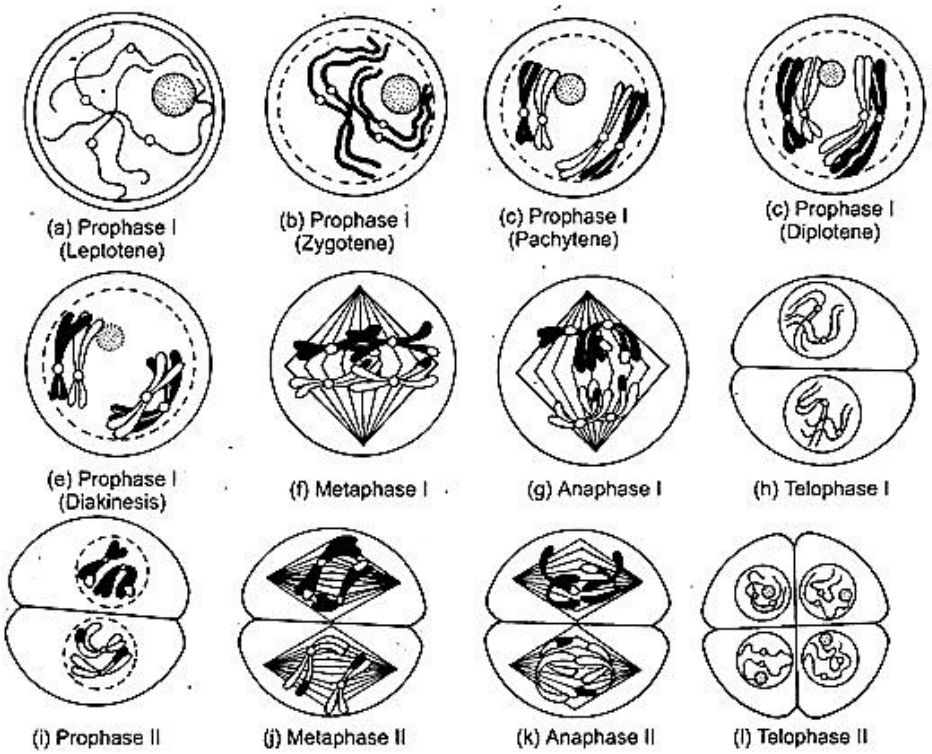
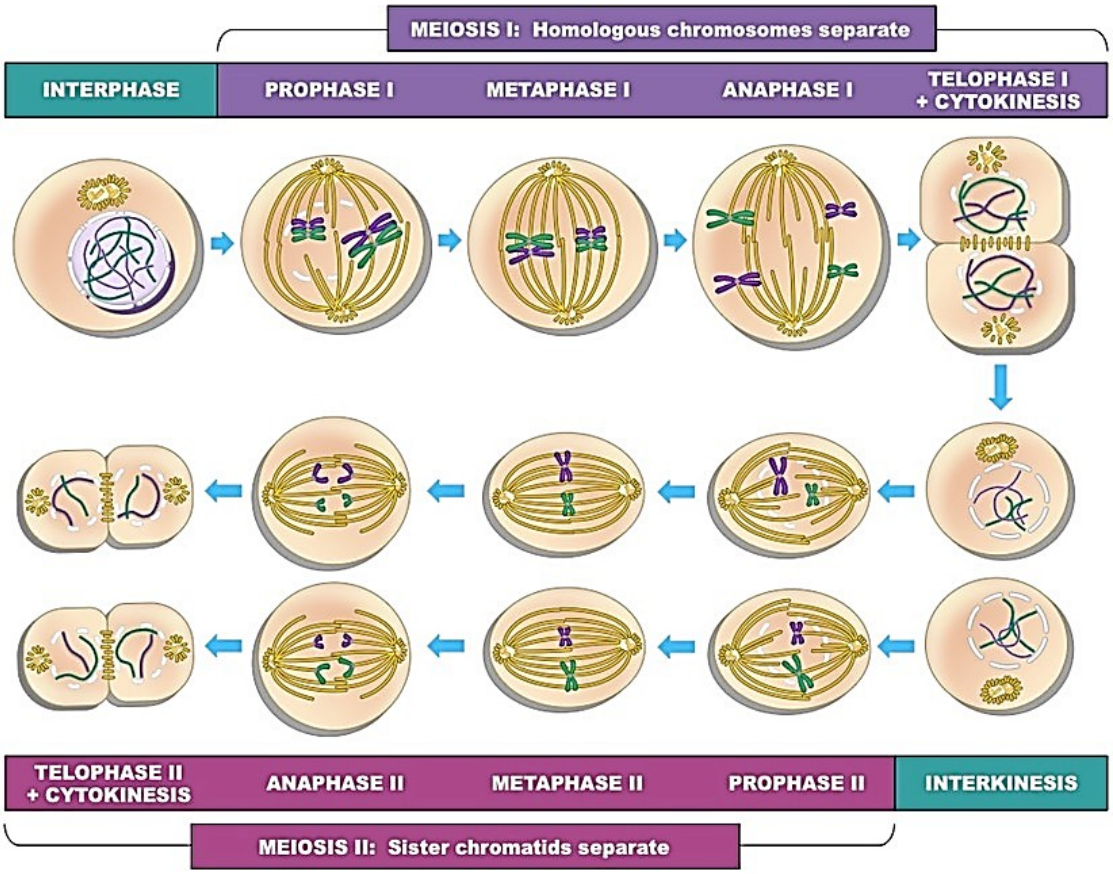
MEIOSIS

(DR. C. CHATTERJEE)





Meiosis

Every sexually reproducing organism is characterized by another type of cell division occurring in the germinal line, where the chromosome number undergoes reduction. This division occurs in the male and female organs of flowers in plants and gonads in animals.

In meiosis, single interphase is followed by two nuclear divisions — Meiosis-I and Meiosis-ll. Meiosis I is reductional division and Meiosis-II is equational division.

1. Meiosis results in formation of four daughter cells from a single mother cell in each cycle of cell division. In other words, the nuclei divide twice in each cell cycle.

2. Daughter cells are identical to mother cell in shape and size but different in chromosome composition. The daughter cells have haploid chromosome number. The chromosome types also differ in daughter cells due to segregation and recombination.

3. Meiosis occurs in reproductive organs like anthers and ovaries and leads to the production of gametes or spores.

4. The complete process of meiosis consists of two types of division. The first division results in reduction of chromosome number to half and is called reductional division. The second division is like mitotic division.

5. Meiosis results in segregation of chromosomes and genes and their independent assortment. Crossing over and recombination also occur during meiosis.

Stages of Meiosis:

The process of meiosis as indicated earlier, consists of two types of division, viz., first meiotic and second meiotic division. Before initiation of meiosis, there is an interphase which consists of G_1, S and G_2 phases like mitosis. But here the G_2 phase is of very short duration.

The S phase occurs only once in the entire process of meiosis. There is no S phase after first division of meiosis. During S phase 99.7% of the total DNA present in the nucleus is synthesized and remaining 0.3% DNA synthesis takes place during zygotene stage.

Meiosis I and II

- **Meiosis I** separates the pairs of homologous chromosomes, reduces the cell from diploid to haploid.
- **Meiosis II** separates each chromosome into two chromatids (chromosome behavior in meiosis II is like that of mitosis)

Prophase I

- The homologous chromosomes pair and exchange DNA to form recombinant chromosomes.
- **Note** - in oocyte development, from birth until puberty oocytes are in "prophase I arrest" at diplotene stage. This is important for sustaining the ovarian oocyte pool and lutenizing hormone (LH) induces resumption of meiosis I.

Prophase I is further divided into five stages (phases):

Leptotene

- leptotene phase, leptonema; Greek, *leptotene* = "thin threads"
- the duplicated paired chromosome homologs condense.

Zygotene

- zygotene phase, zygonema, Greek, *zygotene* = "paired threads"
- homologous chromosomes become closely associated (synapsis) to form pairs of chromosomes consisting of four chromatids (tetrads).
- the synaptonemal complex begins to form between the two sets of sister chromatids in each bivalent (the duplicated chromosome paired with its homologous duplicated chromosome).

Pachytene

- pachytene phase, pachynema; Greek, *pachytene* = "thick threads"
- crossing over between pairs of homologous chromosomes (meiotic recombination or synapsis) to form chiasmata (form between two nonsister chromatids at points where they have crossed over)
- synaptonemal complex is complete and can be stable for some time.
- Autosomal non-sister chromatids of homologous chromosomes can now extensively exchange segments in regions of homology.
- Only small regions of non-paired sex chromosomes interact
- Mutations that compromise meiotic recombination in male spermatocytes result in arrest and apoptosis at this stage.

Diplotene

- diplotene phase, diplonema; Greek, *diplonema* = "two threads"
- homologous chromosomes begin to separate but remain attached by chiasmata.
- synaptonemal complex degrades and the chromosomes separate from one another a small amount giving this appearance.
- It is possible that some chromosome uncoiling may also occur allowing some gene transcription.
    - In the developing human ovary, oocytes remain at the diplotene stage from fetal life through postnatal childhood, until puberty when the lutenizing hormone (LH) surges stimulate the resumption of meiosis.

Diakinesis

- diakinesis phase; Greek, *diakinesis* = "moving through"
- homologous chromosomes continue to separate, and chiasmata move to the ends of the chromosomes.
- prophase I ends and chromosomes now recondense, transcription stops and the transition to metaphase occurs.

Prometaphase I

- Spindle apparatus formed, and chromosomes attached to spindle fibres by kinetochores.

Metaphase I

- Homologous pairs of chromosomes (bivalents) arranged as a double row along the metaphase plate. The arrangement of the paired chromosomes with respect to the poles of the spindle apparatus is random along the metaphase plate. (This is a source of genetic variation through random assortment, as the paternal and maternal chromosomes in a homologous pair are similar but not identical. The number of possible arrangements is 2n, where n is the number of chromosomes in a haploid set. Human beings have 23 different chromosomes, so the number of possible combinations is 223, which is over 8 million.)

Anaphase I

- The homologous chromosomes in each bivalent are separated and move to the opposite poles of the cell.

Telophase I

- The chromosomes become diffuse and the nuclear membrane reforms.

Cytokinesis I

- Cellular cytoplasmic division to form two new cells, followed by Meiosis II.
- **Note -** in oocyte meiosis, the extrusion of the first polar body (1 PB) indicates completion of the first meiotic division.

Prophase II

- Chromosomes begin to condense, nuclear membrane breaks down and spindle forms.

Metaphase II

- Spindle fibres attach to chromosomes, chromosomes align in cell centre.

Anaphase II

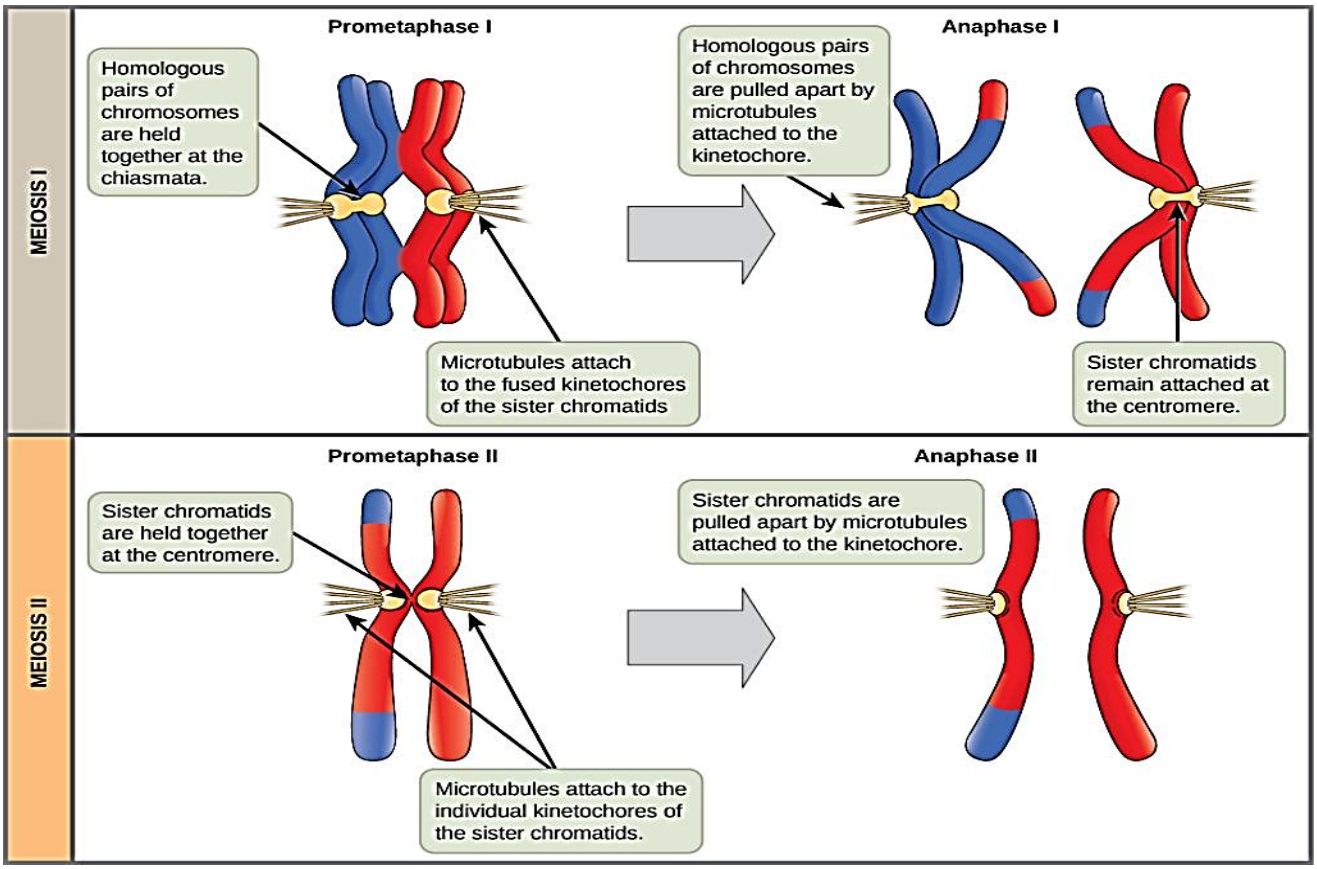
- Chromosomes separate and move to the opposite poles of the cell.

Telophase II

- Chromosomes reach spindle pole ends and the nuclear membrane reforms.

Cytokinesis

Cellular cytoplasmic division to form new cells. The division of cytoplasm takes place either by cell plate method (in plants) or by furrow method (in animals). The cytokinesis may take place after meiosis I and meiosis II separately or sometimes it may take place at the end of meiosis II only. In maize, it occurs after meiosis I and meiosis II. However, in Trillium cytokinesis occurs only at the end of Meiosis II.



Synaptonemal Complex:

According to Moses (1955), the synaptonemal complex is a organized structure of filaments between the paired chromosomes in zygotene and pachytene stages of meiosis, i.e., the morphological expression of the synapsed chromosome. At the end of zygotene, contact between a pair of parental homologous chromosomes occur and the pairing is exact and point to point. The process is known as synapsis and this is probably due to existence of specific mutual attractive forces between the homologous chromosomes, known as synaptic force.

Ultrastructure :

In cross section it can be observed that the synaptonemal complex is flattened ribbon like structure. Under electron microscope the synaptonemal complex appears consisting of parallel dense strands lies in a single plane that are curved and are twisted along its axis. These are flanked by chromatin.

The distance between the homologous chromosomes is considerable in molecular forms, more: than 200 nm of the three dense lines – the central element is of variable prominence, whereas the two lateral arms are very dense. The central element may also appear as a long tripartite bar with ladder like transverse connections .

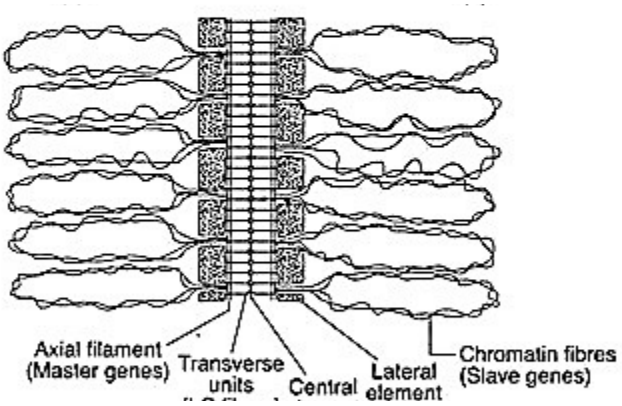
The lateral arms vary in width in various species. They are formed of electron dense coarse granules or fibres. These arms are joined to the adjacent chromosomes by fine fibrils. The lateral elements show sub-divisions in two longitudinal components.

Series of lateral loops of chromatin arise from lateral elements. These loops fuse in the middle line to form central element. The synaptonemal complex is attached at both ends through its lateral elements to the inner surface of the nuclear membrane.

Function

Synaptonemal complex is considered as prerequisite to chiasma formation and crossing over (Meyer). Moses inferred that it may serve chiasma formation by facilitating effective synapsis by maintaining pairing in fixed state, and by providing a structural framework within which molecular recombination may occur.

King suggested that the synaptonemal complex may orient the non-sister chromatids of homologous chromosomes in a manner that facilitates enzymatically induced exchanges between their DNA molecules. Coming & Okada suggested that synaptonemal complex pulls homologous chromosomes into approximate association with each other.



Genetic Control of Meiosis:

It is believed that meiosis is genetically controlled. Various features of meiosis are controlled by genes.

Some of the features of meiosis which are genetically controlled are described below:

1. Synapsis and Exchange:

Synapsis or pairing between homologous chromosomes may depend on the presence of a specific allele. For example, in maize when this allele is absent, synapsis is prevented between all homologous loci. In the absence of synapsis, no exchange occurs between homologous chromosomes and distribution of chromosomes is also irregular during anaphase I.

In Drosophila male, crossing over does not occur because the homologous chromosomes pair only in the heterochromatic region near centromere. Heterochromatin is considered devoid of active genes, hence exchange is prevented. However, the pairing is normal in females.

2. Centromere Behaviour:

The specific behaviour of centromere during meiosis is genetically controlled. At metaphase II, centromeres of sister chromatids lie very close together. But when one of them faces one pole of spindle, the other one automatically faces the opposite pole.

In Drosophila, in the presence of a particular allele, sister centromeres separate early at metaphase II and orient to the spindle independently. As a result, both sister centromeres sometimes orient to the same pole and hence are not distributed to daughter nuclei properly. However, this allele has no effect on mitosis or meiosis I.

3. Spindle Shape:

The shape of spindle is governed by a specific allele. The presence of abnormal alleles changes the shape of spindle in maize and Drosophila during meiosis but not mitosis. A normal allele causes the meiotic spindle to have convergent ends.

With such spindle, all the chromosomes come together in group to the pole and are included in a telophase nucleus. In the presence of abnormal allele, divergent spindles are formed. Such spindles lead to the spread of chromosomes at anaphase in such a way that some are left but of telophase nuclei.

4. Spindle Orientation:

The orientation is usually similar in meiosis I and meiosis II. This leads to formation of four nuclei or cells. When this direction is opposite to that of meiosis I, the result is a cluster of four nuclei or cells.

Significance of Meiosis:

Meiosis plays a very important role in the biological populations in various ways as given below:

1. It helps in maintaining the chromosome number constant in a species. Meiosis results in production of gametes with haploid (half) chromosome number. Union of male and female gametes leads to formation of zygote which receives half chromosome number from male gamete and half from the female gamete and thus the original somatic chromosome number is restored.

2. Meiosis facilitates segregation and independent assortment of chromosomes and genes.

3. The recombination of genes also takes place during meiosis. Recombination of genes results in generation of variability in a biological population which is important from evolution points of view.

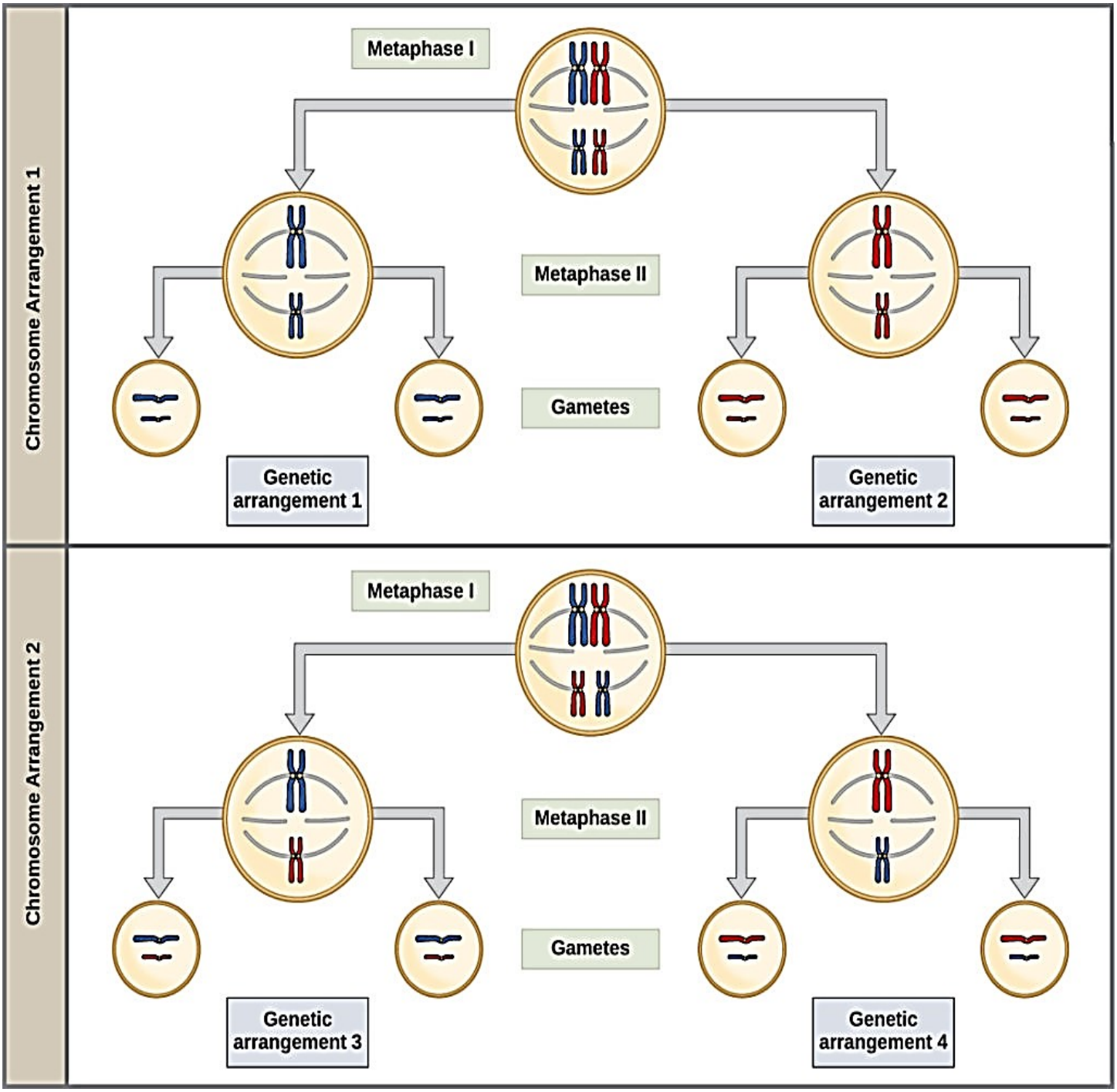
4. In sexually reproducing species, meiosis is essential for the continuity of generation. Because meiosis results in the formation of male and female gametes and union of such gametes leads to the development of zygote and thereby new individual.

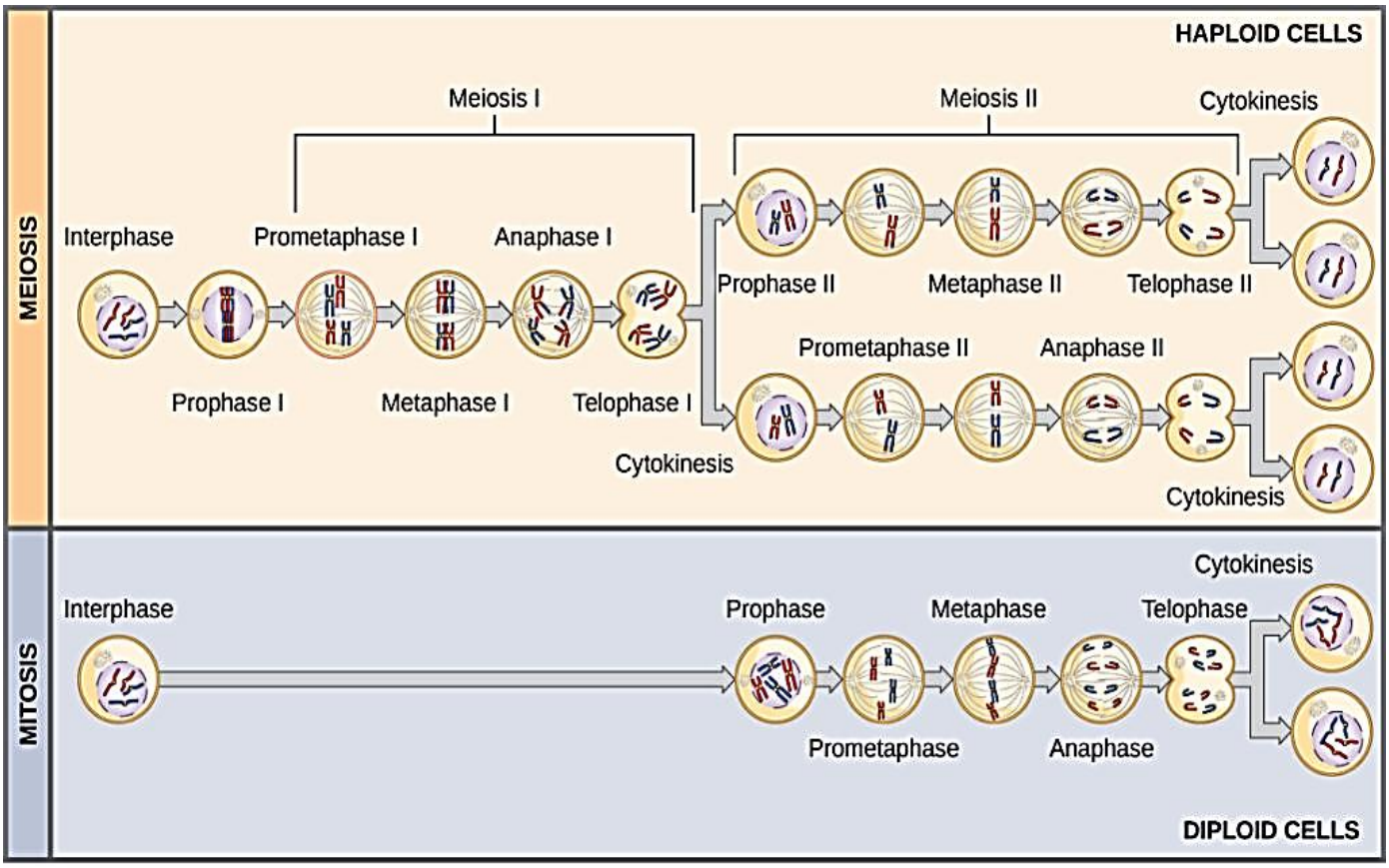
Importance of Meiosis:

The meiosis is a logical and necessary part in the life cycle of sexually reproducing organisms, since it leads to the formation of gametes or sex cells, capable of engaging in fertilization. These gametes are haploid cells having only one member of each homologous pair.

The meiosis is concomitant of doubling of chromosome number due to gametic fusion. The gametes formed as a result of meiosis are haploid and the zygote formed by their fusion is diploid. Thus it is the only means for restoring the chromosome number, characteristic of the species.

Meiosis provides for new combinations of genetic material. During crossing over, the hereditary factors from male and female parents get mixed due to breakage and exchange of chromatids in pachytene. Thus the gametes produced are not all alike but with variable combination of genes. The random segregation of paternal and maternal chromosomes and the new alignments of genes in them resulting from crossing over, ensure genetic variations in the population. This inherited variability leads to the evolution of organisms.


Chromosome Arrangement 1
Metaphase I
Metaphase II
Gametes
Genetic arrangement 1
Genetic arrangement 2
Chromosome Arrangement 2
Metaphase I
Metaphase II
Gametes
Genetic arrangement 3
Genetic arrangement 4



						OUTCOME
PROCESS	DNA synthesis	Synapsis of homologous chromosomes	Crossover	Homologous chromosomes line up at metaphase plate	Sister chromatids line up at metaphase plate	Number and genetic composition of daughter cells
MEIOSIS	Occurs in S phase of interphase	During prophase I	During prophase I	During metaphase I	During metaphase II	Four haploid cells at the end of meiosis II
MITOSIS	Occurs in S phase of interphase	Does not occur in mitosis	Does not occur in mitosis	Does not occur in mitosis	During metaphase	Two diploid cells at the end of mitosis