TOPIC: CELL DIVISION:MEIOSIS

LECTURE NO:14
B.SC PART-II(SUB.)-GROUP A
DATE: 15TH APRIL 2020
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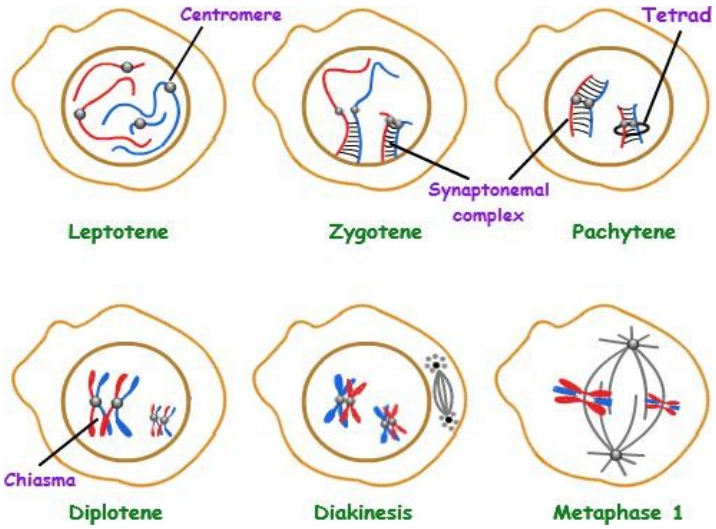
Meiosis:-

In 1887, August Weismann predicted on theoretical grounds that the number of chromosomes must be reduced by one-half during gamete formation. **Edouard Van Beneden** demonstrated reduction division in1887. **J.B. Farmer and Moore** introduced the term "meiosis" in 1905.

Mitosis occurs in all kinds of eukaryotic cells, while meiosis is confined to certain cells and takes place at a particular time. Only the cells of sexually reproducing organisms undergo meiosis, and only special cells in the multicellular organisms switch over from mitosis to meiosis at the specific time in the life cycle. Meiosis produces gametes or gametic nuclei in animals, some lower plants, and various protists and fungus groups. Meiosis forms spore in higher plants. The spores give rise to gamete producing structure called gametophytes, which produces gametes by mitosis.



Meiosis consists of two divisions that take place in rapid succession, with the chromosomes replicating only once. Thus, a parent cell produces four daughter cells, each having half the number of chromosomes and half of the nuclear DNA amount present in the parent cell. Meiosis is therefore also known as **reduction division**. The two divisions of meiosis are known as the first and the second meiotic divisions or **meiosis-I and meiosis-II.**

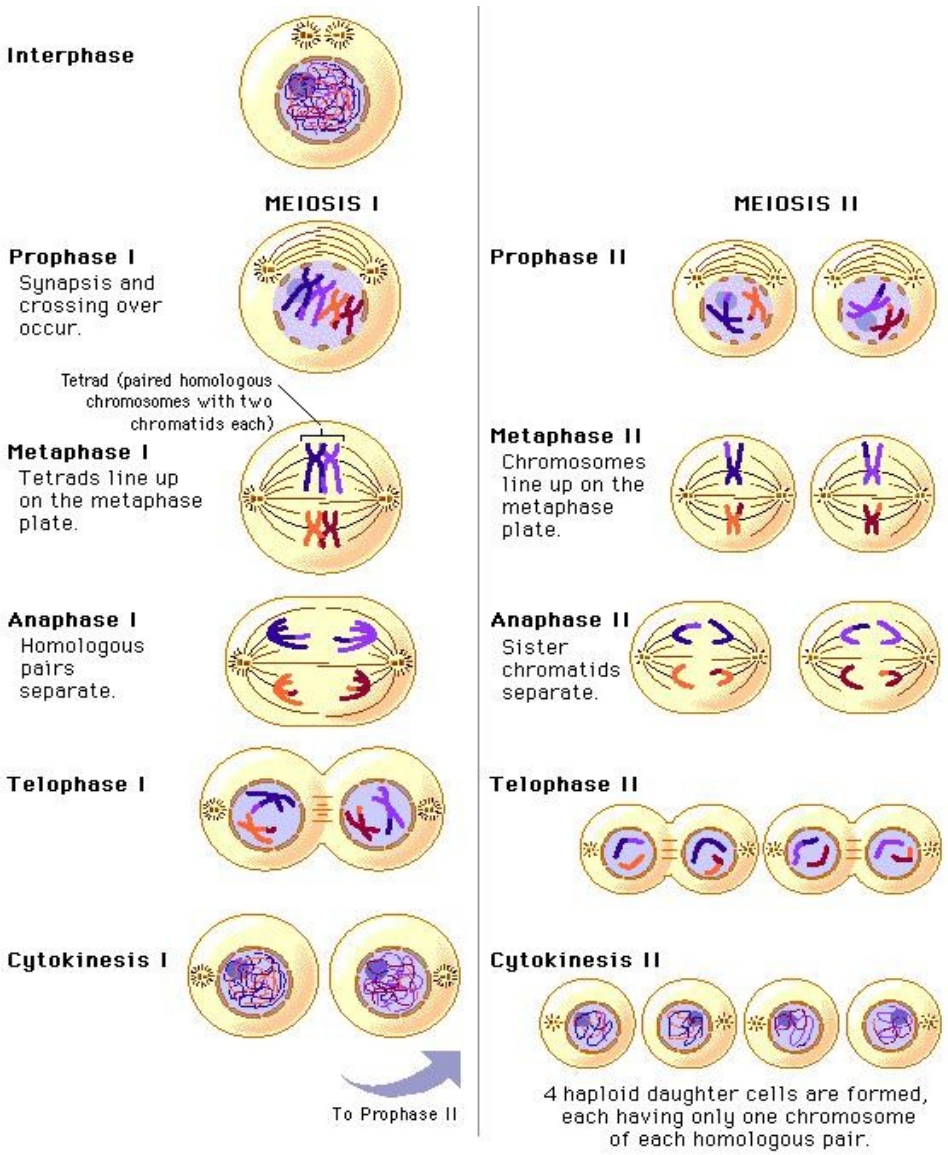


Fig.: Stages of meiosis in animal cells

Divisions of Meiosis:-

First meiotic division or Meiosis-I :-

During the first meiotic division, the two homologous chromosomes of each pair separate from each other and go to separate daughter cells. This reduces the number of chromosomes from diploid to haploid condition**. Meiosis-I** is therefore known as **heterotypic division**. The four phase of this division are called Prophase-1, metaphase-1, anaphase-1 and telophase-1.

Prophase--. The meiotic prophase-1 is **more complex** than the mitotic prophase because of the process of recombination that occurs in it. It also lasts **much longer** than the mitotic prophase in the same organism. It may extend over weeks, months or even years. Although it is more or less a continuous process, it is divided into 5 sub-stages: leptotene, zygotene, pachytene, diplotene and diakinesis.

Leptotene- Leptotene begins when chromosomes appear as thin threads by condensation. The chromosomes become thicker as condensation proceeds. They lie jumbled up so that it is not possible to trace individual chromosomes. Each chromosome is double, consisting of two chromatids due to DNA replication during premeiotic interphase. However, the chromatids are closely adhered together and are not distinguishable.

Zygotene- The homologous chromosomes come to lie side by side in pairs. The pairing of homologous chromosomes is called **Synapsis or conjugation**. A pair of homologous chromosome lying together is termed as a **bivalent**. Pairing is so through that the corresponding ends and all the corresponding genes of the two homologous chromosomes lie exactly opposite to each other. The centrosome of the chromosomes also lies adjacent to one

another. The chromatids are still not visible. A regular space of about 0.15 to 0.2 µm wide exists between the synapsed homologous chromosomes, bearing a highly specialized fibrillar organelle, **the synaptonemal complex**. The synaptonemal complex consists of three parallel and equally spaced longitudinal filaments flanked by chromatin and interconnected by short transverse filaments. The complex contains DNA and some specific proteinaceous material. It was discovered by Montrose J. Moses in 1955 in crayfish.

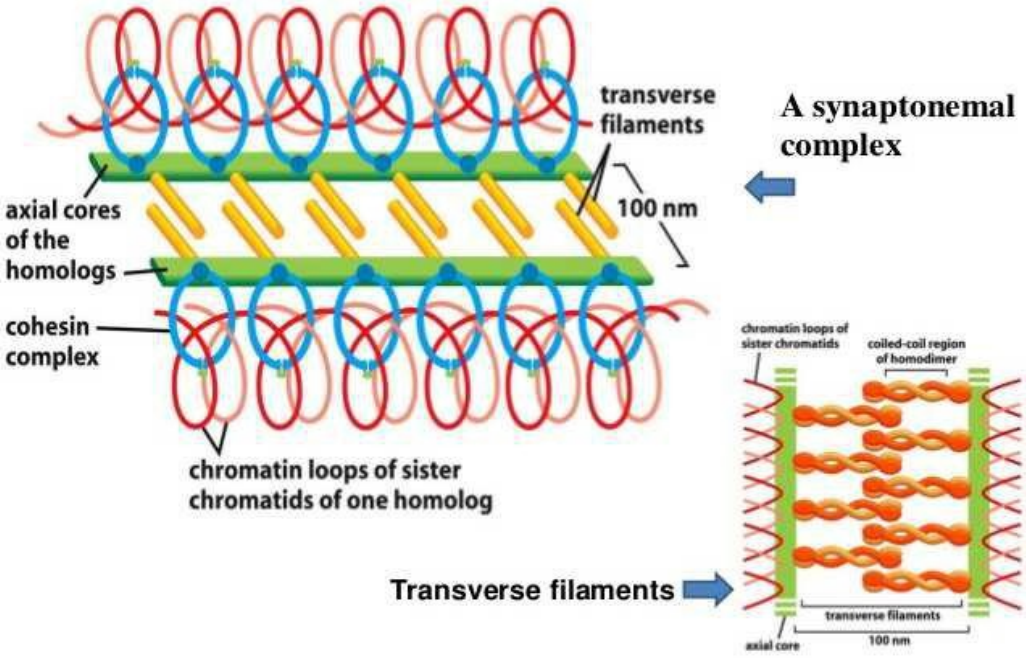


Fig. : Synaptonemal complex

Pachytene- The synapsed chromosomes continue to become short and thick. The chromatids of each synapsed chromosome slightly separate and become visible. A chromosome with two visible chromatids is known as **dyad**. A group of four homologous chromatids (two dyads) is called a **tetrad**. The number of tetrads equals the haploid number of chromosomes. The two chromatids of the same chromosomes are called are called sister chromatids and those of the two homologous chromosomes are called non-sister chromatids. The leptotene and the zygotene stages last for a few hours, the pachytene may take weeks, months or even years. It is prolonged because recombination or crossing over occurs in it.

Recombination involves mutual exchange of the corresponding segments of non-sister chromatids of homologous chromosomes. It occurs by breakage and reunion of non sister chromatid segments. Certain structures mediate the meiotic recombination by marking the sites of crossing over. These are known as **recombination nodules** (RNs). They are multicomponent proteinaceous ellipsoids found in association with the synaptonemal complex during prophase-I of meiosis (Carpenter, 1975b). The **synaptonemal complex**, a protein structure, helps in recombination by keeping the homologous chromosomes in paired state for the required period and also by containing and aligning the enzymes needed for breakage and union.

Diplotene- At this stage the **homologous chromosomes separate** at many places. This is called **disjunction**. It occurs because the synaptic forces and the synaptonemal complex disappear. The chromatids become more distinct and tetrads seem very clear. The homologous chromosomes do not separate at certain points. These points are called **chiasmata**. The chiasmata mark the sites where the exchange of chromatids occurred during pachytene. The number of chiasmata is related to the length of the chromosomes. Longer chromosomes have more chiasmata than the shorter ones. In case of single chiasmata, the bivalent looks like a cross; in case of two chiasmata, it looks like a ring; and in case of many it shows series of loops.

Diakinesis- In this stage the chromosomes condense again into short, thick rods. The chiasmata disappear by sliding towards the tips of chromosomes due to tight condensation. This process is called **terminalization**. The centrioles already duplicated in premeiotic interphase, move apart in pairs to the opposite ends of the cell. Asters form around each centriole pair. Spindle develops between the centriole pairs. The nucleolus disintegrates. The nuclear envelope breaks down into vesicles. The tetrads are released into the cytoplasm.

Metaphase- The spindle shifts to the position that is earlier occupied by the nucleus. The tetrads scattered in the cytoplasm move to the equator of the spindle. Here, they **align in two parallel metaphase plates**, one formed by chromosomes and other by their homologous. The attachment of the tetrads to the spindle microtubules in metaphase-I is different from that of mitotic metaphase chromosomes. Each homologous chromosome has two kinetochores, one for each of its two chromatids.

Both the kinetochores of a homologous chromosome connect to the same spindle pole. The two kinetochores of its homologue join the opposite spindle pole.

Anaphase-I- From each tetrad, two chromatids of a chromosome move as a unit (dyad) to one pole of the spindle, and the other two chromatids of its homologue migrate to the opposite pole. Thus, the two homologous chromosomes of each pair are separated in the anaphase-I of meiosis. The process is also called as **disjunction.** As a result half of the chromosomes, which appear in early prophase, go to each pole. Thus, it is during anaphase-I that the real reduction in the chromosome number occurs. Each chromosome at the pole is still double and consists of two chromatids. Thus, the group of chromosomes at each pole though has only one member of each homologous pair still contains twice the haploid amount of DNA.

Telophase-During telophase-I, the chromosome at each pole of the spindle partly unfold and elongate, and form a nucleus with nucleolus and nuclear envelope. The spindle and asters disappear.

The cytoplasm divides at its middle by constriction in an animal cell and by cell plate formation in a plant cell. This produces, two daughter cells, each with one nucleus. The nucleus of each daughter cell has received only one chromosome from each homologous pair. Thus, it has **half the number of chromosome, but double the amount of nuclear DNA as each chromosome is double.**

First meiotic division or Meiosis-II

The meiosis-II is similar to mitosis as in this division, the two chromatids of each chromosome separate from each other and go to separate daughter cells. With the result, the number of chromosomes remains the same as produced by meiosis-I. Meiosis-II is, therefore, known as **homotypic division.** The four stages of this division are called prophase-II, metaphase-II, anaphase-II and telophase-II.

Prophase-I- When there is no interkinesis, the telophase-I spindle is replaced by two new spindles; and the centrioles and asters, if present, duplicate and one copy of each comes to lie at each pole of the new spindles. The telophase-I chromosomes move from the poles of the old spindle to the equators of the new spindles. If decondensation has occurred during telophase-I, the chromosome recondense to short rod lets as they migrate to the metaphase-II spindles.

If interkinesis is present, centrioles move apart and asters are formed around them. A spindle is formed between the centrioles. Chromosomes each consisting of two chromatids, appear in the nucleus. They are set free in the cytoplasm by breakdown of the nuclear envelope. Nucleus disappears.

Metaphase-II- The chromosomes get arranged at the equator of the spindle as a metaphase plate. The chromatids of each chromosome are joined at their kinetochores by chromosomal microtubules extending from the opposite poles of the spindle as in mitosis.

Anaphase-II- The two chromatids of each chromosome separate and move to the opposite poles of the spindles. Here they are called chromosomes. Each pole has **haploid number of chromosomes and haploid amount of DNA**. This amount is one-fourth of the DNA present in the original cell which entered meiosis.

Telophase-I-: The chromosome at each pole decondenses, and nuclear envelope develops around them. This produces two

nuclei. Nucleolus is formed in each nucleus. Spindle and asters disappear. In cases that lack interkinesis, four nuclei are formed in telophase-II.

Cytokinesis:-

Cytoplasm divides at its middle by constriction in an animal cell and by cell plate formation in a plant cell. This produces two daughter cells. The later have half the number of chromosomes, and half the amount of nuclear DNA, i.e., in Reduction division is complete when this point is reached. The cells formed by meiosis-II in animals are mature gametes. They do not divide further. A gamete must fuse with another suitable gamete before a new individual can develop. The cells formed by meiosis-II in plants are the spores. The spores can develop into new individuals without fusing in pairs. In fact the main difference between a spore and a gamete is the ability of the spore to develop directly into a new individual.

Comparison between Mitosis and Meiosis

Mitosis and meiosis can be differentiated through following points:-

S. No.	Mitosis	S. No.	Meiosis
	It occurs in all kinds of cells and may continue throughout life.		It occurs only in special cells(gamete mother cells or spore mother cells) and at specific times
	It involves a single division, resulting in two daughter cells only.		It involves two successive divisions, resulting in four daughter cells.
3.	A cell can repeat mitosis almost	3.	Meiosis takes place only once in a cell.

	indefinitely.	
	All mitotic divisions are alike.	Two meiotic divisions are dissimilar, first is reductional and second equational.
5.	Each mitotic division is preceded by an interphase	5. The second meiotic division is generally not preceded by an interphase.
6.	Chromosomes replicate before each mitotic division.	6. Chromosome do not replicate before second meiotic division.
7.	Prophase is relatively short and simple.	7. Prophase-1 is very long and elaborate, comprising 5 sub phases.
8.	Prophase chromosomes appear double from the very start.	8. Prophase-1 chromosomes do not look double in the beginning.

9.There is no pairing of homologous chromosomes, hence no chance of crossing over.

No chiasmata are formed.

Chromatids are genetically similar to chromosomes they arise from

No synaptonemal complex forms between chromosomes.

Chromosomes do not unfold, and no transcription and protein synthesis occur in prophase.

All chromosomes form a single plate in metaphase.

The two kinetochores of a chromosome connect to both the poles of the spindle.

Anaphase involves separation of chromatids of each chromosome.

Telophase occurs in all cases.

Daughter cells have diploid number of chromosomes like the parent cell.

Daughter cells have 2n amount of DNA unlike 4n amount in

Homologous chromosomes pair and often undergo crossing over in prophase-1.

Chiasmata form temporarily where crossing over occurs.

Chromatids may differ genetically from the chromosomes they arise from due to crossing over.

Synaptonemal complex forms between synapsed homologous chromosomes

Chromosomes unfold and, transcription and protein synthesis may occur in diplotene of prophase-I.

Chromosomes form two parallel plates in metaphase-I and one plate in metaphase-II.

The kinetochores of a chromosome connect to the same spindle pole in metaphase-I and to both the poles in metaphase-II.

Anaphase-I involves separation of homologous chromosomes. The chromatids move apart in anaphase-II.

Telophase-I is eliminated in some cases.

Daughter cells have haploid number of chromosomes unlike the parent cell.

Daughter cells have 1n amount of DNA unlike the 4n amount in the parent cell.

	the parent cell.		
20.	Daughter cells divide again after interphase.	20.	Daughter cells, if gametes, do not divide further.
21.	Mitosis brings about growth, repair and healing.	21.	Meiosis forms gametes or spores, helps maintain the number of chromosomes constant from generation to generation, and introduces variation.
22.	Mitosis is much shorter than meiosis in the same animal.	22.	Meiosis is much longer than mitosis in the same animal.
23.	Cytokinesis follows usually karyokinesis.	23.	Cytokinesis often doesn't occur after meiosis-I, but always occur after meiosis-II, forming four cells simultaneously.
24.	Mitosis may occur in haploid or diploid cells	24.	Meiosis always occurs in diploid cells.
25.	Chromosomes do not show chromomeres.	25.	Chromosomes may show chromomeres.

Summary:-

Cell division is a continuous and dynamic process that involves replication of DNA, karyokinesis and cytokinesis. Mitosis and meiosis are the two types of cell division. In mitosis somatic cells are divided in two daughter cells of equal size and containing equal number of chromosomes, while meiosis is a reductional cell division that takes place in germ cells. Cell cycle undergoes various phases like long interphase (time between the end of telophase and beginning of next phase); G_1-Phase (time between previous mitosis and beginning of DNA synthesis; S-Phase during which duplication of each chromosomes takes place; G_2-Phase, the gap between DNA synthesis and nuclear division and a short mitotic phase during which the already duplicated chromosomes are equally distributed to the diploid daughter cells. The cell cycle is controlled by various parameters like nucleo-cytoplasmic ratio; cyclic nucleotides; phosphorylation and the protein cyclin. Mitosis or the equational cell division involves various stages like prophase, metaphase, anaphase and telophase followed by cytokinesis. It is a vital process as it maintains the size, growth, chromosome number of the cell along with carrying out repairs, healing and regeneration and reproduction of cell. Meiosis involves two stages, meiosis-I and meiosis-II that takes place in rapid succession, with the chromosomes replicating only once. During meiosis-I two homologous chromosomes of each pair separate from each other and go to separate daughter cells, reducing the number of chromosomes from diploid to haploid condition. Its first stage is prophase-I that is further divided into 5 sub stages: i) Leptotene (during leptotene condensation of chromosomes takes place), ii) zygotene (during zygotene homologous chromosomes pair and synaptonemal complex is formed.) iii) pachytene is the third sub-stage in which two chromatids of synapsed chromosomes becomes visible and is known as dyad. Recombination also takes place during this stage. iv) At the stage of diplotene disjunction at many points takes

place on homologous chromosomes. v) Diakinesis: During diakinesis terminalization takes place. Meiosis-II is similar to mitotic division in which two chromatids of each chromosome separate from each other and go to separate daughter cells. Various stages involved are prophase-II, metaphase-II, anaphase-II and telophase-II. At the end of the cell division cytoplasm divides at its middle by constriction in an animal cell and by cell plate formation in a plant cell. This process is called cytokinesis.

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