called **histones**. At some point during interphase, the chromosomes replicate themselves to become **doubled chromosomes**. The **centrioles** also replicate themselves. The centrioles are two cylindrical bodies that lie at right angles to each other near the nucleus.

The cell will also build proteins to be used in the cell membrane or as enzymes to be used in chemical reactions that control the duplication of genetic material. In addition, the cell will carry out its normal functions such as growth and maintenance.

**Mitosis**

Mitosis is the assortment and division of identical sets of chromosomes in the nucleus. It maintains the number of chromosome sets in the nucleus from one generation to the next. *Why is this important?* For example, there are 46 chromosomes in each cell in humans.

**Cytokinesis**

This is cytoplasmic division. It occurs when mitosis is near completed or after it is completed. Cytokinesis results in the production of two daughter cells, each containing one of the new nuclei and half of the cytoplasm and organelles form the parent.

In humans, during anaphase, the cell membrane will begin to pinch in by the center (equator). By the end of telophase, the membrane will pinch in to form two separate daughter cells. A **cleavage furrow** is formed in animals during cytokinesis. Special proteins enable the cell membrane to be drawn towards the equator and pinch in. In plants, the **cell plate** is formed which develops into the cell wall.

The distinction between mitosis and cytokinesis is that mitosis involves nuclear division whereas cytokinesis involves cytoplasmic division. Mitosis and cytokinesis are used in asexual reproduction (binary fission) of unicellular organisms. In multicellular organisms, mitosis and cytokinesis are used to form new cells for tissue growth or to repair damaged tissues. It occurs in somatic (body) cells as opposed to sex cells in multicellular organisms.

**Phases of Mitosis**

# Prophase

* During prophase, the genetic material will begin to shorten and contract into thicker rods. The doubled chromosomes will become evident.

## Doubled Chromosome

 chromatid

 • centromere

 chromatid

* The two pairs of centrioles move to opposite ends (poles) of the cell.
* Star-shaped structures called **asters** (made up of microtubules) will extend from each pair of centrioles.
* Other microtubules will go from pole to pole to form a football shaped structure called the **spindle**.
* Some microtubules of the spindle will attach to the **centromeres** of the chromosomes.
* The **kinetochore** is the protein structure on centromere of the chromosome where the [spindle fibers](http://en.wikipedia.org/wiki/Spindle_fibers) attach during division to pull the chromosomes apart.
* Chromosomes will begin to move towards the **equator** (a point midway between the poles).
* The nucleolus and nuclear membrane will disappear

### Early Prophase

**(You will draw in class)**

**Middle Prophase**

**Late Prophase**

# Metaphase

* The spindle is completely formed and microtubules are attached to all centromeres
* Centromeres are completely lined up at the equator
* At the end of metaphase, centromeres divide and the two chromatids become separate chromosomes

###  Metaphase

# Anaphase

* Sister chromatids have separated to form separate chromosomes. The microtubules of the spindle enable the separation chromatids and centromeres.
* These duplicated chromosomes moved towards opposite poles, resulting in identical sets being at opposite poles
* Cytokinesis begins to occur and the cell membrane begins to pinch in at the equator.

### Early Anaphase Late Anaphase

# Telophase

* Chromosomes reach the poles
* Spindle and aster disappear
* Chromosomes uncoil, lengthen and become threadlike. In other words, chromatin is being reformed.
* Nuclear envelop and nucleolus reappear

Telophase is the end of nuclear division. Cytokinesis is usually completed and the daughter cells will enter a new period of growth and differentiation in interphase.

### Early Telophase

**Late Telophase**

**Mutations Affecting Cell Division**

**Textbook Reference: 14.1**

A *mutation* is a permanent change in the DNA that changes the genetic information of the gene and causes it to function improperly. Mutations can be caused by *chemicals,* *radiation* or *viruses*. They can also occur spontaneously during replication. This mutation is passed on to daughter cells.

A mutation may not cause any serious effects. They may just prevent the cell from functioning normally. The cell can be simply replaced by other normal cells.

If a gene is affected that controls the normal division process, then cancer can result. Cancer is known as the rapid, uncontrolled growth and division of cells that do not specialize

Genes can work like switches to regulate mitosis. At the end of the cell cycle, certain genes are “switched on” to stop the process of mitosis. If these genes are “switched off” by a mutation, these cells could divide uncontrollably. The genes that start mitosis can also be affected by mutations. If these genes are “switched on” then there can be uncontrolled cell growth. These genes that are either “switched on or off” are known as **oncogenes**.

**Radiation and Chemotherapy**

Cancer treatments are aimed at attacking cells that divide rapidly. *Radiation therapy* involves directing radiation (x-rays or gamma rays) at the affected part of the body. There is also *internal radiation* in which radioactive material is placed inside the body near the cancerous growth. This radioactive material works by damaging the chromosomes in the cancers cells and preventing them from growth. Unfortunately, radiation therapy will also damage nearby healthy tissues.

*Chemotherapy* will use a course of one or several types of drugs, depending on the cancer. They also attack cells that are dividing quickly. Chemotherapy is normally used when a cancer is spread throughout the body such as leukemia. This drug will also affect healthy cells.

Effects of radiation can include skin inflammation and fatigue. Radiation in the brain can cause hair loss. Radiation in the testes can cause sterility. Chemotherapy includes side effects of hair loss, nausea or diarrhea. Healthy cells that divide quickly are normally affected such as bone marrow, skin cells, hair cells, cells in the GI tract and cells of the reproductive system.

**Technologies Based on Cell Division**

**Textbook Reference**: Pgs. 478-9

1. **Cloning**: This technology skips the meiosis stage of reproduction in which the sperm and egg meet to produce offspring non-identical to either parent. Instead, the nucleus of an egg cell from a surrogate mother animal is removed and replaced with the diploid nucleus of the organism to be cloned. The egg cell is implanted into the surrogate mother’s uterus. The cell develops into the exact copy of the animal that donated it nucleus.

There are two types of human cloning:

1. *Therapeutic cloning* is the culturing of human cells for use in treating medical disorders. These stem cells can *potentially* treat diseases in any body organ or tissue by replacing damaged cells. The risk of immunological rejection is alleviated because the patient's own genetic material is used.
2. *Reproductive cloning* is the development of a cloned embryo for the purpose of creating a cloned human being.

All types of cloning involved ethical issues. Therapeutic cloning holds the promise of eliminating human disease. All cloning, however, involves the artificial creation and deliberate destruction of hundreds of embryos.

1. **Stem Cell Research**: Stem cells are undifferentiated cells that can give rise to any cells type in an organism. They may exist in two forms: embryonic stem cells and adult stem cells. If scientists can learn what triggers theses cell to divide into certain specialized cells, then they hold the key to treating a multitude of disorders. They can be used to treat spinal cord injuries, cancer, Parkinson’s disease and replace damaged organs such as the liver or heart.

There are ethical issues surrounding the use of embryonic stem cells since involves the cultivation and destruction of human embryos.

1. **Spinal Cord Injury**: A gene called *Nogo* has recently been discovered that inhibits spinal cord regeneration. The purpose of the protein produced by *Nogo* is to prevent the uncontrollable growth of tissue. It is hope that understanding the gene sequence of *Nogo* can lead to drug therapies that aid in the regeneration of nerve cells. Stem cell research is also considered as another possible treatment.
2. **Cancer Treatment**: Cancer treatments are aimed at attacking cells that divide rapidly. *Radiation therapy* involves directing radiation (x-rays or gamma rays) at the affected part of the body. There is also *internal radiation* in which radioactive material is placed inside the body near the cancerous growth. This radioactive material works by damaging the chromosomes in the cancers cells and preventing them from growth. Unfortunately, radiation therapy will also damage nearby healthy tissues.

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Meiosis

**Textbook Reference: Section 14.2**

Meiosis occurs in sexual reproduction. It results in the offspring being genetically different from either parent. Meiosis results in the production of gametes. **Gametes** are the male and female sex cells. The fusion of male and female gametes produces a zygote in the process of fertilization.

Through the process of meiosis, gametes have half the number of chromosomes as the parent cell. During fertilization and the formation of the zygote, the original number of the chromosomes is restored. Gametes contain the **haploid number** **or monoploid number** of chromosomes and this is represented as *n*. They have half of the number of chromosomes as the parent cell. In humans, this number is 23. The zygote will contain the **diploid number** of chromosomes which is represented as *2n*. In humans, the number is 46.

In humans, meiosis will takes place in the testes (spermatogenesis) and the ovaries (oogenesis).

# Homologous Chromosomes

Chromosomes can be grouped into similar chromosomes. Homologous chromosomes are similar in size and shape. They are also similar in genetic content. The 46 chromosomes found in the cells of humans (except sex cells) can be grouped into 23 pairs of homologous chromosomes. It is the homologous chromosomes that divide during meiosis. Each gamete has only one chromosome from a homologous pair.

*Stages of Meiosis*

Meiosis is separated into two cell divisions called Meiosis I and Meiosis II. In Meiosis I, homologous chromosomes are separated to produce the haploid number. It is sometimes called the **reduction division**. There are two cells produced.

In Meiosis II, the doubled chromosomes are separated into two sister chromatids. There are a total of four haploid cells by the end of this phase.

The replication of chromosomes has occurred before meiosis has taken place. Chromosomes appear as doubled chromosomes, each containing an identical sister chromatid. Centrioles have also been replicated before meiosis begins.

*Meiosis I*

**Prophase I**:

* The doubled chromosomes line up with their homologous pair and joined at their centromeres. This pairing process is called the **synapsis** and each group of four chromatids is called a **tetrad**.
* The nuclear membrane disappears
* The spindle begins to form
* Homologous pairs begin to move towards the center
* Centrioles begin to move to opposite poles

*Crossing Over*

During prophase, the strands of the tetrads may twist around each other and exchange parts. This is known as **crossing over**. Finish the diagram below:

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Homologous chromosomes Synapsis Exchange of genetic material

**Early Prophase I**

**Middle Prophase I**

**Late Prophase I**

**Metaphase I**

* Centromeres of tetrads line up at equator
* Spindle fibres attach to centromeres

**Metaphase I**

**Anaphase I**

* Homologous chromosomes of each tetrad separate and begin to move opposite poles. This is known as **disjunction** or **segregation**.
* Each chromosome is still doubled
* Reduction division is occurring

**Anaphase I**

**Telophase I**

* Cytoplasm begins to divide and forms two daughter cells containing the haploid number
* Nuclear membrane may reform
* Centrioles will replicate
* The two cells are not identical as in mitosis. Why?

**Telophase I**

*Meiosis II*

**Prophase II**

* The centrioles will have replicated prior top prophase II however the chromosomes will not replicate. Why?
* Nuclear membrane dissolves
* Spindle forms
* Doubled chromosomes move to the equator

**Prophase II**

**Metaphase II**

* Doubled chromosomes along equator are fastened to spindle fibres

**Metaphase II**

**Anaphase II**

* Centromeres divide and sister chromatids separate
* Chromosomes move to opposite poles and are pulled apart by spindle fibres

**Telophase II**

* Daughter cells have divided into four haploid cells
* Nuclear membrane reforms
* Spindle disintegrates

**Telophase II**

Meiosis and Variation

There are three ways that variation in offspring can be created through the process of meiosis:

1. The process of meiosis creates variation in offspring since the offspring receive half of its genetic material from the mother and the other half form the father upon fertilization.
2. Variation can also be produced during *crossing over* during meiosis I when the genetic material is exchanged between homologous chromosomes.
3. There are many possible gametes that can be formed from the separation of

 homologous chromosomes. This is because the chromosomes must segregate

 independently of each other. For example, if an organism has only two pairs of

 homologous chromosomes, then they could line up four (22) ways during Meiosis I.

 If here are three pairs, than there are eight ways (23).

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| Diagram |

Since humans have 23 pairs of homologous chromosomes,there are more than 8 million (223) ways that homologous chromosomes may be aligned to produce daughter cells.

*Question:* Distinguish between homologous chromosomes and duplicated (doubled) chromosomes.

*Answer:* humans have 46 chromosomes. Humans are diploid which means that they have 23 sets of homologous chromosomes. Homologous chromosomes are similar or same type chromosomes. They do not vary in the location of gene but may vary in the type of gene (ie. Blue or green eye color)

 During mitosis and meiosis the 46 chromosomes are duplicated. Each duplicated chromosome appears as two sister chromatids joined by a centromere. Chromatids are identical and are separated during mitosis or Meiosis II. In mitosis, this maintains the same number of chromosomes in each daughter cell as the parent cell.

**Production of Sperm (Spermatogenesis)**

**Textbook Reference**: p.477-8

Under the influence of testosterone, the testes produce sperm. Sperm are haploid cells produced by meiosis. Human diploid cells have 46 chromosomes. Human sperm have 23 chromosomes. Unlike, the female egg, sperm is continuously produced throughout a male’s lifetime.

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| Diagram of Spermatogenesis |

The spermatogonia (germ cell) will produce a *primary spermatocyte*. This cell has a diploid number. This cell undergoes the *first meiotic division* and produces two haploid *secondary spermatocytes*.

The two haploid secondary spermatocytes will undergo the *second meiotic division* to produce a total of 4 haploid *spermatids*. Each sperm cell matures into a sperm cell in the epididymus by shedding most of its cytoplasm and developing a flagellum for movement.

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| Structure of Sperm |

The head of the sperm is important in reproduction because it contains the DNA in its nucleus. It also contains a cap called the *acrosome* that contains several enzymes that help the sperm enter the egg. The tail of the sperm is important in its movement. The mitochondria absorb fructose from the seminal fluid and convert it to ATP. This energy is used by the flagellum to propel the sperm.

**Production of the Egg (Oogenesis)**

Each ovary is responsible for producing the ovum. Like the sperm, they are haploid cells produced by meiosis and contain 23 chromosomes. Egg production results in an egg that has a large amount of cytoplasm. In fact, the ovum is about 100,000 times larger than the sperm cell. **Why?**

Egg production does not occur continuously throughout a female’s lifetime. The first stage of egg production occurs before birth and about 1 million diploid *primary oocytes* (oogonia) are produced. Ovum development does not continue until puberty.

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| **Diagram of Oogenesis** |

Beginning at puberty, the first meiotic division of the *primary oocyte* will be completed about every 28 days in the follicles of the ovary. This division produces two haploid cells. One cell is the *secondary oocyte* and contains most of the cytoplasm. The second cell is called the first *polar body* and will eventually disintegrate.

It is the secondary oocyte that is released form the follicles of the ovary during ovulation and enters the oviduct. The second meiotic division occurs in the oviduct at fertilization. The ovum is produced and contains almost all of the cytoplasm. Another polar body is produced and will contain very little cytoplasm.

The first polar body will also undergo a second meiotic division to produce two more polar bodies. All polar bodies will eventually disintegrate.

**NOTE**

Sperm production results in the production of 4 sperm from the primary spermatocyte. Egg production results in the production of one egg and 3 polar bodies that later disintegrate. The ovum will also disintegrate in 48 hours, if it is not fertilized. Sperm cells can survive between 24 to 72 hours once released from the epididymus.

***Comparing the Structure of Sperm and Egg Cells***

Use page 478 of your text to complete the chart.

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| **Characteristic** | **Sperm Cell** | **Egg Cell** |
| Relative sizes |  |  |
| Energy reserves |  |  |
| Mitochondria |  |  |
| Numbers produced |  |  |
| Motility |  |  |
| Importance of the enzyme cap |  |  |