How Does a Cell Know What Cell to Become?

To ensure that the new cells being formed are the same as its progenitor, it refers to an internal blueprint on how to construct itself. This blueprint is referred to as DNA, which, as established, consists of sequenced nitrogen bases, phosphate groups, and sugar backbones.

DNA in its uncondensed form can span thousands of kilometers, which is why it is condensed by being wrapped around a histone. This new structure is referred to as a *nucleosome*. Then, nucleosomes are further condensed by coiling and forming a *chromatin fiber*. Condensed groups of chromatin fibers form a single *chromatid*. When two (2) chromatids are linked at the centromere by a kinetochore, it forms a *chromosome,* which is the most condensed form of genetic material.

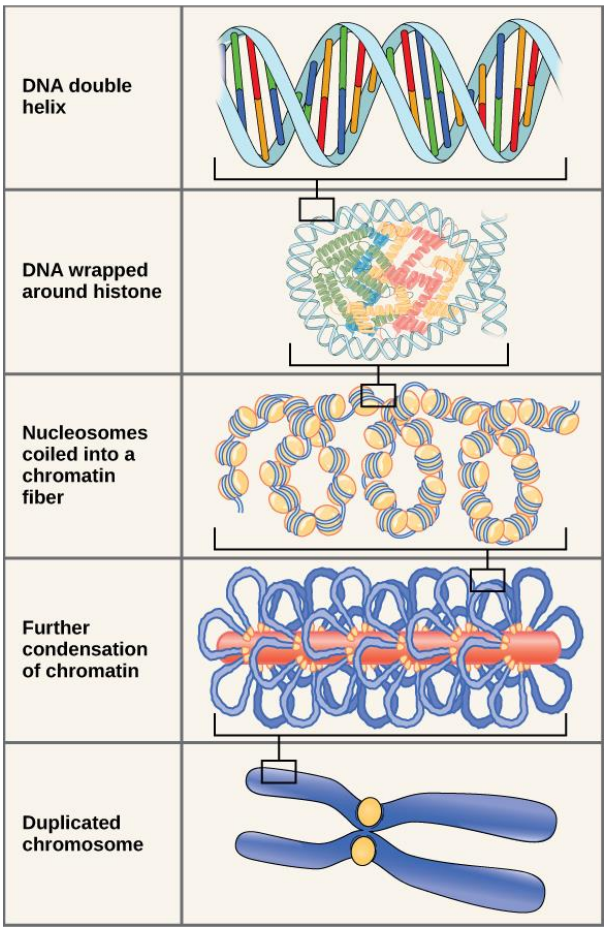

Figure 1. Organization of Eukaryotic Genetic Material
Source: Rye, et al., 2016

The Cell Cycle

The cell cycle is the ordered series of events involving cell growth and division to produce new cells (daughter cells). An overview of the cell cycle shows two (2) major phases: *interphase* and *mitotic* phase. These two (2) are further subdivided into different phases. Interphase is divided into four (4) phases, while mitotic phase is divided into five (5) phases.

Although eukaryotes and prokaryotes have similar cell cycles, the processes to be discussed are specific to eukaryotes. This is because eukaryotic cells are more complex, and the cell cycle of prokaryotes are simplified versions of the former.

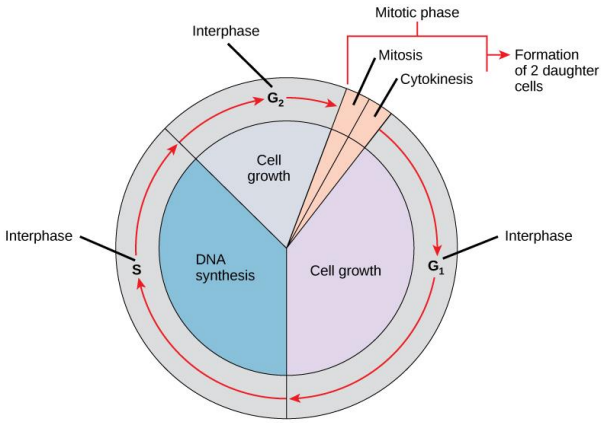

Figure 2. Cell Cycle
Source: Rye, et al., 2016

Interphase

This phase is dedicated to the growth, preparations, DNA synthesis, and replication. It is subdivided into three (3) phases: Gap 0 (G0), Gap 1 (G1), Synthesis (S), and Gap 2 (G2).

- **G0**

  This phase is where the cell spends the longest amount of time. It is the normal state of the cell where it undergoes standard levels of growth, metabolism, and no active division. Cells can stay in this state for minutes to years. It is also referred to as the *resting state.*

- **G1**

  This phase is directly associated with G1 and is the second-longest phase of the

cell cycle. Although visually similar to G0, the biochemical aspect of the cell is much more active. Proteins, building blocks for DNA, and energy are being accumulated by the cell in preparation for the following phases.

- **S**

Once the cell has accumulated enough building blocks and energy, it beings the process of replicating DNA. Genetic material is normally observed as semi-condensed chromatids. The centrosome will be duplicated to form the mitotic spindle, which will be important in the separation of chromatids.

- **G2**

Significant changes to the organelles and cell structure occur during this phase. The cytoskeleton is dismantled, organelles are duplicated, proteins needed to separate chromosomes are synthesized, and large amounts of energy are stored.

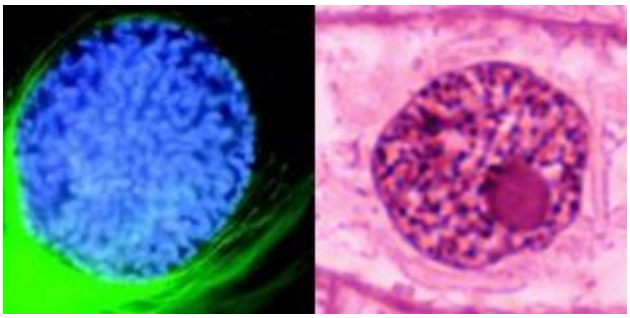

Image 1. Visualization of Interphase
Left - a fluorescent micrograph of a lung cell showing interphase; Right - a light compound micrograph of an onion cell showing interphase
Sources: Risler, 2011 & Reschke, n.d.

Mitotic Phase

After the preparations done during interphase are completed, the cell begins the process of aligning genetic material, separating them, dividing the cell, and forming the two (2) new daughter cells. The M phase can be subdivided five (5) phases: *prophase, metaphase, anaphase, telophase,* and *cytokinesis.*

- **Prophase**

Condensed chromosomes must be identified to differentiate prophase with the end of interphase. DNA replication has ended at this point and is being condensed into thick, bulky structures called *chromosomes.*

Protein structures called *centrioles* begin to form and migrate toward opposite ends of the cell. The centrioles then organize an array of microtubules (spindle fibers), which will later be sued to attach and pull the chromosomes. Another set of microtubules will connect the centriole to the cell membrane, which is referred to as an *aster.*

The disintegration of the nuclear envelope signifies the late phase of prophase and the transition to metaphase known as *prometaphase.*

Image 2. Visualization of Prophase
Left - a fluorescent micrograph of a lung cell showing late prophase; Right - a light compound micrograph of an onion cell showing late prophase
Sources: Risler, 2011 & Reschke, n.d.

- **Metaphase**

After the nuclear envelope is removed, the microtubules attach to the kinetochore of the chromosomes. Each chromosome has two (2) kinetochores, and each kinetochore will be connected a microtubule from one (1) of the centrioles. This results in the chromosome being pulled into the center of the cell.

Once the microtubules have pulled all the chromosomes, they will align at an imaginary equator known as the *metaphase plate*. Metaphase ends when all chromosomes have been neatly aligned at the plate.

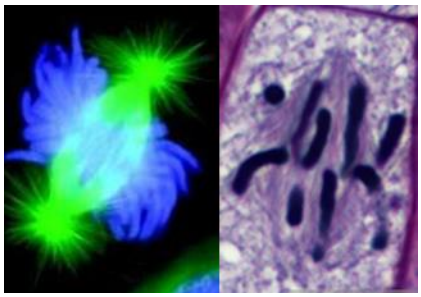

Image 3. Visualization of Metaphase
Left - a fluorescent micrograph of a lung cell showing late metaphase; Right - a light compound micrograph of an onion cell showing early metaphase
Sources: Risler, 2011 & Reschke, n.d.

- **Anaphase**

This phase is the shortest, most crucial, and visually active phases of the M phase. The initiation of anaphase starts with the removal of cohesion proteins (responsible for the presence of the centromere). This results in the two (2) chromatids of a chromosome (sister chromatids) to separate.

Anaphase is divided into two (2) parts: Anaphase A and Anaphase B. Anaphase A can be observed once the kinetochores (and in relation the chromatids) are pulled toward the opposite poles. The "pulling" is not caused by the microtubules contracting, rather the subunits of the microtubule directly attached to the kinetochore are removed, resulting in the chromatid to draw closer.

Anaphase B is observed when the poles themselves move apart. This causes the chromatids to move away from the center of the cell, allowing a clear separation. The cell membrane will be visibly elongated at this point.

Once anaphase is complete, the accurate division and separation of the cell's genome have been accomplished.

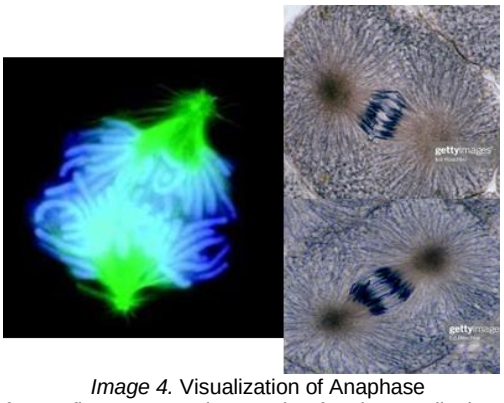

Image 4. Visualization of Anaphase
Left - a fluorescent micrograph of a lung cell showing anaphase; Top Right - a light compound micrograph of a whitefish cell showing anaphase A; Bottom Right - a light compound micrograph of a whitefish cell showing anaphase B
Sources: Risler, 2011 & Reschke, n.d.

- **Telophase**

The second to the last phase is initiated once the separated chromosomes are clearly located on opposite poles of the cell. Microtubules and centrioles disassemble to construct the new cytoskeleton of the daughter cells. A nuclear envelope will form around the chromosomes. Once enclosed, these will uncoil and begin replication for gene expression.

During late telophase, two (2) new nucleoli can be seen in the daughter cells. Daughter cells are either *diploid* (denoted as 2n) or *haploid* (denoted as n). 2n indicates that the cell contains two (2) sets of matching chromosomes from the original cell, while n indicates that the cell contains only one (1) set of chromosomes. Human cells that are not involved in reproduction (known as somatic cells) are diploid, while those that are involved in reproduction (known as gametes) are haploid.

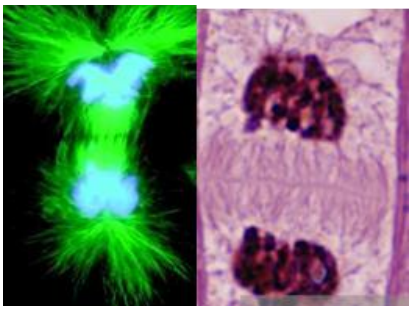

Image 5. Visualization of Telophase
Left - a fluorescent micrograph of a lung cell showing late telophase; Right - a light compound micrograph of an onion cell showing telophase
Sources: Risler, 2011 & Reschke, n.d.

- **Cytokinesis**

  Once the chromatids have been separated, the microtubule spindle will form an actin ring in between the two (2) new daughter cells. For animal cells, this is known as a *cleavage furrow*, while in plant cells it is known as the *cell plate*. This results in the splitting of the cell membrane, hence the name cyto – cells, and kinesis – movement. Cytokinesis is different from karyokinesis - which is the overall movement of genetic material.

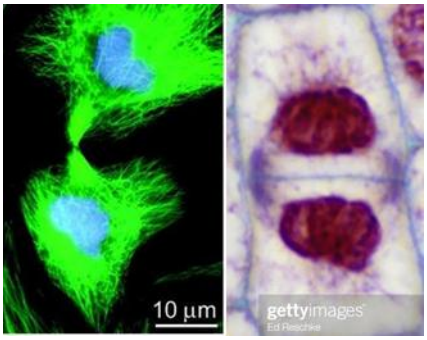

Image 6. Visualization of Cytokinesis
Left - a fluorescent micrograph of a lung cell showing cytokinesis; Right - a light compound micrograph of an onion cell showing cytokinesis.
Sources: Risler, 2011 & Reschke, n.d.

Checkpoints and Regulation of the Cell Cycle

The cell cycle requires specific indicators before proceeding with each phase. To limit the errors that may occur during each phase, three (3) main checkpoints are established. Each checkpoint is found in between critical phases that may require regulation.

- **G1 Checkpoint**

  During Gap 1, the cell is focused on increasing cell size and accumulating proteins and energy. The G1 checkpoint therefore evaluates if the necessary conditions for DNA replication have been met. If the G1 checkpoint has not been met, the cell will either remedy the necessary conditions or revert back into Gap 0 and wait until additional signals indicate that the cell is ready for division.

- **G2 Checkpoint**

  Similar to the G1 checkpoint, the G2 checkpoint asses the cell size and protein reserves of the cell. However, the main feature of G2 checkpoint is that it evaluates the DNA replicated. If the amount of DNA replicated is not enough or if there is damage detected, the cell will not proceed until the necessary changes have been made. The G2 checkpoint is the last checkpoint before proceeding with M phase.

- **M Checkpoint**

  The M Checkpoint is also referred to as the spindle checkpoint. It checks if all sister chromatids are attached to their corresponding microtubules. If the M Checkpoint is not met, the cycle will not continue. This is crucial because Meta-anaphase will determine the number of chromosomes found in each cell.

Diversity in Individuals

Mitosis is focused on cell division and producing daughter cells that are the same as the mother cell. This similarity is due to the same number of chromosomes present in the daughter cells as in the mother cell (e.g. mother has 12 chromosomes, daughters each have 12 chromosomes).

The cells in an organism's body can be categorized as either gametes (reproductive cells) or somatic (non-reproductive cells). Somatic cells in humans have two (2) sets of

chromosomes. If a cell has two (2) sets, it is referred to as a diploid cell (designated as 2n). Gametes, on the other hand, are composed of only one (1) set of chromosomes and are known as haploid cells (designated as n). For example, if an organism has 2n: 46, then its gametes are n: 23.

Diversity and variation in organisms occur when gametes from two (2) different organisms combine to form a 2n individual. This mix and match of chromosomes establishes diversity in the gene pool. The formation of gametes is known as **Meiosis.**

Meiosis

The main goal of meiosis is to take a diploid cell, reduce its chromosome number to produce haploid daughter cells. Meiosis accomplishes this by performing steps similar to Mitosis. Meiosis features two (2) specific stages referred to as Meiosis I and II.

Meiosis I

The processes found in Meiosis I are similar to that of Mitosis (there is Prophase I, Metaphase I, Anaphase I, and Telophase I). However, differences arise during the organization of genetic material. Below are the list of unique processes and events found in Meiosis I.

Name of Process	When it Occurs	Description
Synapsis	Prophase I	Pairing of homologous chromosomes and attachment via synaptonemal complex.
Crossing-over/ Recombination	Prophase I	Exchange of genetic material between attached homologous chromosomes
Formation of Tetrad	Prophase I	After recombination, the homologs are attached only at the chiasmata
Independent Assortment	Metaphase I	Homologous chromosomes are aligned at the metaphase plate but oriented randomly to ensure that each cell undergoing meiosis will have a unique arrangement.
Formation of two (2) haploid cells	Telophase I	The two (2) daughter cells contain only one (1) chromosome set and each chromosome is represented by two (2) sister chromatids.

Meiosis II

After Telophase I, a brief interphase known as interkinesis will occur before Meiosis II. This is similar to the interphase of Meiosis I but does not contain the S phase (meaning no new DNA is replicated). Meiosis II will have the same general processes of Mitosis (Prophase II, Metaphase II, Anaphase II, and Telophase II). Below are the list of processes and events found in Meiosis II.

Name of Process	When it Occurs	Description
Re-condensation	Prophase II	If the chromosomes have decondensed, they will revert to their condensed forms in Prophase II. Additionally, any formed organelles or envelopes will be fragmented.
Separation of Sister Chromatids	Anaphase II	Sister chromatids will be separated
Formation of four (4) haploid cells	Telophase	A total of four (4) daughter cells will be formed and each will contain a sister chromatid from each original homologous chromosome.

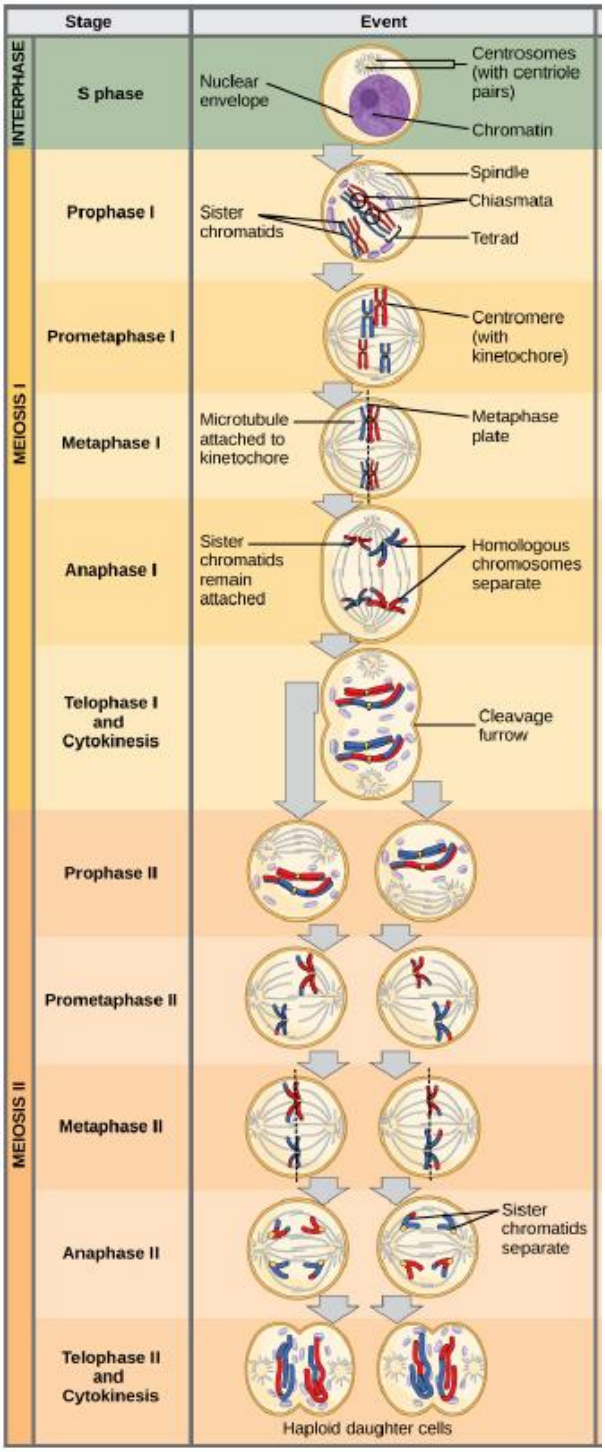

Figure 3.0 *Summary of Meiosis*
Source: (Mason, Losos, & Singer, 2017)

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