1. Details of Module and its structure

Module Detail	
Subject Name	Biology
Course Name	Biology 01 (Class XI, Semester - 1)
Module Name/Title	Meiosis – Part 4
Module Id	Kebo_11004
Pre-requisites	General knowledge cell structure and function
Objectives	After going through this lesson, the learners will be able to understand the following : 1. Meiosis II 1.1 Prophase II 1.2 Metaphase II 1.3 Anaphase II 1.4 Telophase II
Keywords	Meiosis, telephase, anaphase, prophase

2. Development Team

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Table of contents :

1.Introduction

2. Meiosis II

    2.1. Prophase II

    2.2. Metaphase II

    2.3. Anaphase II

    2.4. Telophase II

3. Summary

4. Important terms used in Meiosis

1. Introduction

Chromosomal replication does not occur between meiosis I and meiosis II; meiosis I proceeds directly to meiosis II without going through interphase. The second part of the meiosis, meiosis II, resembles mitosis more than meiosis I. Chromosomal numbers, which have already been reduced to haploid (*n*) by the end of meiosis I, remain unchanged after this division. In meiosis II, the phases are, again, analogous to mitosis: prophase II, metaphase II, anaphase II, and telophase II (see figure below). As shown in the figure below, meiosis II begins with two haploid (n = 2) cells and ends with four haploid (n = 2) cells. Notice that these four meiocytes are genetically different from one another. In humans ($2n$ = 46), who have 23 pairs of chromosomes, the number of chromosomes remains unchanged from the beginning till the end of meiosis II (n = 23).

2. Meiosis II

Meiosis II is the second meiotic division, and usually involves equational segregation, or separation of sister chromatids. Mechanically, the process is similar to mitosis, though its genetic results are fundamentally different. The end result is production of four haploid cells (n chromosomes, 23 in humans) from the two haploid cells (with n chromosomes, each consisting of two sister chromatids) produced in meiosis I. The four main steps of meiosis II are: prophase II, metaphase II, anaphase II, and telophase II.

2.1. In **prophase II** we see the disappearance of the nucleoli and the nuclear envelope again as well as the shortening and thickening of the chromatids. Centrosomes move to the polar regions and arrange spindle fibers for the second meiotic division.

2.2. In **metaphase II**, the centromeres contain two kinetochores that attach to spindle fibers from the centrosomes at opposite poles. The new equatorial metaphase plate is rotated by 90 degrees when compared to meiosis I, perpendicular to the previous plate.

2.3. This is followed by **anaphase II**, in which the remaining centromeric cohesin is cleaved allowing the sister chromatids to segregate. The sister chromatids by convention are now called sister chromosomes as they move toward opposing poles.

2.4. The process ends with **telophase II**, which is similar to telophase I, and is marked by decondensation and lengthening of the chromosomes and the disassembly of the spindle. Nuclear envelopes reform and cleavage or cell plate formation eventually produces a total of four daughter cells, each with a haploid set of chromosomes.

Meiosis is now complete and ends up with four new daughter cells.

Origin and function

The **origin and function of meiosis** are fundamental to understanding the evolution of sexual reproduction in eukaryotes. There is no current consensus among biologists on the questions of how sex in Eukaryotes arose in evolution, what basic function sexual reproduction serves, and why it is maintained, given the basic two-fold cost of sex. It is clear that it evolved over 1.2 billion years ago, and that almost all species which are descendants of the original sexually reproducing species are still sexual reproducers, including plants, fungi, and animals.

Meiosis is a key event of the sexual cycle in Eukaryotes. It is the stage of the life cycle when a cell gives rise to two haploid cells (gametes) each having half as many chromosomes. Two such haploid gametes, arising from different individual organisms, fuse by the process of fertilization, thus completing the sexual cycle.

Meiosis is ubiquitous among eukaryotes. It occurs in single-celled organisms such as yeast, as well as in multicellular organisms, such as humans. Eukaryotes arose from prokaryotes more than 2.2 billion years ago and the earliest eukaryotes were likely single-celled organisms. To understand sex in eukaryotes, it is necessary to understand (1) how meiosis arose in single celled eukaryotes, and (2) the function of meiosis.

Nondisjunctio*n*

The normal separation of chromosomes in meiosis I or sister chromatids in meiosis II is termed *disjunction*. When the segregation is not normal, it is called *nondisjunction*. This results in the production of gametes which have either too many or too few of a particular chromosome, and is a common mechanism for trisomy or monosomy. Nondisjunction can occur in the meiosis I or meiosis II, phases of cellular reproduction, or during mitosis.

Most monosomic and trisomic human embryos are not viable, but some aneuploidies can be tolerated, such as trisomy for the smallest chromosome, chromosome 21. Phenotypes of these aneuploidies range from severe developmental disorders to asymptomatic. Medical conditions include but are not limited to:

- Down syndrome – trisomy of chromosome 21
- Patau syndrome – trisomy of chromosome 13
- Edwards syndrome – trisomy of chromosome 18
- Klinefelter syndrome – extra X chromosomes in males – i.e. XXY, XXXY, XXXXY, etc.
- Turner syndrome – lacking of one X chromosome in females – i.e. X0
- Triple X syndrome – an extra X chromosome in females
- XYY syndrome – an extra Y chromosome in males.

The probability of nondisjunction in human oocytes increases with increasing maternal age, presumably due to loss of cohesin over time.

In plants and animals

Overview of chromatides' and chromosomes' distribution within the mitotic and meiotic cycle of a male human cell

Meiosis occurs in all animals and plants. The end result, the production of gametes with half the number of chromosomes as the parent cell, is the same, but the detailed process is different. In animals, meiosis produces gametes directly. In land plants and some algae, there is an alternation of generations such that meiosis in the diploid sporophyte generation produces haploid spores. These spores multiply by mitosis, developing into the haploid gametophyte generation, which then gives rise to gametes directly (i.e. without further meiosis). In both animals and plants, the final stage is for the gametes to fuse, restoring the original number of chromosomes.

3. Summary

Most of the organelle duplication also occurs during this phase. S phase marksthe phase of DNA replication and chromosome duplication. G2 phase is theperiod of cytoplasmic growth. Mitosis is also divided into four stages namelyprophase, metaphase, anaphase and telophase. Chromosome condensationoccurs during prophase. Simultaneously, the centrioles move to the oppositepoles. The nuclear envelope and the nucleolus disappear and the spindlefibres start appearing. Metaphase is marked by the alignment of chromosomesat the equatorial plate. During anaphase the centromeres divide and thechromatids start moving towards the two opposite poles. Once the chromatidsreach the two poles, the chromosomal elongation starts, nucleolus and thenuclear membrane reappear. This stage is called the telophase. Nucleardivision is then followed by the cytoplasmic division and is called cytokinesis.

Mitosis thus, is the equational division in which the chromosome number ofthe parent is conserved in the daughter cell.

In contrast to mitosis, meiosis occurs in the diploid cells, which are destined toform gametes. It is called the reduction division since it reduces the chromosomenumber by half while making the gametes. In sexual reproduction when the twogametes fuse the chromosome number is restored to the value in the parent.

Meiosis is divided into two phases – meiosis I and meiosis II. In the first meioticdivision the homologous chromosomes pair to form bivalents, and undergo crossingover. Meiosis I has a long prophase, which is divided further into five phases.

These are leptotene, zygotene, pachytene, diplotene and diakinesis. Duringmetaphase I the bivalents arrange on the equatorial plate. This is followed byanaphase I in which homologous chromosomes move to the opposite poles withboth their chromatids. Each pole receives half the chromosome number of theparent cell. In telophase I, the nuclear membrane and nucleolus reappear. Meiosis

II is similar to mitosis. During anaphase II the sister chromatids separate. Thus atthe end of meiosis four haploid cells are formed.

Important terms used in Meiosis

- **Allele -** an alternative form of a gene (one member of a pair) that is located at a specific position on a specific chromosome.
- **Anaphase -** stage in mitosis where chromosomes begin moving to opposite ends (poles) of the cell.
- **Anaphase 1** - The fourth stage of the first meiotic division (meiosis I), during which maternal and paternal homologous pairs are separated on microtubules.
- **Anaphase 2** - The fourth stage of the second meiotic division (meiosis II), during which either maternal or paternal sister chromatids are separated on microtubules.
- **Asters -** radial microtubule arrays found in animal cells that help to manipulate chromosomes during cell division.
- **Cell Cycle -** the life cycle of a dividing cell. It includes Interphase and the M phase or Mitotic phase (mitosis and cytokinesis).
- **Centrioles -** cylindrical structures that are composed of groupings of microtubules arranged in a 9 + 3 pattern.
- **Centromere -** a region on a chromosome that joins two sister chromatids.
- **Chiasma** - The region of physical linkage between maternal and paternal homologous pairs during genetic reassortment. Marks the location of crossover between two nonsister chromatids.
- **Chromatid -** one of two identical copies of a replicated chromosome.
- **Chromatin -** mass of genetic material composed of DNA and proteins that condense to form chromosomes during eukaryotic cell division.
- **Chromosome -** a long, stringy aggregate of genes that carries heredity information (DNA) and is formed from condensed chromatin.
- **Cytokinesis -** division of the cytoplasm that produces distinct daughter cells.

- **Cytoskeleton -** a network of fibers throughout the cell's cytoplasm that helps the cell maintain its shape and gives support to the cell.
- **Daughter Cell -** a cell resulting from the replication and division of a single parent cell.
- **Daughter Chromosome -** a chromosome that results from the separation of sister chromatids during cell division.
- **Diploid Cell -** a cell that contains two sets of chromosomes. One set of chromosomes is donated from each parent.
- **Diploid number** - The total number of chromosomes present in a cell.
- **Gametes** - Cells with the haploid number of chromosomes. Gametes are created out of germ cells. The sperm and eggs involved in sexual reproduction are gametes.
- **Genes -** segments of DNA located on chromosomes that exist in alternative forms called alleles.
- **Genetic Reassortment** - A process in which DNA packaged as a chromosome is broken and fragments are exchanged with another independent chromosome. Occurs during prophase 1 of meiosis.
- **Germ cell** - Cells that lead to the production of gametes. Produced by meiosis.
- **Haploid Cell -** a cell that contains one complete set of chromosomes.
- **Haploid number** - The number of unique chromosomes or homologous pairs in a cell. Half the diploid number.
- **Homologous pair** - Refers to two similar chromosomes in a diploid cell. One chromosome is derived from the father gamete cell and the other from the mother gamete.
- **Interphase -** stage in the cell cycle where a cell doubles in size and synthesizes DNA in preparation for cell division.
- **Kinetochore Fibers -** microtubules that connect kinetochores to spindle polar fibers.
- **Kinetochore -** a specialized region on the centromere of chromosome where spindle polar fibers attach to the chromosome.

- **Meiosis** - A type of cellular reproduction that results in the formation of four haploid cells from one diploid cell. Contains two cellular divisions that follow only one round of DNA replication. The type of reproduction that produces germ cells.
- **Metaphase 1** - The third stage of the first meiotic division (meiosis I), during which chromosomes align at the center of the cell by way of microtubule force.
- **Metaphase 2** - The third stage of the second meiotic division (meiosis II), during which chromosomes align at the center of the cell by way of microtubule force.
- **Metaphase -** stage in mitosis where chromosomes align along the metaphase plate in the center of the cell.
- **Microtubule** - One of three protein components of the cytoskeleton. Long, cylindrical structures approximately 25 nanometers in diameter. Extend from the centrosome to all parts of the cell, forming tracks on which organelles can travel within the cell.
- **Microtubules -** fibrous, hollow rods, that function primarily to help support and shape the cell.
- **Mitosis -** a phase of the cell cycle that involves the separation of nuclear chromosomes followed by cytokinesis.
- **Nucleus -** a membrane-bound structure that contains the cell's hereditary information and controls the cell's growth and reproduction.
- **Polar Fibers -** spindle fibers that extend from the two poles of a dividing cell.
- **Prometaphase 1** - The second stage of the first meiotic division (meiosis I), during which the nuclear envelope breaks down, allowing microtubule access to chromosomes.
- **Prometaphase 2** - The second stage of the second meiotic division (meiosis I), during which microtubules attach to chromosomes.
- **Prophase 1** - The first stage of the first meiotic division (meiosis I), during which genetic reassortment takes place. Can be very long occupying up to 90% of the entire duration of meiosis.
- **Prophase 2** - The first, brief stage of the second meiotic division (meiosis II), during which condensed chromosomes are visible.
- **Prophase -** stage in mitosis where chromatin condenses into discrete chromosomes.

- **Sister chromatid** - Refers to the copy of a chromosomes that results from DNA replication and is still closely linked to its original.
- **Sister Chromatids -** two identical copies of a single chromosome that are connected by a centromere.
- **Somatic cell** - Any plant or animal cell that is not a germ cell. The class of cell formed during mitosis.
- **Spindle Fibers -** aggregates of microtubules that move chromosomes during cell division.
- **Telophase 1** - The fifth and final stage of the first meiotic division (meiosis I), during which chromosomes arrive at the poles of the cell and begin to recondense.
- **Telophase 2** - The fifth and final stage of the second meiotic division (meiosis II), during which chromosomes arrive at the poles of the cell, the nuclear envelope begins to reform, and the chromosomes begin to recondense.
- **Telophase -** stage in mitosis where the nucleus of one cell is divided equally into two nuclei.