- Biochemically, meiosis uses some of the same mechanism employed during mitosis to accomplish the redistribution of chromosomes. There are several features unique to meiosis, most importantly the pairing and recombination between homologous chromosomes, which enable then to separate from each other.
- The cells of a particular species have a constant number of chromosomes. In sexually reproducing organisms male and female gametes fuse together to form the zygote. If the gamete has the same number of chromosomes number remains constant from generation to generation. This is because of meiotic division which reduces the chromosome number to half, and counteracts the effect of fertilization. Thus fertilization and meiosis are compensating events.

Types of meiosis

- The cells in which meiosis takes place are called meiocytes. In animals, meiocytes are of two types, spermatocytes and oocytes. In higher plants, meiocytes are differentiated into microsporocytes and megasporocytes. Depending upon the stage when meiosis occurs, the latter is of three types - gametic, zygotic and sporic meiosis.

Gametic meiosis

- Meiosis is most of the animal take place during the formation of gametes (gametogenesis). It is termed as genetic meiosis. When two gametes fuse in fertilization, a diploid zygote is formed. Gametic meiosis results in diplontic life cycle

Zygotic meiosis

- In some lower plants meiosis takes place in the zygote and the resulting organism are haploid. It is called zygotic meiosis. Organism having zygotic meiosis have haplontic life cycle.

Sporic meiosis

- In plants, meiosis generally occurs at the time of sporogenesis (formation of spore or microspores and megaspores) It is called sporic meiosis or intermediate meiosi. Spores produce a new gametophytic phase in the life cycle. Gametes are formed by gametophytes. Because of the presence of two distinct multicelluar phase, diploid and haploid, life cycle of plant is diplohaplontic .

Phases of meiosis

- Because of meiosis is “a one-way” process, it cannot be said to engage in a cell cycle as mitosis does. However, the preparatory steps that lead up to meiosis are identical in pattern and name of the interphase of the mitotic cell cycle.

- Meiosis is a type of cell division that is vital for sexual reproduction. Meiosis takes place in the reproductive organs. It results in the formation of gametes with half the normal chromosomes number. Therefore, haploid sperms are made in the testis and haploid eggs are made in the ovaries. In flowering plants, haploid gametes are made in the anthers and ovules.
- Meiosis involves two divisions of the cell. These two division are termed meiosis I nad meiosis II. Each one includes prophase, metaphase, anaphase and telophase.
- Meiosis I consists of separating the pairs of homologous chromosomes, each made up of two sister chromatids, into two cells. One entire haploid content of chromosomes is contained in each of the resulting daughter cells; the first meiotic division therefore reduces the ploidy of the original cell by a factor of 2.

Meiosis I

- In meiosis I, the homologous pairs in a diploid cell separate, producing two haploid cells, so it is also referred to as a reduction division. Like mitosis, it is studied under for stages – prophase, metaphase, anaphase and telophase.

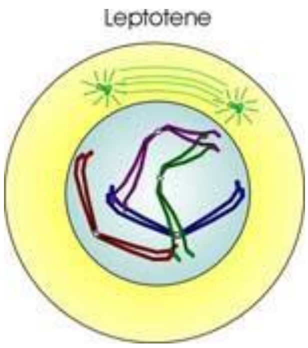
Prophase I

- Prophase I is more complicated and prolonged as compared to the siliar stage of mitosis. For the sake of convenience, prophase I is divided into five sub-phases: Leptotene, zygotene, pachytene, diplotenme and diakinesis. Another sub-phase called preleptoneme is sometimes recognized prior to leptonema. In this phase chromosomes are not distinguishable because of their thinness but sex chromosomes (if present) are often seen as heterochromatic (heteropyknotic) bodies.

Leptotene

- Leptotene also known as leptonema is a first stage of prophase I during which individual chromosomes begin to condense into long strands within the nucleus which are loosly interwoven. However the two sister chromatids are still so tightly bound that they are indistinguishable from one another.
- Leptotene chromosomes may be irregularly arranged or may be polarized towards the centrioles forming a ‘bouquet’. Electron microscope studies have shown that bouquet formation results when a group of chromosomes is attached close together on the nuclear membrane . In plant cells the chromosomes may sometimes form a tangle of threads, called the synizetic knot, on one side of nucleus.
- There are two sets of chromosomes in a diploid cell undergoing meiosis, one set contributed by the male parent and other by the female parent. These are

always two similar chromosomes, having the same size, form and structure. They are called homologous chromosomes. One of them is paternal chromosome and the other maternal chromosome.

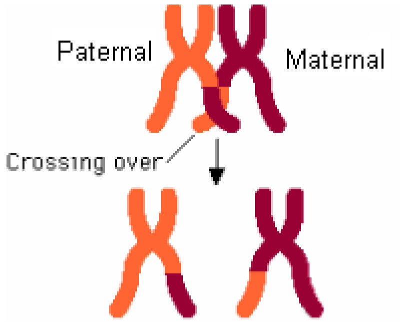


Zygotene

- During zygotene or zygonema the chromosomes become shorter anad thicker. The homologous chromosomes come to lie side by side in pairs . (G. zygon = yolk; tene = thread). This pairing of homologus chromosomes is known as synapsis or syndesis. A pair of homologous chromosomes lying together is called a bivalent. The chromatids are still not visible. A fibrillar, somewhat ladder-like , organelle, called synaptonemal complex, develops between the synapsed homologous chromosomes. It is thought to stabilize the paired condition of chromosomes till crossing over is completed.
- Pairing of two homologous chromosomes begins when their corresponding ends come together on the nuclear matrix. Pairing may occur in one of the following three ways-
  (i) Proterminal pairing : It starts at the ends and proceeds towards the middle
  (ii) Procentric pairing: it begins at the centromeres and progresses towards the ends.
  (iii) Random (intermediate) pairing: It commences at many point towards the ends.
- The synaptonemal complex is attached at both ends through its lateral element to the inner surface of the nuclear membrane. The central elements is not attached directly . Also arising from the lateral elemnent is another series of smaller loops. These loops fuse in the middle line to make up the central element.

Pachytene

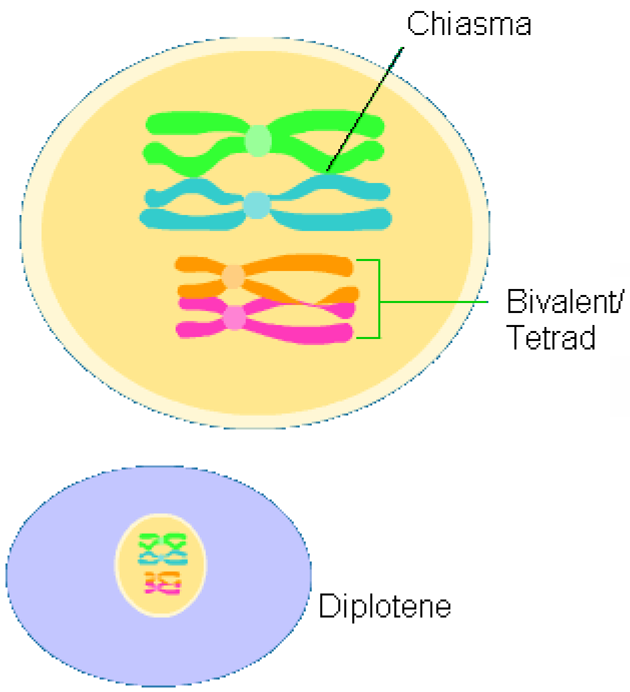
- Zygotene is followed by pachytene or pachynema. It is said to begin when synapsis is completed. It lasts from the completion of the synaptonemal complexes to the stage where their breakdown begins
- The synapsed chromosomes continue to become short and thick (G. pachus = thick, tene = thread). The chromatids of each synapsed chromosome slightly separate and become visible. The two visible chromatids of a chromosome are referred to as a dyad. A group of four homologous chromatids (two dyads) is called sister chromatids and those of two homologous chromosomes (bivalent) are termed non-sister chromatids.
- Crossing over (recombination) occurs during pachytene. Recombination involves mutual exchange of the corresponding segments of non-sister chromatids of homologous chromosomes. It takes place by breakage and reunion of chromatid segments. Breakage, called nicking, is assisted by an enzyme endonuclease and reunion, termed annealing, is aided by an enzyme ligase.
- It has been found that crossing over is a common event. Normally, each tetrad undergoes at least one recombination.



Diplotene

- During diplotene or diplonema the synaptic forces keeping the homologous chromosomes together come to an end. The homologous chromosomes start separating (G. diplos = double; tene = thread). This is called disjunction. It makes chromatids more distinct and the tetrads very clear. Separation of homologous chromosomes does not take place at the points called chiasmata (singular, chiasma). The chiasmata make the sites where crossing over occurred during pachytene (Gr . chiasma = crosspiece). They help in holding homologous chromosomes together.
- The number and position of chiasmata varies with the length of the chromosomes and with the species. Chiasmata are found in the meiosis of almost all eukaryotic organism. However, achiasmatic meiosis (meiosis without chiasma) has been reported in some organisms, e.g. males of higher dipteral (includeing Drosophila), Panorpa (scorpion fly), many mantids and roaches, some grasshoppers and scorpions. A chiasma formed at the ends of chromosomes is called termical chiasma. Chiasmata formed along the lengths of chromosomes are called interstitial chiasmata.

- During diplotene the chiasmata begins to be displaced along the length of the chromosome. The terminal chiasma slips off the ends of the chromosomes, and its position is taken up by an interstitial chiasma, which is now called the terminal chiasma. This process is called terminalization. As diplotene progresses the number of interstitial chiasmata becomes lesser in number. The terminalization may be due to electrostatic force or despiralization of chromosomes.
- When terminalization is completed the homologous remain in contact through the terminal chiasma. The degree of terminalization is expressed by the terminalization coefficient (T).
- The synaptonemal complexes mostly disappear during diplotene. In certain regions short segments may persist. The most common regions where the complexes persists are, near the ends of the bivalents where the lateral elements are attached to the nuclear membrane, and at the sites of chiasmata formation. With the disappearance of the synaptonemal complexes the axial filaments become unpaired.
- In diplotene, the chromosomes may unfold to nearly normal form and start transcription of mRNA and rRNA to build up food reverves in the cytoplasm. This process is most profound in the primary ooctytes of amphibians, reptiles and brids. In some species, the chromosomes enlarge greatly, assuming lampbrush form.



Diakinesis

- Diakinesis is not sharply differentiated from diplotene. The chromosomes become more conctracted. The bivalents are more evenly distributed in the nucleus and migrate towards the periphery. RNA synthesis stops. Nucleolus degenerates. A spindle begins to develop, with or without centrioles.

Prometaphase I

- The nuclear membrane disappears in prometaphase I and the chromosomes reach their maximum contraction. Spindle formation begins

Metaphase I

- The chromosomes now become arranged on a equator of the cell, The spindle is formed. Spindle fibres becomes attached to the centromeres of the two homologous chromosomes. The two centromeres of each bivalent lie on opposite side of the equatorial plate.
- The attachment of tetrads to the spindle fibres in metaphase I is different from that of mitotic metaphase chromosomes. Each homologous chromosome has two kinetochore, 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 homologous join the opposite spindle pole. In metaphase I of meiosis there are bivalents, each bivalent consisting of two centromeres.

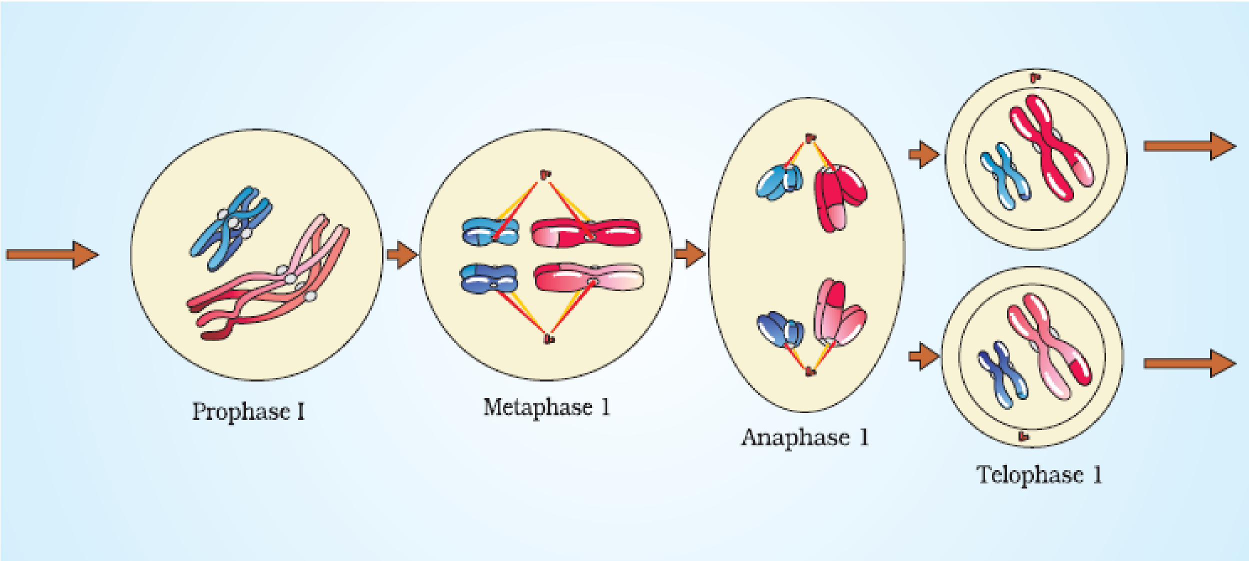
Anaphase I

- During anaphase I, from each tetrad two chromatids of a chromosome move as a unit (dyad) to one pole of a spindle, and the remaining two chromatids of its homologue migrate to the opposite pole.
- Thus, the homologous chromosomes of each pair, rather than the chromatids of a chromosome, are separated. As a result, half of the chromosomes, which appear in early prophase, go to each pole. It is here in the anaphase I that the real reduction in the poles is still double and consists of two chromatids. This is in contrast to the single-stranded chromosomes of mitotic anaphase
- The paternal and maternal chromosomes of each homologous pair segregate during anaphase I independently of the other chromosomes. Anaphase I is cytological event that corresponds to Mendel's law of independent assortment. Although the paternal and maternal chromosomes of a homologous pair have the genes for the same traits, either chromosome of a pair may carry different alleles of same genes. Therefore, independent assortment of homologous chromosomes in anaphase I introduces genetic variability.

Telophase I

- During telophase I the chromosomes at each pole of the spindle uncoil and elongate, but remain straight and often do not assume interphase form. The satellite chromosome develop forms around the chromosomes and nucleoli. The spindle and the astral rays gradually disappear.

- The cytoplasm divides at its middle by cleavage (constriction) in an animal cell and by cell plate formation in plant cell. This produces two daughter cell, each has received only one chromosome from each homologous pair. Thus it has half the number of chromosomes, but double the amount of nuclear DNA as each chromosome is still double.
- The daughter cells formed by meiosis I are called secondary spermatocytes or secondary oocytes in male and female animals.
- Cell enter a period of rest as interkinesis or interphase II. No DNA replication occurs during this stage. Protein and RNA synthesis may occur. It is important for bringing true haploidy.



Meiosis II

- The second meiotic division is essentially similar to mitosis. 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. If however, differs from mitosis in that DNA does not duplicate, while centromere do so. It has 4 phases – Prophase II, metaphase II, anaphase II, and telophase II.

Prophase II

- Prophase II takes an inversely proportional time compared to telophase I. In this process we see the disappearance of nucleoli and the nuclear envelop again as well as the shortening and thickening of chromatids. Centrioles move to the polar region and are arranged by spindle fibres.

Metaphase II

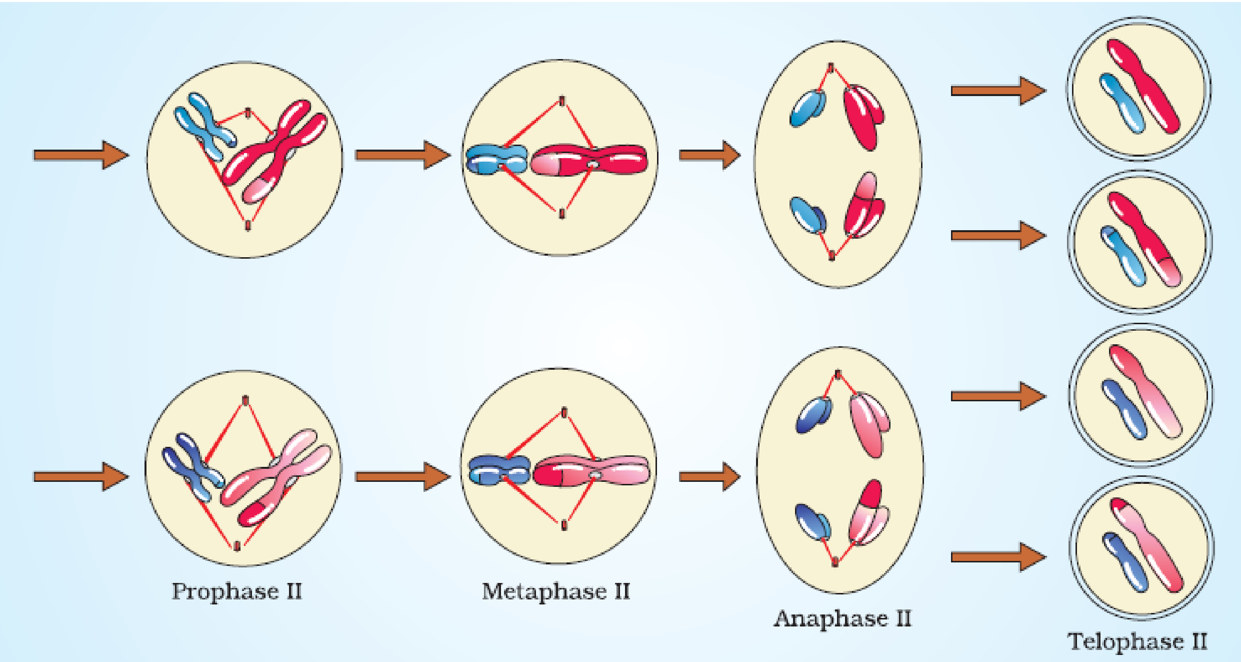
- In metaphase II the chromosomes become oriented on the equatorial plate and have the relationship to the spindle as in mitosis.

Anaphase II

- Anaphase II, where the centromeres are cleaved, allows the kinetochores to pull the sister chromatids apart. The sister chromatids by convention are now called sister chromosomes, and they are pulled towards opposite poles

Telophase II

- In telophase II the group of chromosomes at each pole of the spindle gets enclosed by a nuclear envelope. Nucleoli are laid sown, Astral rays and spindles are lost



Cytokinesis

- Cytoplasm divides at its middle by furrowing in an animal cell and by cell plate formation in a plant cell. This produces two daughter cells. The latter have half the number of chromosomes and half the amount of nuclear DNA. These cells are mature gametes in animals and spores in plants.
- Cytokinesis may occur after each nuclear division. In such cases, it is said to be of successive type. First the diploid parent cell divides by heterotypic division into two haploid cells, which then produce four haploid cells by homotypic division. The four daughter cells may form a linear or isobilateral tetrad. Often cytokinesis is delayed until both the nuclear divisions are completed, so that four cells are simultaneously formed, each with a haploid nucleus. The cytoplasmic division in such cases is said to be of simultaneous type

Significance of meiosis

- Formation of gametes – Meiosis forms gametes that are essential for sexual reproduction .
- Genetic information – It switches on the genetic information for the development of gametes or gametophytes and switches off the sporophytic information
- Meiosis facilitates stable sexual reproduction – Without the halving of ploidy, or chromosome count, fertilization would result in zygotes that have twice the number of chromosomes than the zygotes from the previous generation. Successive generations would have an exponential increase in chromosome count, resulting in an unwildy genome that would cripple the reproductive fitness of the species. Most importantly, however, meiosis produces genetic variety in gametes that propagates to offspring. Recombination and independent assortment allows for a greater diversity of genotype in the population. As a system of creating diversity, meiosis allows a species to maintain stability under environment changes.
- Crossing over- It introduces new combination of traits or variations.
- Mutations – Chromosomal and genomatic nutations can take place by irregularities of meiotic divisions. Some of these mutations are useful to the organism and are perpetuated by natural selection.
- Evidence of basic relationship of organisms – Details of meiosis are essentially similar in the majority of organisms showing their basic similarity and relationship.

ABNORMAL CELL GROWTH

- Cell division is a gene controlled process. The telomere of chromosomes contains repetitive sequence of six nucleotide. These regions code for an enzyme telomerase which control cell division. As cells go on dividing with each division the number of nucleotide decreases and ultimately cells stop dividing.
- Uncontrolled cell division may lead to the formation of undifferentiated aggregate of cells termed tumor or neoplasm.
- Uncontrolled cell division leads to hyperplasis, hypertrophy, metaplasis, neoplasia, and He La cell.
- The increased production and growth of normal cells in a tissue or organ is termed hyperplasia. It is an accelerated rate of cell division resulting from an increased level of cell metabolism. This generally results in an enlargement of tissue mass and organ size. It occurs only in tissues capable of mitosis such as the epithelium of skin, intestine and glands. Some cells do not divide and thus can not undergo hyperplasia, for example nerve and muscle cells.
- An increase in the size of a tissue or organ brought about by the enlargement of its cells is termed hypertrophy. When cells hypertrophy, components of the

cell increase in number with increased functional capacity to meeting increased cells needs. Hypertrophy generally occurs in situations where the organ or tissue can not adapt to an increased demand by formation of more cells. This is commonly seen in cardiac and skeletal muscles cells, which do not divide to form more cells.

- The process of conservation of normal tissue cells into an abnormal form in response to stress or injury or infection is termed metaplasia. It is a cellular replacement process.
- The new and abnormal development of cells that may be benign or malignant is termed neoplasia. There are two types of neoplasm – benign and malignant
  - Benign growth : the benign growth is restricted to a particular site of the body and the cells never spread out to different parts of the body e.g. simple tumor
  - Malignant growth : in malignant growth after the cells are being formed at a particular site, the cells move out different parts of the body and initiate similar type of growth. The stage of malignant growth in which the cells spread out through the body fluid to different parts of the body is termed metastasis. Malignant growth is also termed cancerous growth.
- He La cells (an aneuploid epithelial cells) are cell line culture of first human cancerous cells donated by Henrietta Lacks from their uterine carcinoma cells since 1952. These cells are maintained for use in studying cellular processes.