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Meiosis is how eukaryotic cells (plants, animals, and fungi) reproduce sexually. It is a process of chromosomal reduction, which means that a diploid cell (this means a cell with two complete and identical chromosome sets) is reduced to form haploid cells (these are cells with only one chromosome set). The haploid cells produced by meiosis are germ cells, also known as gametes, sex cells or spores in plants and fungi. These are essential for sexual reproduction: two germ cells combine to form a diploid zygote, which grows to form another functional adult of the same species.

The process of chromosomal reduction is important in the conservation of the chromosomal number of a species. If chromosome numbers were not reduced, and a diploid germ cell was produced by each parent, then the resulting offspring would have a tetraploid chromosome set: that is, it would have four identical sets of chromosomes. This number would keep increasing with each generation. This is why the chromosomal reduction is vital for the continuation of each species.

Meiosis occurs in two distinct phases: meiosis I and meiosis II. There are many similarities and differences between these phases, with each phase producing different products and each phase being as crucial to the production of viable germ cells.

Before meiosis, the chromosomes in the nucleus of the cell replicate to produce double the amount of chromosomal material. After chromosomal replication, chromosomes separate into sister chromatids. This is known as interphase, and can be further broken down into two phases in the meiotic cycle: Growth (G), and Synthesis (S). During the G phase proteins and enzymes necessary for growth are synthesized, while during the S phase chromosomal material is doubled.

Meiosis is then split into two phases: meiosis I and meiosis II. In each of these phases, there is a prophase, a metaphase, and anaphase and a telophase. In meiosis I these are known as prophase I, metaphase I, anaphase I and telophase I, while in meiosis II they are known as prophase II, metaphase II, anaphase II and telophase II. Different products are formed by these phases, although the basic principles of each are the same. Also, meiosis I is preceded in interphase by both G phase and S phase, while meiosis II is only preceded by S phase: chromosomal replication is not necessary again.

After Interphase I meiosis I occurs after Interphase I, where proteins are grown in G phase and chromosomes are replicated in S phase. Following this, four phases occur. Meiosis I is known as reductive division, as the cells are reduced from being diploid cells to being haploid cells.

Prophase I is the longest phase of meiosis, with three main events occurring. The first is the condensation of chromatin into chromosomes that can be seen through the microscope; the second is the synapsis or physical contact between homologous chromosomes; and the crossing over of genetic material between these synapsed chromosomes. These events occur in five sub-phases:

- **Leptonema** – The first prophase event occurs: chromatin condenses to form visible chromosomes. Condensation and coiling of chromosomes occur.

- **Zygonema** – Chromosomes line up to form homologous pairs, in a process known as the homology search. These pairs are also known as bivalents. Synapsis happens when the homologous pairs join. The synaptonemal complex forms.

- **Pachynema** – The third main event of prophase I occurs: crossing over. Nonsister chromatids of homologous chromosome pairs exchange parts or segments. Chiasmata form where these exchanges have occurred. Each chromosome is now different to its parent chromosome but contains the same amount of genetic material.

- **Diplonema** – The synaptonemal complex dissolves and chromosome pairs begin to separate. The chromosomes uncoil slightly to allow DNA transcription.

- **Diakinesis** – Chromosome condensation is furthered. Homologous chromosomes separate further but are still joined by a chiasmata, which moves towards the ends of the chromatids in a process referred to as terminalization. The nuclear envelope and nucleoli disintegrate, and the meiotic spindle begins to form. Microtubules attach to the chromosomes at the kinetochore of each sister chromatid.

Homologous pairs of chromosomes align on the equatorial plane at the center of the cell. Independent assortment determines the orientation of each bivalent but ensures that half of each chromosome pair is oriented to each pole. This is to ensure that homologous chromosomes do not end up in the same cell. The arms of the sister chromatids are convergent.

Microtubules begin to shorten, pulling one chromosome of each homologous pair to opposite poles in a process known as disjunction. The sister chromatids of each chromosome stay connected. The cell begins to elongate in preparation for cytokinesis.

Meiosis I ends when the chromosomes of each homologous pair arrive at opposing poles of the cell. The microtubules disintegrate, and a new nuclear membrane forms around each haploid set of chromosomes. The chromosomes uncoil, forming chromatin again, and cytokinesis occurs, forming two non-identical daughter cells. A resting phase known as interkinesis or interphase II happens in some organisms.

Meiosis II may begin with interkinesis or interphase II. This differs from interphase I in that no S phase occurs, as the DNA has already been replicated. Thus only a G phase occurs. Meiosis II is known as equational division, as the cells begin as haploid cells and end as haploid cells. There are again four phases in meiosis II: these differ slightly from those in meiosis I.

Chromatin condenses to form visible chromosomes again. The nuclear envelope and nucleolus disintegrate, and spindle fibers begin to appear. No crossing over occurs.

Spindle fibers connect to the kinetochore of each sister chromatid. The chromosomes align at the equatorial plane, which is rotated 90° compared to the equatorial plane in meiosis I. One sister chromatid faces each pole, with the arms divergent.

The spindle fibers connected to each sister chromatid shorten, pulling one sister chromatid to each pole. Sister chromatids are known as sister chromosomes from this point.

Meiosis II ends when the sister chromosomes have reached opposing poles. The spindle disintegrates, and the chromosomes recoil, forming chromatin. A nuclear envelope forms around each haploid chromosome set, before cytokinesis occurs, forming two daughter cells from each parent cell, or four haploid daughter cells in total.

Figure 1. The phases of meiosis I and meiosis II, showing the formation of four haploid cells from a single diploid cell.

Image Source: Wikimedia Commons

Meiosis is the production of four genetically diverse haploid daughter cells from one diploid parent cell. Meiosis can only occur in eukaryotic organisms. It is preceded by interphase, specifically the G phase of interphase. Both Meiosis I and II have the same number and arrangement of phases: prophase, metaphase, anaphase, and telophase. Both produce two daughter cells from each parent cell.

However, Meiosis I begins with one diploid parent cell and ends with two haploid daughter cells, halving the number of chromosomes in each cell. Meiosis II starts with two haploid parent cells and ends with four haploid daughter cells, maintaining the number of chromosomes in each cell. Homologous pairs of cells are present in meiosis I and separate into chromosomes before meiosis II. In meiosis II, these chromosomes are further separated into sister chromatids. Meiosis I includes crossing over or recombination of genetic material between chromosome pairs, while meiosis II does not. This occurs in meiosis I in a long and complicated prophase I, split into five sub-phases. The equatorial plane in meiosis II is rotated 90° from the alignment of the equatorial plane in meiosis I.

The table below summarizes the similarities and differences between meiosis I and meiosis II.

Table 1. The similarities and differences between meiosis I and meiosis II.

Meiosis I	**Meiosis II**
Can only occur in eukaryotes	
G phase of interphase usually occurs first	
Production of daughter cells based on parent cell's genetic material	
Means of sexual reproduction in plants, animals, and fungi	
Four phases occur: prophase, metaphase, anaphase, telophase	
Starts as diploid; ends as haploid	Starts as haploid; ends as haploid
Reductive division	Equational division
Homologous chromosome pairs separate	Sister chromatids separate
Crossing over happens	Crossing over does not happen
Complicated division process	Simple division process
Long duration	Short duration
Preceded by S-phase and G-phase	Preceded only by G-phase

Sister chromatids in prophase have convergent arms	Sister chromatids in prophase have divergent arms
Equatorial plane is centered	Equatorial plane is rotated 90°
Prophase split into 5 sub-phases	Prophase does not have sub-phases
Ends with 2 daughter cells	Ends with 4 daughter cells

Meiosis is essential for the sexual reproduction of eukaryotic organisms, the enabling of genetic diversity through recombination, and the repair of genetic defects.

The crossing over or recombination of genes occurring in prophase I of meiosis I is vital to the genetic diversity of a species. This provides a buffer against genetic defects, susceptibility to disease and survival of possible extinction events, as there will always be certain individuals in a population better able to survive changes in environmental condition. Recombination further allows genetic defects to be masked or even replaced by healthy alleles in offspring of diseased parents.

We now know that meiosis is the process of the production of haploid daughter cells from diploid parent cells, using chromosomal reduction. These daughter cells are genetically distinct from their parent cells due to the genetic recombination which occurs in meiosis I. This recombination is essential for genetic diversity within the population and the correction of genetic defects.

Meiosis I and II are similar in some aspects, including the number and arrangement of their phases and the production of two cells from a single cell. However, they also differ greatly, with meiosis I being reductive division and meiosis II being equational division. In this way, meiosis II is more similar to mitosis. Both stages of meiosis are important for the successful sexual reproduction of eukaryotic organisms.

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