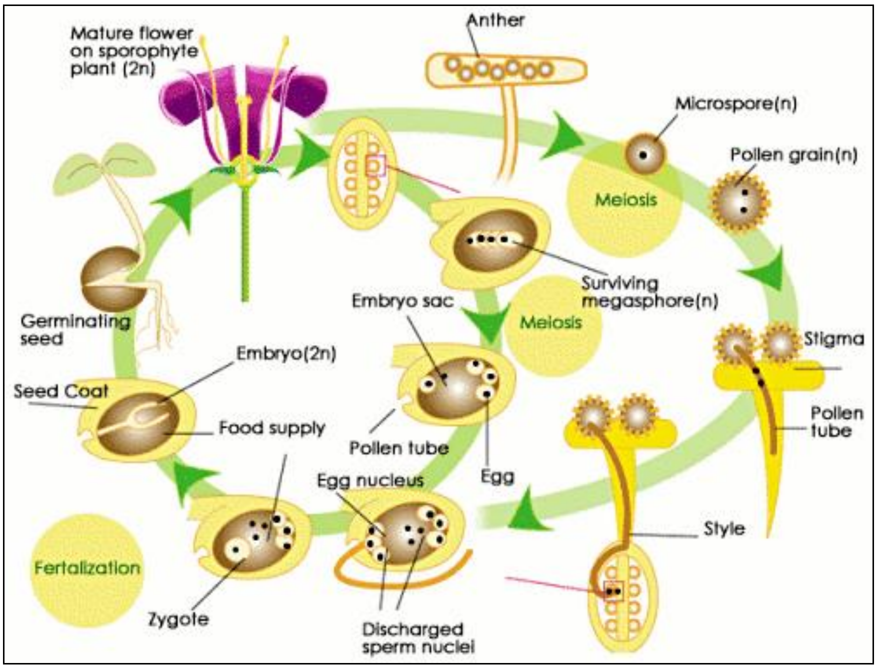
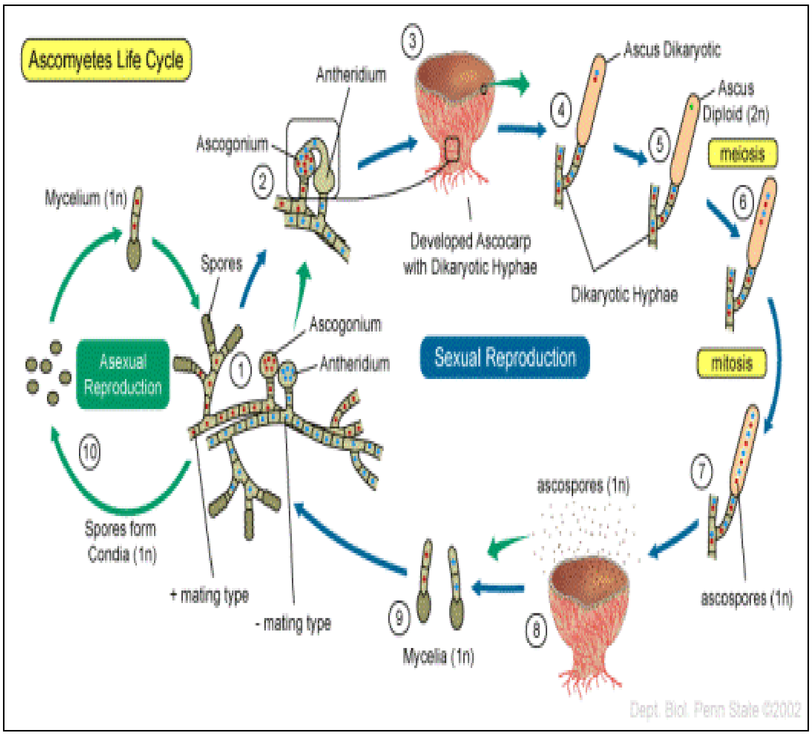
MEIOSIS AND SEXUAL REPRODUCTION

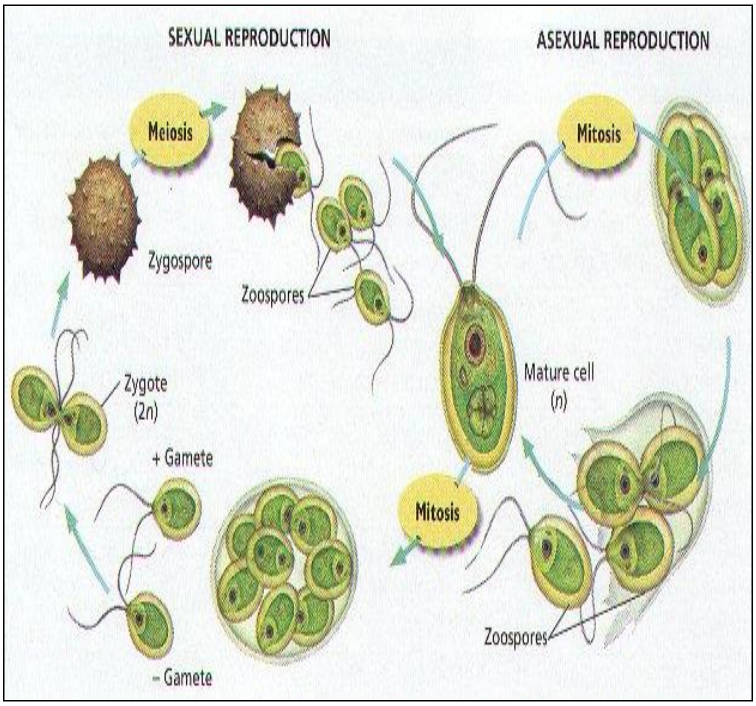
Meiosis is a special type of cell division necessary for sexual reproduction, in eukaryotes, such as plants, algae, fungi and animals, to produce gametes (figure below).



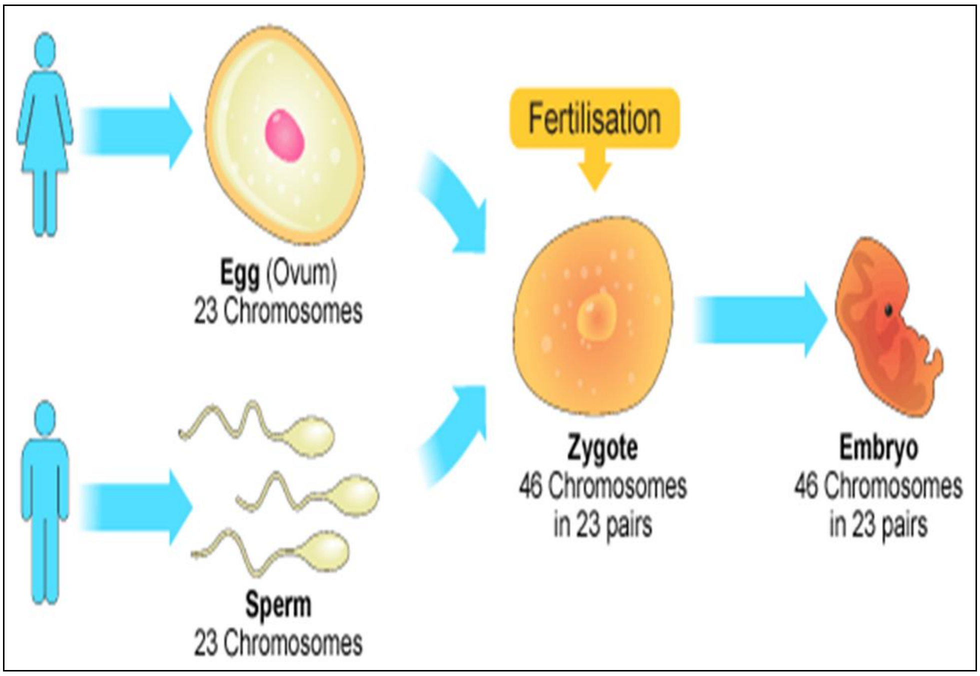
Flowering plants



Fungus

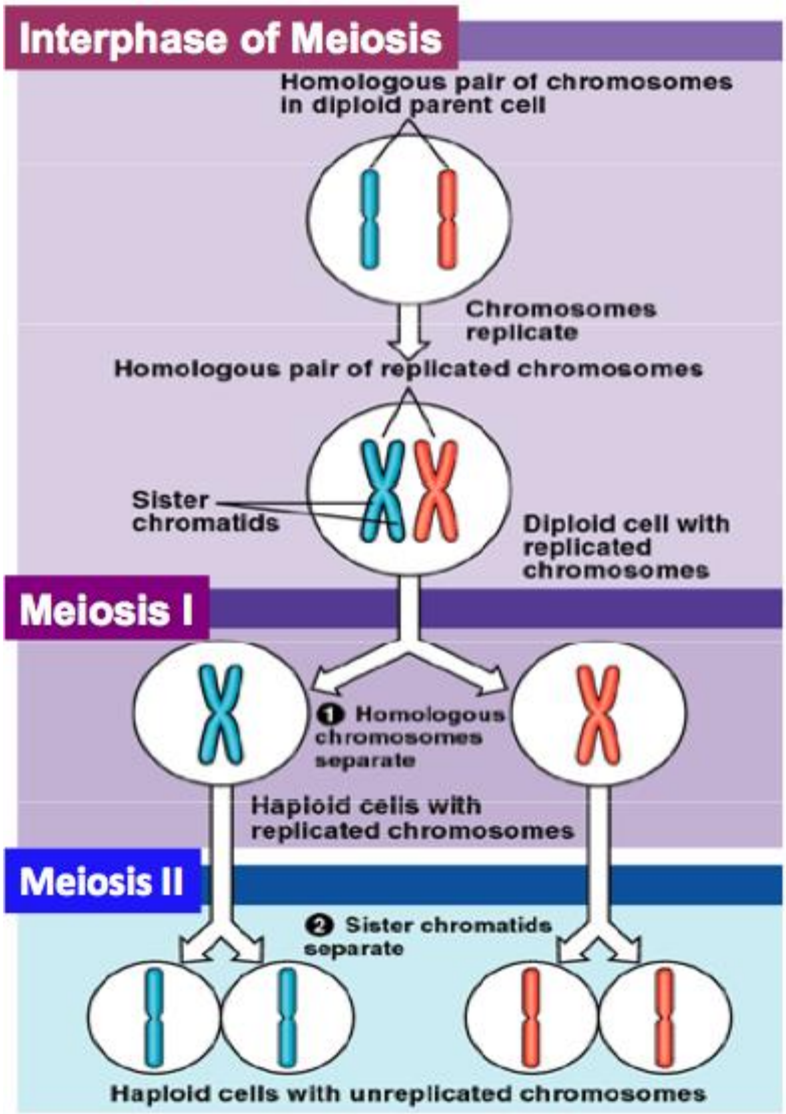

SEXUAL REPRODUCTION
ASEXUAL REPRODUCTION
Meiosis
Mitosis
Zygospore
Zoospores
Mature cell
(n)
Zygote
(2n)
+ Gamete
– Gamete
Mitosis
Zoospores

Alga

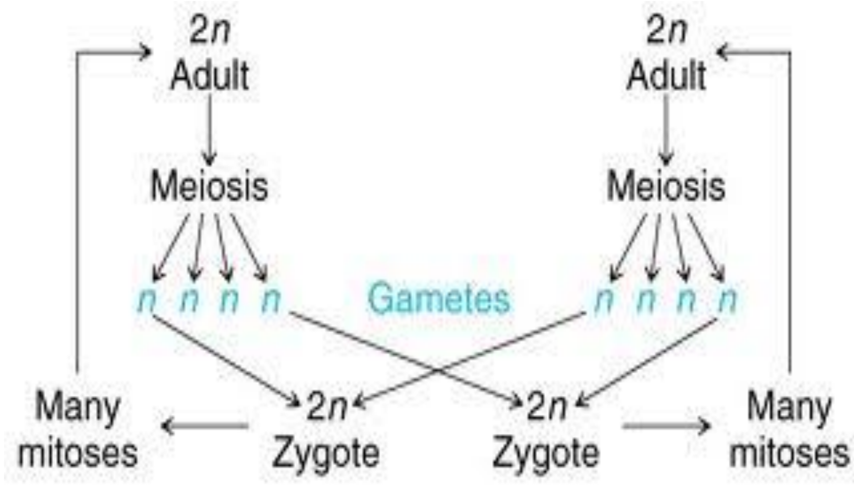

Fertilisation
Egg (Ovum)
23 Chromosomes
Sperm
23 Chromosomes
Zygote
46 Chromosomes
in 23 pairs
Embryo
46 Chromosomes
in 23 pairs

Human

The process includes: 1) number of sets of chromosomes in the cell undergoing meiosis is reduced to half the original number, typically from two sets (diploid) to one set (haploid). 2) the chromosome is reduced from double to single structure.



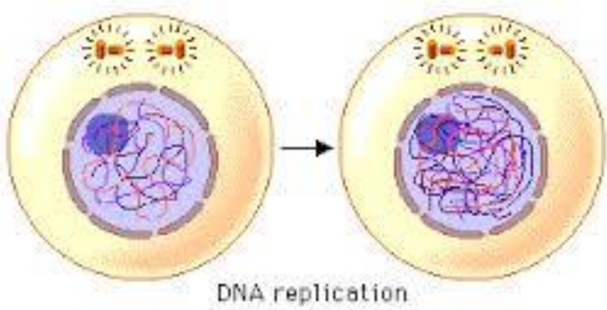
In many organisms, including all animals and land plants (but not some other groups such as fungi), gametes are called sperm in males and egg cells (or ova) in females. Since meiosis has halved the number of sets of chromosomes, when two gametes fuse during fertilization, the number of sets of chromosomes in the resulting zygotes restored to the original number.



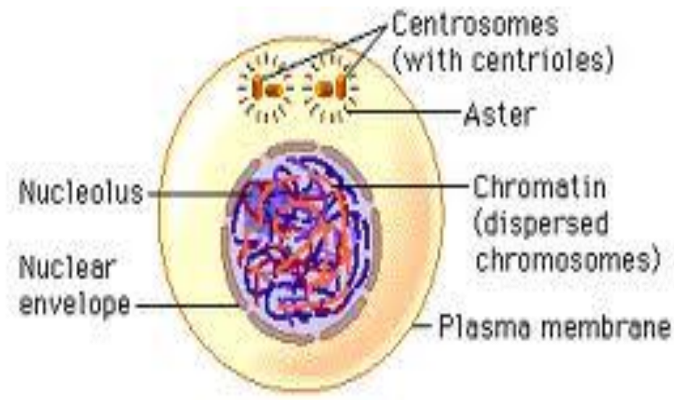
Meiosis is divided into two stages, meiosis I and meiosis II which are further divided into Karyokinesis I (prophase I, metaphase I, anaphase I, telophase I) and Cytokinesis I then Karyokinesis II (prophase II, metaphase II, anaphase II, telophase II) and Cytokinesis II, respectively, dividing the cells once at each stage.

Meiosis I (reduction division)

Because meiosis is a "one-way" process, it cannot be said to engage in a cell cycle as mitosis does. However, the preparatory steps that leads up to meiosis are identical in pattern and name to the interphase of the mitosis. So, just before meiosis I there is Interphase I where there is DNA replication, organelle synthesis and an increase in energy stores.

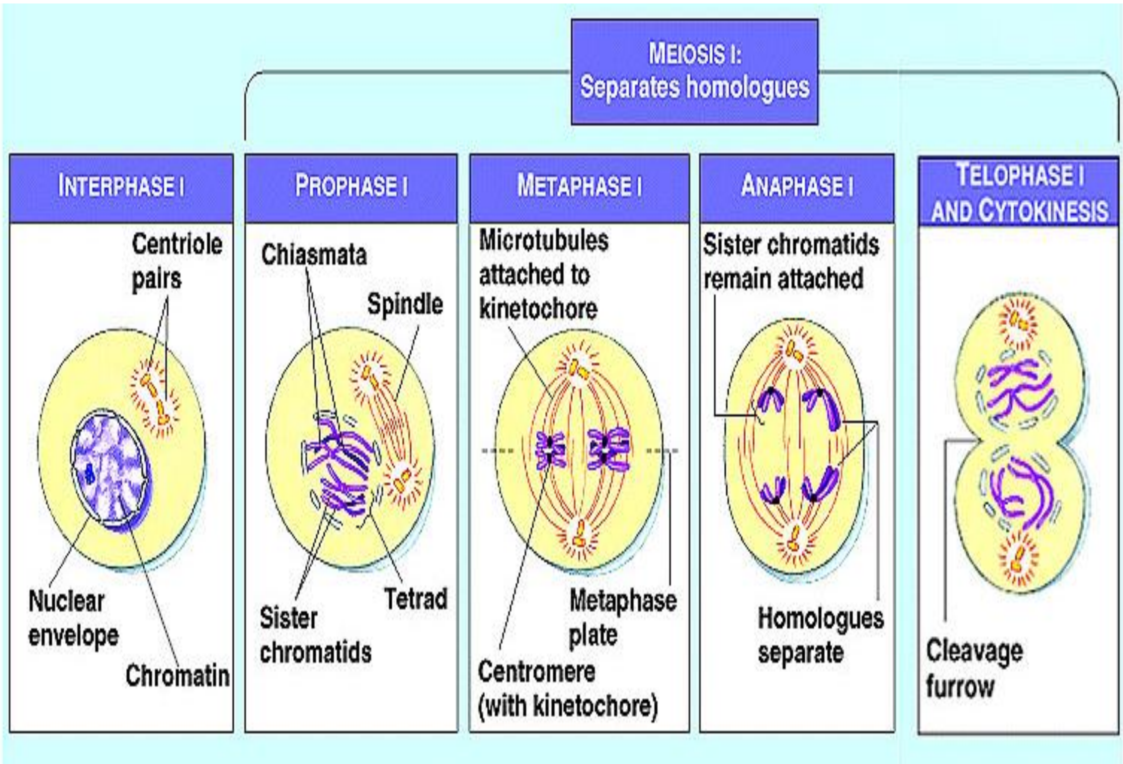


Interphase I



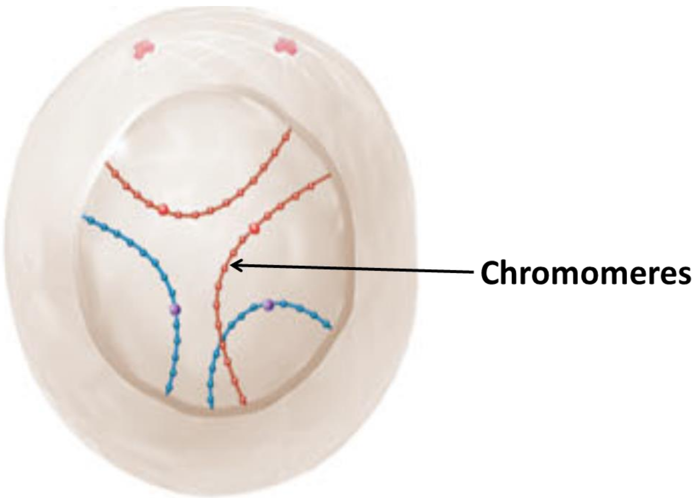
In Meiosis I, the number of sets of chromosomes in the cell undergoing meiosis I is reduced to half the original number, typically from diploid to haploid (reduction division or separates homologues), but the chromosome structure remains double.

Meiosis I is divided into Karyokinesis I (prophase I, metaphase I, anaphase I, telophase I) and Cytokinesis I (figure below).

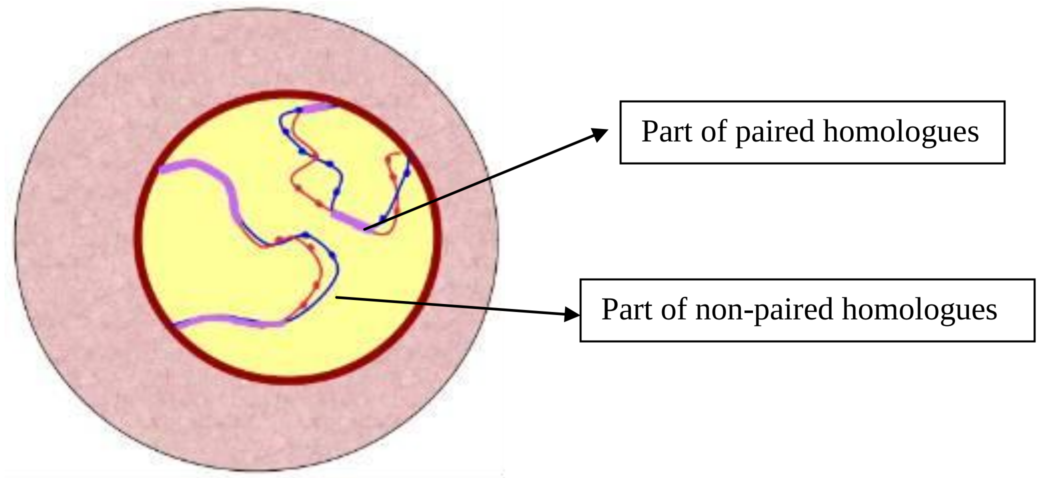


Prophase I: It is the longest phase of meiosis. It is subdivided into the following 5 substages (figure below):

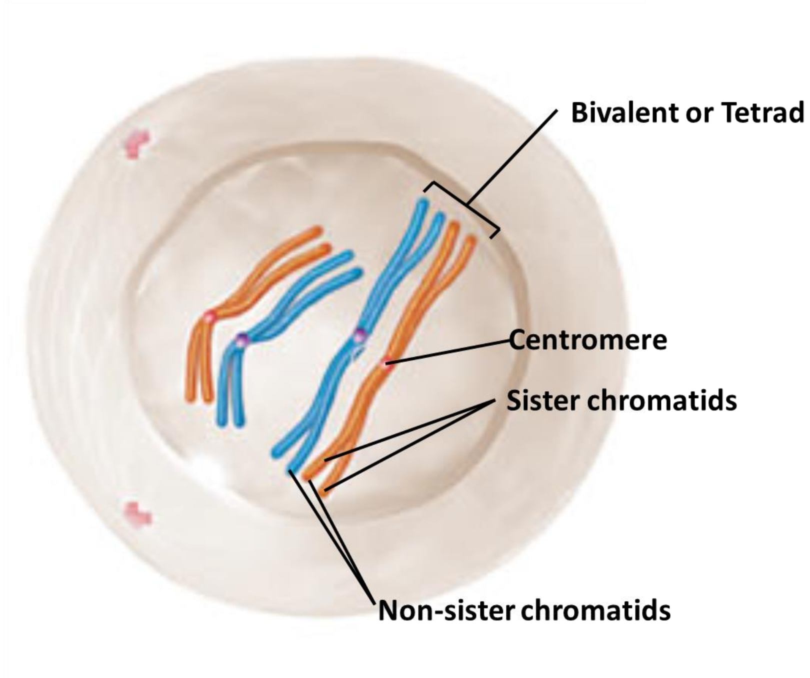
Leptotene (leptonema)**:** The first stage of prophase I that means "thin threads". This stage is of very short duration in which the individual chromosomes (each consisting of two sister chromatids, **Dyad**) change from the diffuse state into visible strands within the nucleus but they are not yet fully condensed. Along each chromosome some localized condensations are present and resemble beads on a string known as **chromomeres**. The chromosomes, while they have this threadlike form, are called *chromatonemata* (sing. chromonema; -*nema* is Greek for *thread*). The chromosomes appear single because the sister chromatids are still so tightly bound to each other that they cannot be separately seen. Sister chromatids of each dyad are held together along their length by cohesin and at centromeres region, they are held together by both cohesin and Shugoshin proteins. The chromosomes are 2n and double in structure (2n dyad).

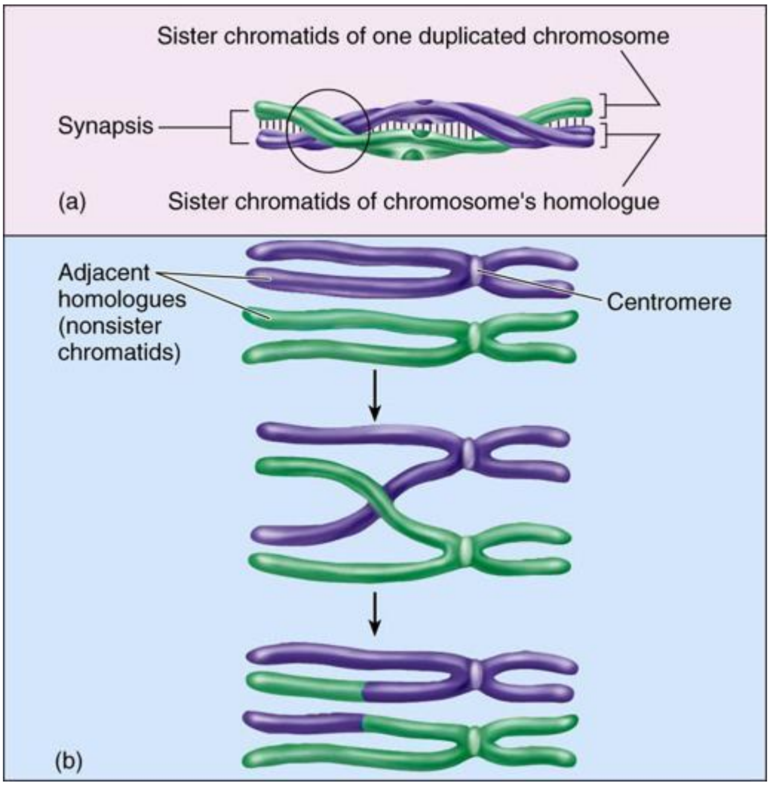


Zygotene (zygonema)**:** This stage means "paired threads", in which the chromosomes continue to shorten and thicken. Homologous chromosomes undergo initial alignment with one another (rough pairing) At this stage, the synapsis (pairing/coming together) of homologous chromosomes take place so, the fused homologs look like a single chromosome under the light microscope, but they are actually double. **Synapsis** is the process of fusion that occurs between homologs by *synaptonemal complex* and begins at various points along the chromosome and extends outward until it completes the entire lengths in the next step. Individuals of a pair are equal in length and in position of the centromere thus pairing is highly specific and exact. The paired chromosomes are called bivalent or tetrad chromosomes. Sister chromatids of each dyad still held together along their length by cohesin and at centromeres region, they also held together by both cohesin and shugoshin proteins.

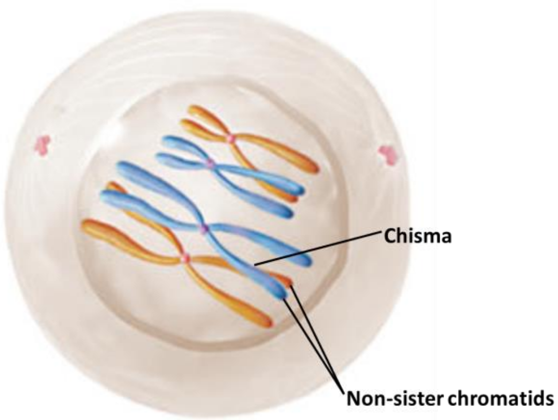


Pachytene (pachynema): it means "thick threads". At this stage, chromosomes become thicker and synapsis is completed chromosomal crossover occurs. Non-sister chromatids of homologous chromosomes may twist and start to exchange segments over regions of homology. Sex chromosomes, however, are not wholly identical, and only exchange information over a small region of homology. At the sites where exchange happens, **chiasmata form**. The exchange of information between the non-sister chromatids results in a recombination of information (mixed info) in a certain part, while the rest is the information it had before. Although the physical exchange occurred during the pachynema stage, it is visible only in Diplonema. The chromosomes are n bivalent (n tetrad).

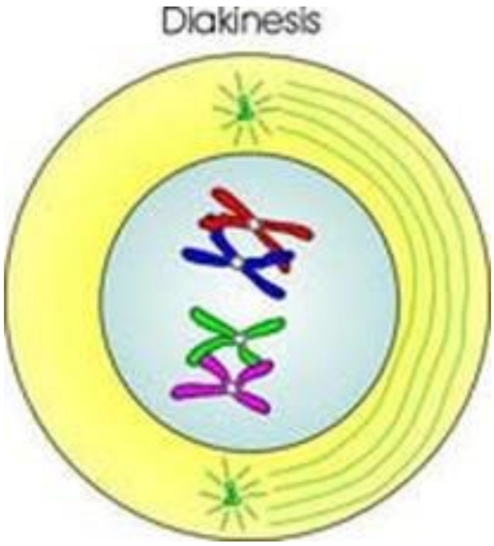


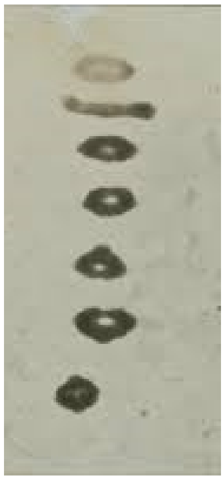


Diplotene (diplonema)**:** It means "two threads". During this stage, the crossover appears clearly due to the degradation of the synaptonemal complex (disassembly) that separate a little the homologous chromosomes from one another leading them to uncoil a bit (desynapsis). However, the homologous chromosomes of each bivalent remain tightly bound at chiasmata, the regions where crossover occurred. Chiasmata appear to the tips of the chromatids, where they remain attached in a process known as **terminalization**. The chiasmata remain on the chromosomes until they are separated in anaphase I. The chromosomes still n bivalent (n tetrad).



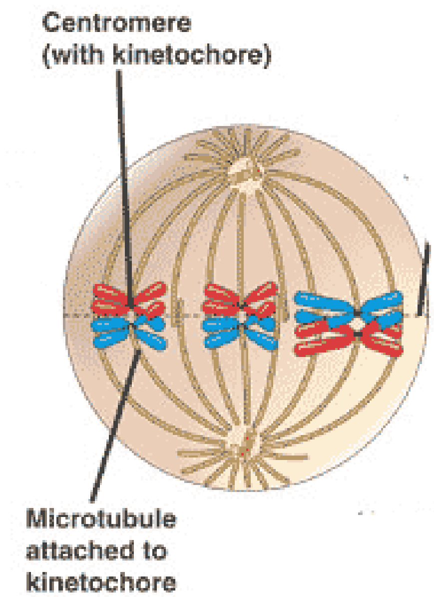
Diakinesis: It means "moving through". Chromosomes condense further during this stage. The **terminalization** of the tetrads continues to get either ring or rod bivalents when it is completed or intermediate chiasmata may be formed due to incomplete terminalization in same/other chromosomes. The chromosomes still n bivalent. Other than this observation, the rest of the stage closely resembles late prophase of mitosis; the nucleoli disappear, the nuclear membrane disintegrates into vesicles, and the meiotic spindle begins to form and attach to kinetochores.





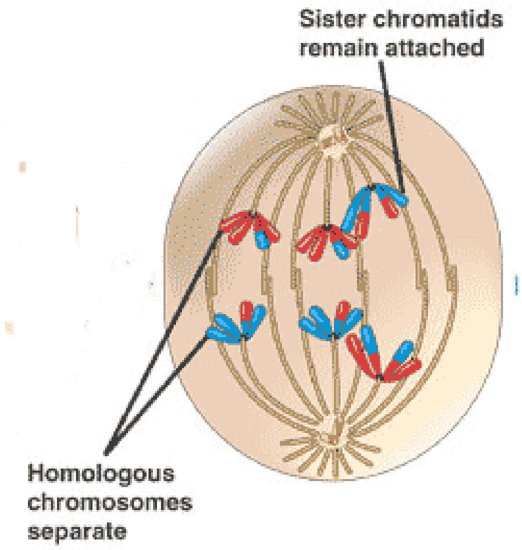
ring or rod bivalents

<u>Metaphase I:</u> Homologous pairs (tetrads) move together along the metaphase plate that bisects the spindle fibers. The physical basis of the independent assortment of chromosomes is the random orientation of each bivalent along the metaphase plate, with respect to the orientation of the other bivalents along the same equatorial line. Complete disappearance of nuclear membrane and nucleolus. The chromosomes still n bivalent (n tetrad).



Anaphase I

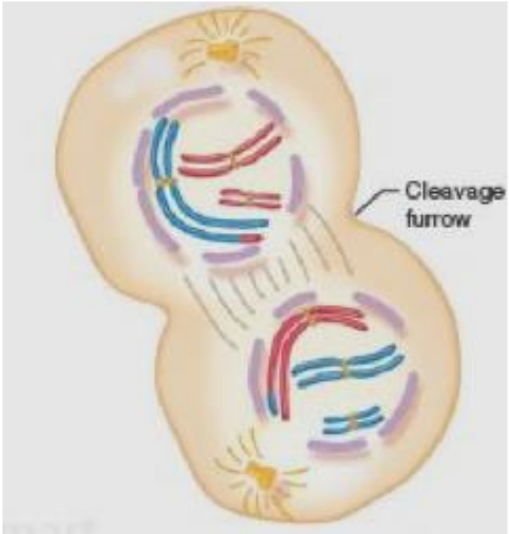
Microtubules of spindle shorten leading to breaking of chiasmata, so spindle fibers separate the 2 dyads, carrying them to opposite poles. Each pole receives n number double in structure (reduction in number). The cell elongates in preparation for division down the center.



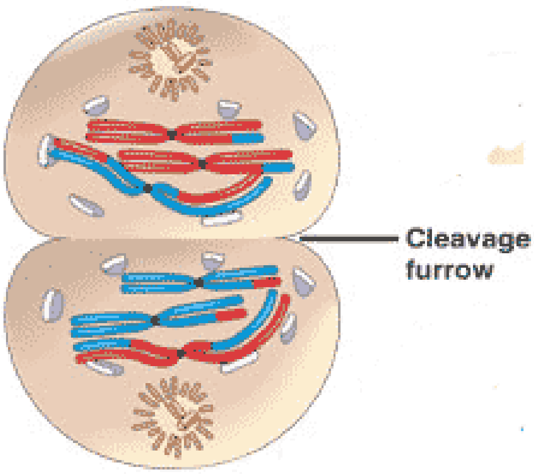
NOTE:

If crossover had not occurred in the first meiotic prophase, each dyad at each pole would consist of either paternal or maternal chromatids. However, the exchanges produced by crossover create mosaic (mix) chromatids from both paternal and maternal origin.

Telophase I: The first meiotic division effectively ends when the chromosomes arrive at the poles. Each daughter cell now has half the number of the tetrad but each chromosome consists of a pair of chromatids (dyad). The microtubules that make up the spindle network disappear, and a new nuclear membrane surrounds each haploid set. The chromosomes uncoil back into chromatin. Sister chromatids remain attached as dyads during telophase I.

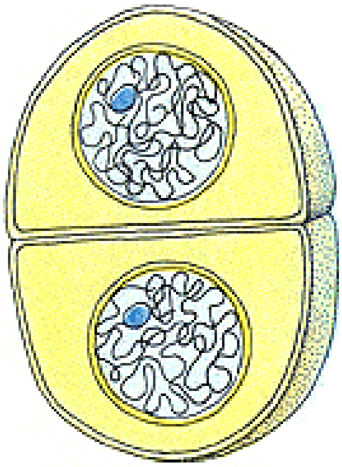


<u>Cytokinesis I</u>: the pinching of the cell membrane in animal cells or the formation of the cell wall in plant cells may or may not occur for completing the creation of two daughter cells. Like Mitosis, the cytoplasm and organelles are usually shared approximately equally between the daughter cells.



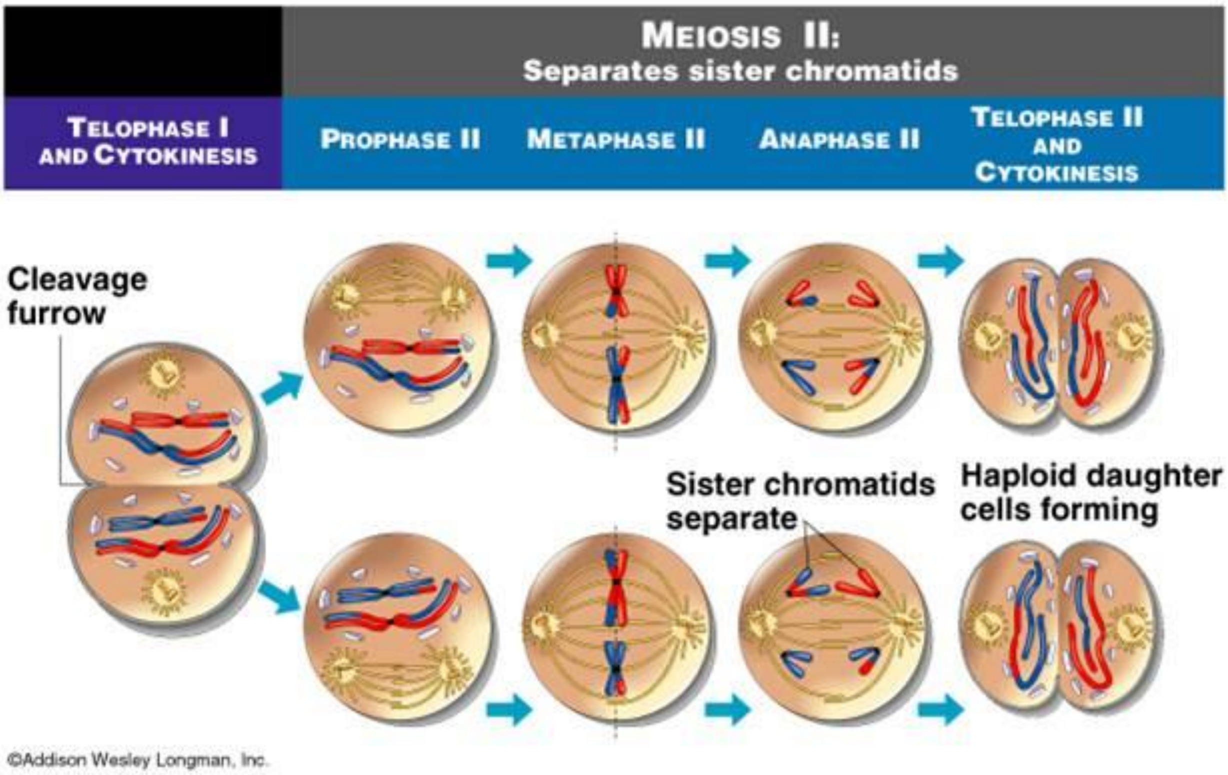
<u>NOTE:</u>

Cells may enter a period of rest known as **interkinesis or interphase II** where **<u>no DNA replication occurs</u>**. Like Mitosis, the genetic material in the nucleus is in form of chromatin, which appears only as dark granules because they are uncoiled into long, thin strands. Both nucleolus and nuclear membranes are present and clearly visible.

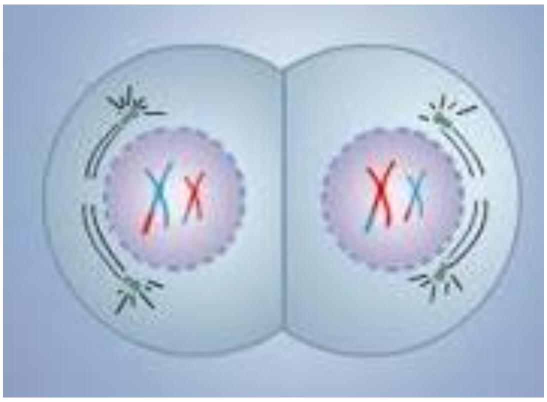


Meiosis II (similar to mitosis, reduction in structure)

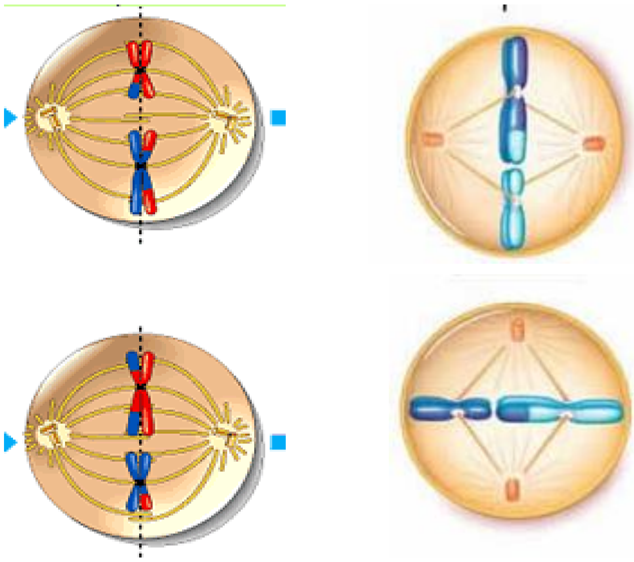
In this process, the two haploid cells (n dyads) produce 4 haploid (n monads) genetically different known as gametes. This division is physically the same as Mitosis, but the genetics of the cells are different. Meiosis II consists of Karyokinesis II (prophase II, metaphase II, anaphase II, telophase II) and Cytokinesis II (figure below).



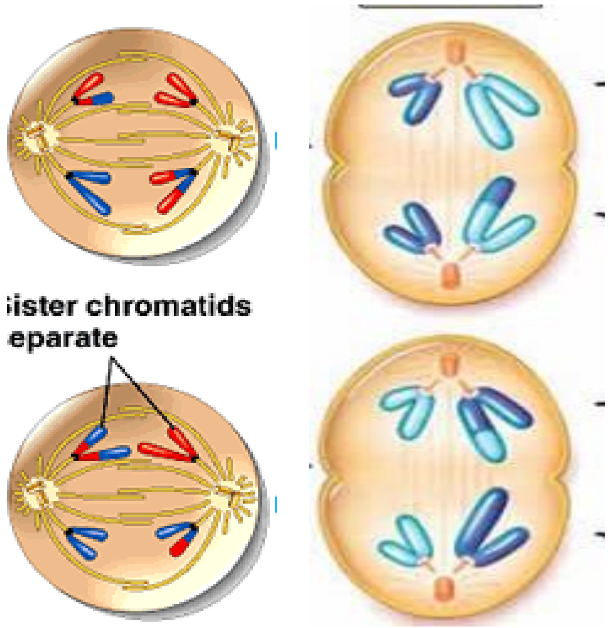
Prophase II: we see the disappearance of the nucleoli and the nuclear envelope again as well as the shortening and thickening of the chromatids which appear as dyads. Centrioles move to the polar regions and arrange spindle fibers for the second meiotic division.



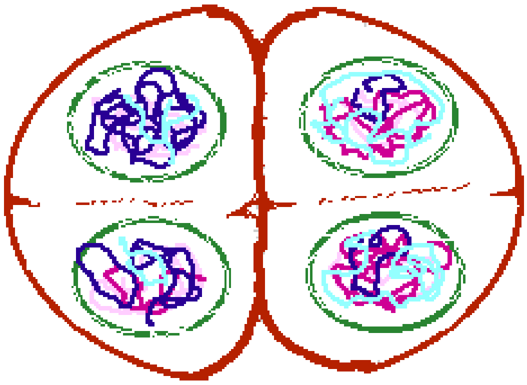
Metaphase II: The kinetochores of the dyads attach to spindle fibers formed from the centrosomes (centrioles) at each pole (i.e. directed towards the opposite poles). The chromatids of the dyads (non-homologous chromosomes) are joined by their centromeres with cohesin and shugoshin complex and aligned along the equator. In case of ♀ mother cells: the new equatorial metaphase plate is parallel to the spindle of metaphase I. In case of ♂ mother cells: the new equatorial metaphase plate is perpendicular (rotated by 90 degrees) to the previous plate of metaphase I.



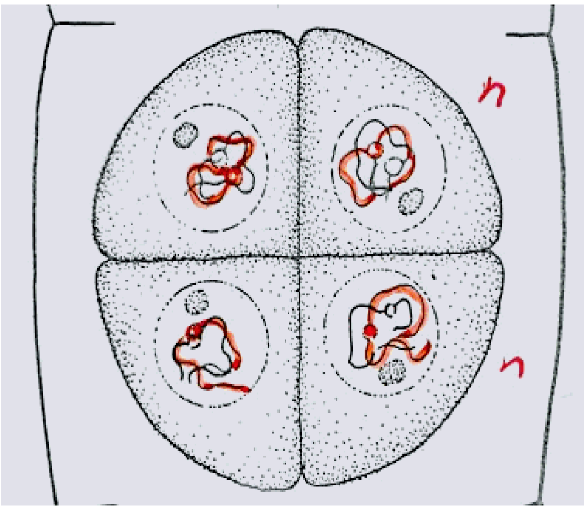
This is followed by **Anaphase II (reduction in structure)**, where the centromeres are cleaved by degrading cohesin and shugoshin complex, allowing microtubules attached to the kinetochores to pull the sister chromatids apart. The sister chromatids by convention are now called chromosomes (monads) as they move toward opposing poles (n single structure to each direction).



The Karyokinesis II process ends with **Telophase II**, which is similar to telophase I, and is marked by uncoiling and lengthening of the chromosomes and the disappearance of the spindle. Nuclear envelopes and nucleolus are reformed. Now we have 4 new haploid nuclei with monad chromosomes in one cell.

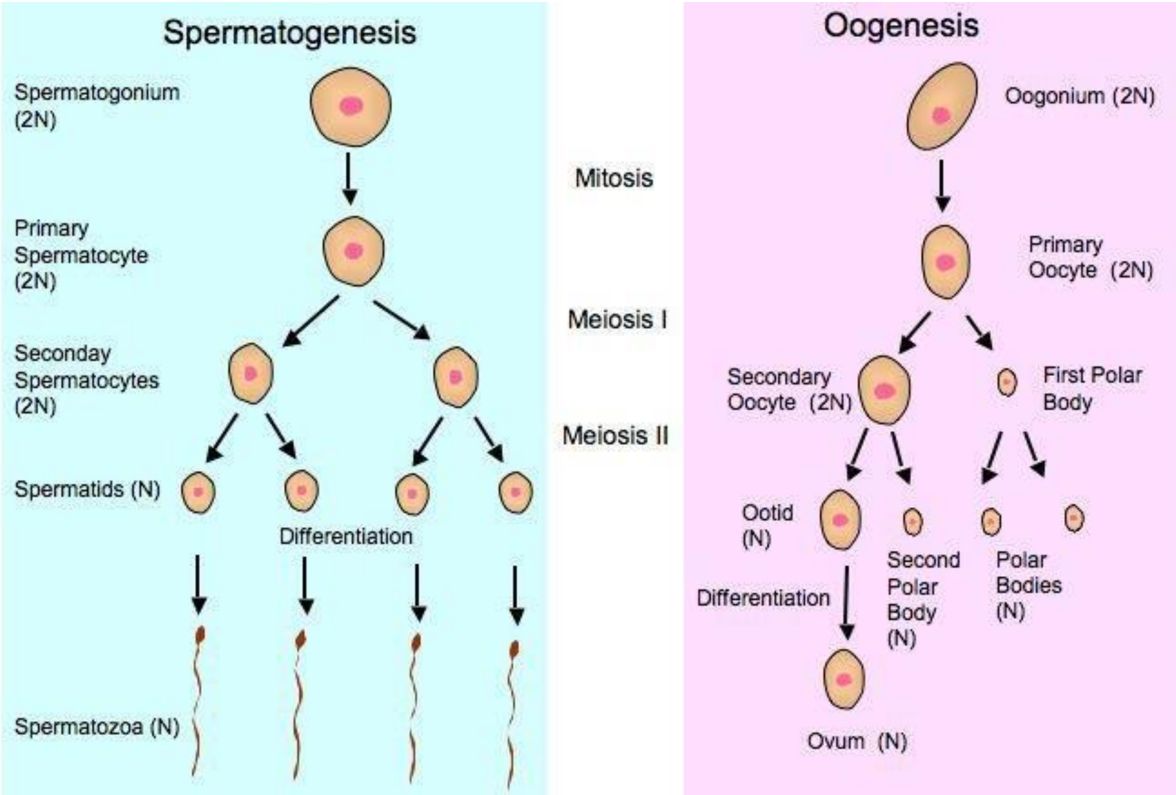


<u>Cytokinesis II</u>: Meiosis is now complete and ends up with four new cells by cleavage of the cell membrane in animal cells or the formation of the cell wall in plant cells producing a total of four cells, each with a haploid set of chromosomes which are single structure.



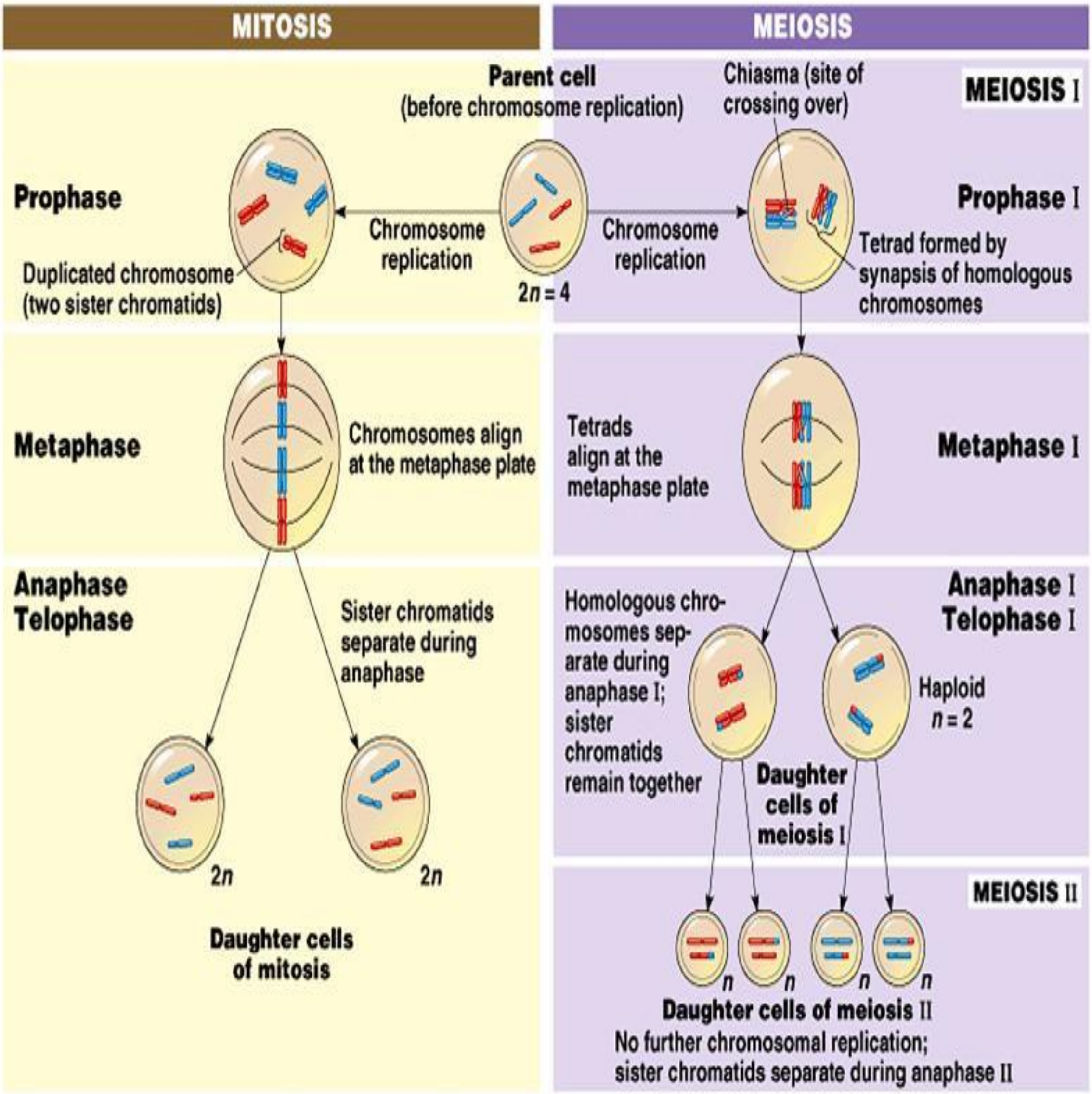
Gametogenesis:

It is the process by which the produced 4 haploid cells undergo some differentiation and developmental events to produce gametes (haploid sex cells, germ cells). It includes the formation of ♂ gametes (spermatogenesis in animals and microsporogenesis in plants) or the formation of ♀ gametes (oogenesis in animals and megasporogensis in plants) i.e. all the sex cells whether are in plants or animals undergo meiosis. Similarly, Eukaryote microorganisms produce gametes by meiosis but with different nomenclatures.


Spermatogenesis
Spermatogonium (2N)
Primary Spermatocyte (2N)
Seconday Spermatocytes (2N)
Spermatids (N)
Differentiation
Spermatozoa (N)
Mitosis
Meiosis I
Meiosis II
Oogenesis
Oogonium (2N)
Primary Oocyte (2N)
Secondary Oocyte (2N)
First Polar Body
Ootid (N)
Second Polar Body (N)
Polar Bodies (N)
Differentiation
Ovum (N)

Differences between Mitosis and Meiosis:

	Mitosis	**Meiosis**
Number of divisions	1	2
Number of produced cells	2 (daughter cells)	4 (gametes)
Genetically identical?	Yes	No
Chromosome #	Same as parent	Half of parent
Where	Somatic cells	Germ cells
Synapsis and crossover	Absent	Present
Centromere in Anaphase	Divided at anaphase	Not divided at anaphase I but at Anaphase II
When	Throughout life	At sexual maturity
Role	Growth, development, regeneration and repair	Sexual reproduction



IMPORTANCE OF MEIOSIS:

- Meiosis generates genetic diversity through:
    1. the exchange of genetic material (crossover) between homologous chromosomes during Prophase I-Meiosis I.
    2. the random alignment of chromosomes in Meiosis I and Meiosis II.
- Meiosis maintains the chromosome number in sexually reproducing organisms.