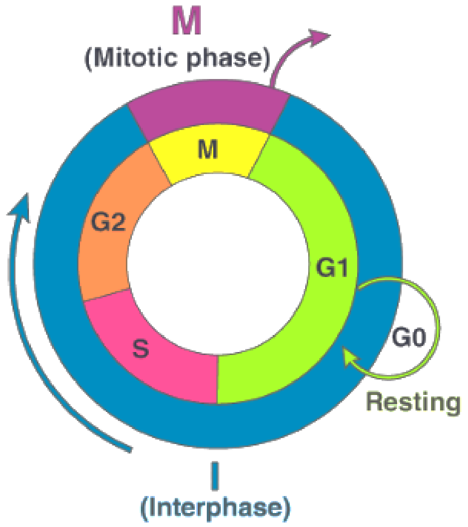
CHAPTER 7

THE CELL CYCLE

Definition

"**Cell cycle** refers to the series of events that take place in a cell, resulting in the duplication of DNA and division of cytoplasm and organelles to produce two daughter cells."



The events in a cell cycle include duplication of its genome and synthesis of the cell organelles followed by division of the cytoplasm.

Phases of the cell cycle

A typical eukaryotic cell cycle is divided into two main phases, i.e interphase and M-phase

1. Interphase

Also known as the resting phase of the cell cycle; interphase is the time during which the cell prepares for division by undergoing both cell growth and DNA replication. It occupies around 95% time of the overall cycle. The interphase is divided into three phases;

(i) G1 phase (Gap 1);

G1 phase is the phase of the cell between mitosis and initiation of replication of the genetic material of the cell. During this phase, the cell is metabolically active and continues to grow without replicating its DNA.

(ii) *S phase* (Synthesis phase);

DNA replication takes place during this phase. If the initial quantity of DNA in the cell is denoted as *2n*, then after replication it becomes *4n*. However, the number of chromosomes does not vary, viz., if the number of chromosomes during G1 phase was *2n*, it will remain *2n* at the end of S phase. The centriole also divides into two centriole pairs in the cells which contain centriole.

(iii) *G2 phase* (Gap 2)

During this phase, RNA, proteins, other macromolecules required for multiplication of cell organelles, spindle formation and cell growth are produced as the cell prepares to go into the mitotic phase.

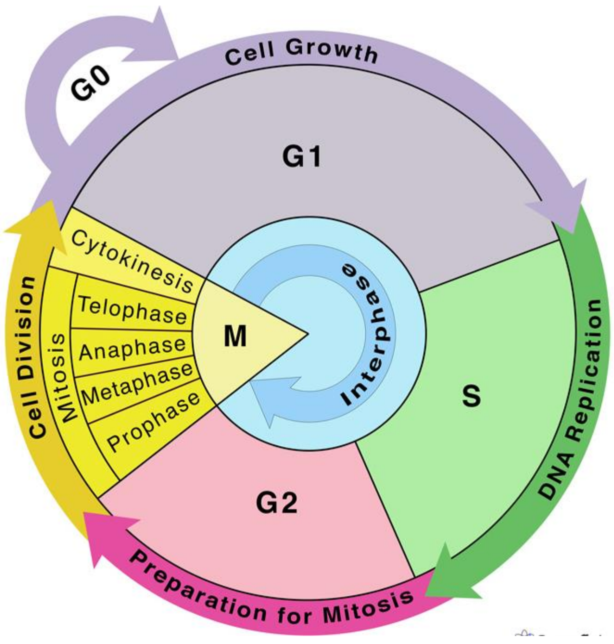
Some cells like cardiac cells in the adult animals do not exhibit division and some others only divide to replace those cells which have been either damaged or lost due to cell death. Such cells which do not divide further attain an inactive G0 phase also known as quiescent phase after they exit the G1 phase. These cells remain metabolically active but do not divide unless called upon to do so.

2. M phase

This is the mitotic phase or the phase of the equational division as the cell undergoes a complete reorganization to give birth to a progeny that has the same number of chromosomes as the parent cell. The other organelles are also divided equally by the process of cytokinesis which is preceded by mitotic nuclear division. The mitotic phase is divided into four overlapping stages;

1. Prophase,
2. Metaphase,
3. Anaphase, and
4. Telophase

Telophase is followed by *cytokinesis*, which is the cytoplasmic division of a cell at the end of mitosis (or meiosis) bringing about its separation into two daughter cells.



CELL DIVISION

Cell division is the splitting of a mature cell to form daughter cells. There are two types of cell division namely;

1. Mitosis.
2. Meiosis.

1. MITOSIS

This is the division of a mature cell (parental cell) to form two identical daughter cells each containing exactly the same number of chromosomes as the parent cell. This is also known as *replication cell division*. The daughter cells are *diploid* **(**2n**)** just like the parent cell

Mitosis takes place throughout the growth period of an organism. Mitosis occurs in four stages i.e.

(i) Prophase.
(ii) Metaphase
(iii) Anaphase.
(iv) Telophase.

The process of mitosis

Before a cell undergoes mitosis, it undergoes a preparation stage known as *interphase*.

(a) Interphase

This is called the *resting stage* but in actual sense the cell is not resting because there are many activities that occur in preparation of the cell for division. These activities include;

- ☞ Production of ATP through cellular respiration to provide sufficient energy needed for cell division.
- ☞ Synthesis or formation of more organelles such mitochondria, chloroplasts, Golgi bodies, centrioles, endoplasmic reticular etc. this ensures equal distribution of cell contents between the daughter cells.
- ☞ Replication of genetic material, DNA replicates, leading to doubling of chromosomal number so that the parental chromosomal number is maintained in the daughter cells.
- ☞ Chromosomes are long and thread like hence not clearly seen and they are highly coiled for easy packing in the nucleus.

(b) Prophase

This has two sub stages i.e. early prophase and late prophase.

During early prophase,

- ☞ Centrioles migrate to opposite poles of the cell spindle fibres are then synthesized by the centrioles and radiate to the nuclear membrane.
- ☞ Chromosomes shorten and thicken hence easily seen.
- ☞ They uncoil and appear to have centromere.

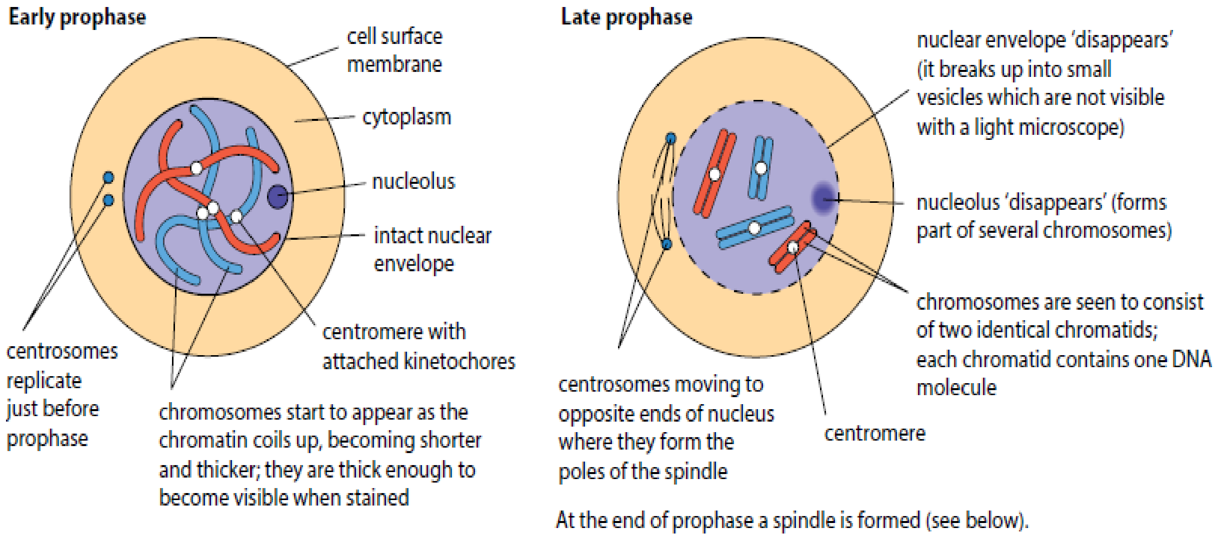
During Late prophase;

- ☞ Chromosomes condense further and separate vertically to form chromatids which remain attached at the same centromere. In this case, the chromosome is said to duplicate.
- ☞ Each chromosome forms the chromatid.

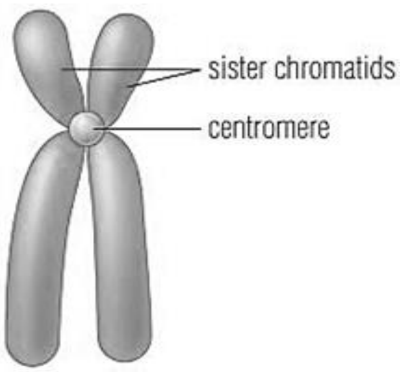
NB: A chromatid is a duplicate or half of a chromosome.

- ☞ Nucleolus disintegrates i.e. breaks down and disappears.

- Spindle fibers form
- Nuclear membrane also degenerates and disappears and this makes the end of prophase.



Enlarged structure of a chromosome



(c) Metaphase

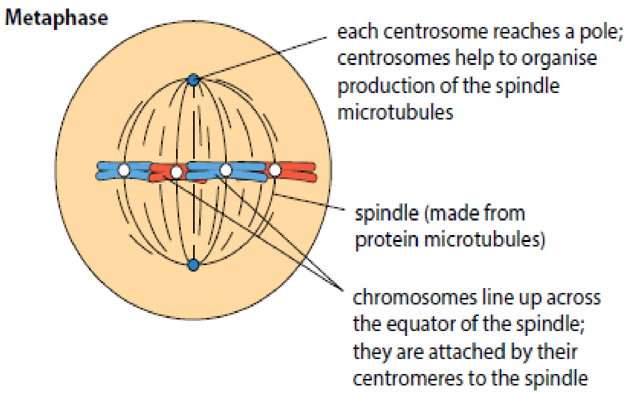
This consists of two sub stages i.e. early metaphase and late metaphase.

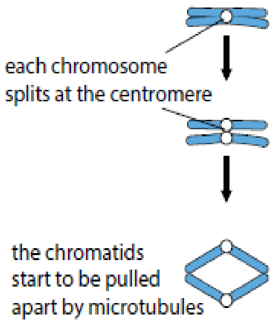
Early metaphase:

- The spindle fibres are fully formed
- Chromosomes condense further
- The chromosomes assemble/align at the equator singly i.e. each chromosome is attached to a single fibre. During the alignment the chromatids face the opposite poles.
- The chromatids are attached at the equator by the spindle fibres being attached at the centromere.

Late metaphase: During late metaphase;

- The chromosomes are pulled along the centromere by the spindles as spindles contract.
- The centromere therefore splits in to two to form independent chromatids that are still held close.





(d) Anaphase

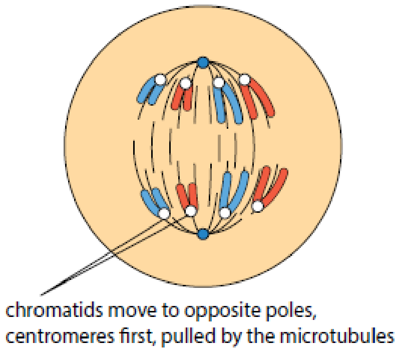
This consists of two sub stages i.e. early anaphase and late anaphase.

Early anaphase:

- The spindle fibres contract further using energy provided by ATP generated by mitochondria.
- The chromatids separate completely.
- Independent chromatids migrate to opposite poles, being pulled by spindle fibres as the spindles contract. During the migration, the centromere leads i.e. faces the pole.

Late anaphase;

- Chromatids reach their destination (opposite poles).

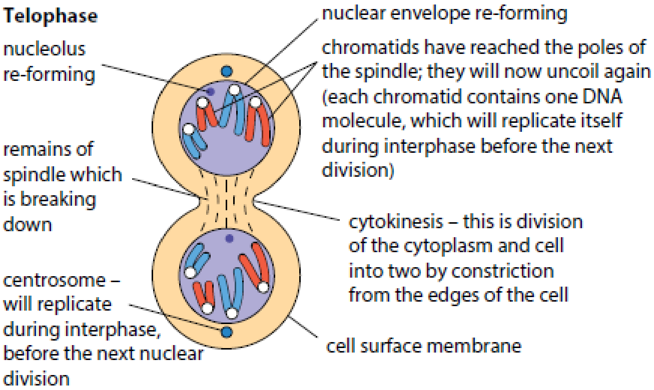


(e) Telophase:

When the chromatids arrive at the poles;

- nuclear membrane reforms/reappears
- Nucleolus also reforms.
- Chromatids become long, thin, coiled hence not easily seen.
- Spindle fibres disintegrate and disappear.

Cell surface membrane folds in (invaginates) to divide the genetic content of the cell equally into two parts. Cytokinesis begins prior to the end of mitosis and completes shortly after Telophase.



In an animal cell cytokinesis occurs when the cell membrane constricts at the centre i.e. along the equator to divide the cytoplasm of the cell into two equal halves each half consisting of a complete nucleus. As a result, two daughter cells are formed and these are identical to the parent cell.

However, in a plant cell, cytokinesis occurs by formation of a cell plate along the equator. During its development, cellulose is deposited in the cell plate to form a cellulose cell wall for each of two identical daughter plant cells.

COMPARISON OF MITOSIS IN PLANTS AND ANIMALS

Similarities: In both;

(i) Spindle fibres form

(ii) During Prophase, chromosomes condense

(iii) Before metaphase, the nuclear envelope breaks down.

(iv) Spindle attaches to chromosomes at centromeres

(v) At metaphase, the chromosomes align at the equator

(vi) At anaphase, chromosomes move towards opposite poles

(vii) At telophase, the nuclear envelope appears again, chromosomes de-condense, and the spindle breaks down

Differences

Mitosis in animal cells	**Mitosis in plant cells**
Occurs almost all over the body	Occurs at apical, lateral and intercalary meristems only.
Centrioles present	Centrioles absent
Cytokinesis occurs by cleavage	Cytokinesis occurs by cell plate formation
Cell becomes round before division	Cell shape does not change before division
A furrow is formed between two daughter cells	A solid middle lamella forms between two daughter cells
Mitotic apparatus contains asters	Mitotic apparatus lacks asters
Spindle degenerates at cytokinesis	Spindle (phragmoplast) persists at cytokinesis.
Several hormones induce cell division, not one specifically	It is induced by a specific hormone called cytokinin

Significance of mitosis

1. *Genetic stability***:** Mitosis produces two daughter cells having same number of chromosomes as parental nucleus. Therefore, ensuring that genetic information remains constant i.e. no variation occurs.

2. *Growth***:** Number of cells in organisms increases by mitosis hence increasing the size of the tissue and hence the organism as a whole. This is the basis of growth.

3. *Asexual reproduction:* In unicellular organisms such as Amoeba, the parental organisms divide into two. During binary fusion in amoeba, the organism divides into two independent organisms. This is a form of mitosis.

4. *Cell replacement and repair***;** new cells replace the worn out cells a process called cell replacement that occurs during healing. Cell replacement involves mitosis, cells are constantly dying and being replaced, an example is the skin, cavity around the mouth etc.

5. *Tissue regeneration***;** enables regeneration of body parts like the tail in reptiles

6. Produces a *clone* of offspring (genetically identical to parents) during vegetative reproduction in some plants.

NB: Cancers show us the importance of controlling cell division precisely, because they are a result of uncontrolled mitosis. Cancerous cells divide repeatedly and form a **tumor**, which is an irregular mass of cells.

2. MEIOSIS.

This is a type of cell division which involves splitting of a mature cell into four daughter cells each containing half the number of chromosomes of the parent cell. In this case, the daughter cells are said to be **haploid**.

Meiosis involves two successive divisions (phases) namely;

Meiosis I (1st meiotic division)

Meiosis II (2nd meiotic division)

The 1st Meiotic Division

Before the cell divides meiotically, it undergoes a preparatory stage known as *interphase***.**

(a) Interphase

During interphase, several activities occur to prepare the cell for effective division. Such activities include:

- Replication of genetic material (DNA) making them to double;
- Synthesis of ATP which is a source of energy required for cell division.
- Formation of more cell organelles such as Golgi body, centrioles, mitochondria, etc.
- The cell increases in size.
- Chromosomes are coiled, long, thin and invisible.

Nuclear division: Nuclear division of meiosis I involve the following stages:

Prophase I

Metaphase I

Anaphase I Telophase I

This is therefore followed by cytokinesis/ cytoplasmic cleavage.

(b) Prophase I.

This is the longest phase of meiosis and it is subdivided in to *five* stages namely

(i) Leptotene (single chromosomes)
(ii) Zygotene (synapsis).
(iii) Pachytene (duplication of chromosomes).
(iv) Diplotene (crossing over of chromatids).
(v) Diakinesis (repulsion of chromosomes to nuclear membrane).

(i) *Leptotene*:

Chromosomes appear to be single stranded without centromeres. They are relatively long.

(ii) *Zygotene*:

The chromosomes continue to shorten and thicken hence easily seen. Centrioles move to opposite poles and spindles start forming. Synapsis occurs i.e. homologous chromosomes pair up to form bivalents.

Homologous chromosomes do not join but lie side by side. Homologous chromosomes appear to have centromeres.

NB: *Homologous chromosomes***:** are pairs of similar chromosomes formed which contain genes that determine particular characters.

Bivalent**:** is a pair of homologous chromosomes formed by synapsis at zygotene of prophase I.

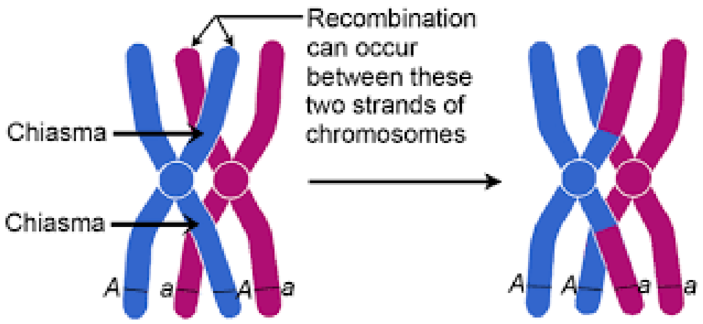
(iii) *Pachytene***:**

Each of the chromosome splits vertically into two to form two chromatids. This is called chromosomal duplication. The chromatids are still attached to the centromere of chromosomes.

(iv) *Diplotene*:

Chromosomes coil around one another. Homologous chromosomes tend to draw apart thereby breaking portions of non-sister chromatids. The portions then rejoin randomly thereby leading to exchange of genetic material between homologous chromosomes a process known as *crossing over*.

Crossing over is the exchange of portions of chromatids of homologous chromosome at points called *chiasmata* leading to exchange of genetic material between homologous chromosomes or non-sister chromatids.



Importance of crossing over

- Crossing over results in to formation of new gene combinations which promote genetic variation among organisms of the same parents. It is very important in evolution of species.

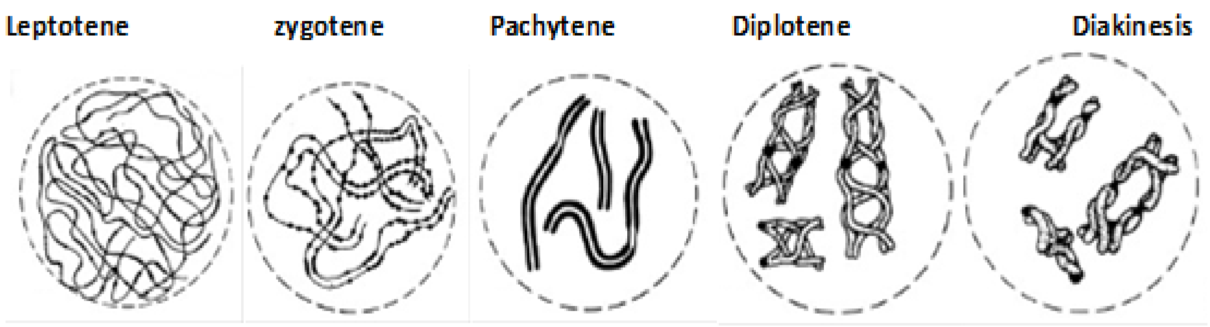
(v) *Diakinesis***.**

Internal coiling occurs and chromosomes repel each other to far distances between them. The homologous chromosomes push themselves to the periphery of nucleus close to the nuclear membrane.

As a result of this opposite movement of chromosomes the number of chiasmata reduces because of breaking up in the process. However, chiasmata formation remains at the tips of the chromosomes.

The nucleus disintegrates by shrinking and disappears.

Nuclear membrane also disintegrates and disappears; this marks the end of prophase I.



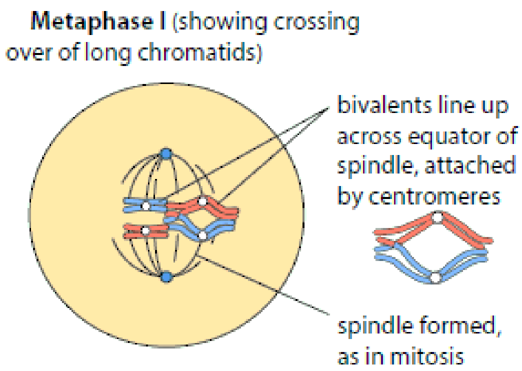
(c) Metaphase I

Centrioles reach opposite poles, spindle fibres form completely.

Bivalents arrange themselves at the equator with each of the pair facing opposite poles.

Alignment of bivalents at the equator is completely random in comparison to other bivalents leading to formation of new gene combinations which result into genetic variation.

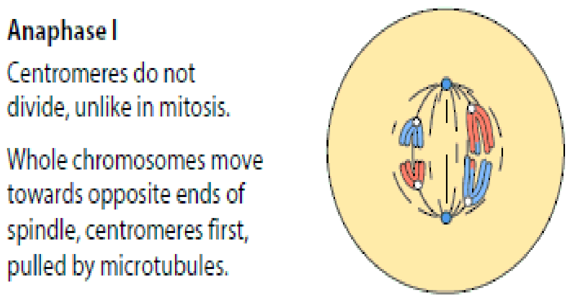
Spindles attached to the centromere contract slightly pulling homologous chromosomes slightly apart there by breaking chiasmata if present.



(a) Anaphase I

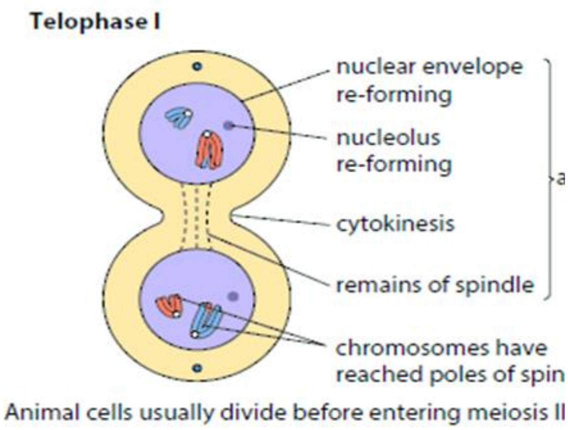
Spindles continue to contract and shorten. Homologous chromosomes part company and migrate to the opposite poles of the cell.

The contraction of spindle fibres and migration of chromosomes require energy provided by the numerous mitochondria in the cell.



NB: A key difference between meiosis and mitosis is that in meiosis during anaphase I, the sister chromatids are still together whereas in mitosis, they separate.

(e) Telophase I



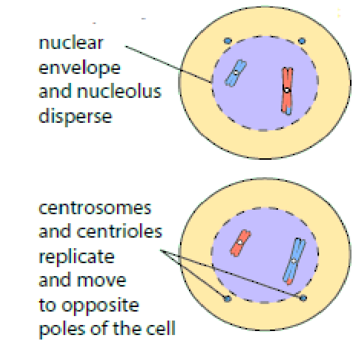
- Chromosomes reach their respective poles.
- Chromosomes become long, thin hence not easily seen. Nucleolus reappears and nuclear membrane reforms.
- Spindle fibres may completely or partially disappear. The centrioles replicate. Finally, cytokinesis occurs to form two daughter cells.

NB: In plant cells, meiosis does not include Telophase I and interphase II; from anaphase I, the dividing cell enters prophase II directly. However, in animal cells, Telophase I and interphase II occur.

THE 2ND MEIOTIC DIVISION

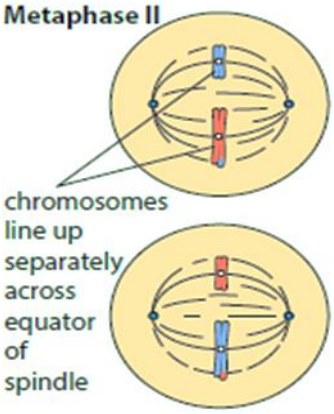
After Telophase I, daughter cells enter directly into prophase II,

(f) Prophase II



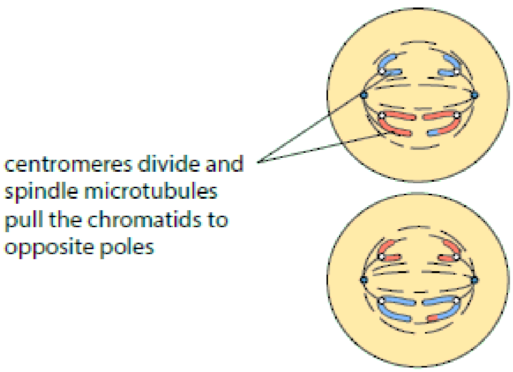
- Centrioles migrate to opposite poles.
- Spindle fibres are then synthesized by centrioles but arranged at right angles to the spindle of meiosis I.
- Chromosomes shorten and thicken hence easily seen.
- Chromosomes condense further to split and form chromatids.
- The chromatids are still attached at the centromeres.
- Nucleolus degenerates and disappears.
- Nuclear membrane also degenerates and disappears

(g) Metaphase II



- Spindles form completely.
- Chromosomes are aligned at the equator singly.
- During alignment, the chromatids face opposite poles.
- Chromosomes are held in position by the spindle fibres that slightly contract**.**
- As a result, centromeres split to form independent chromatids that are still too close to each other.

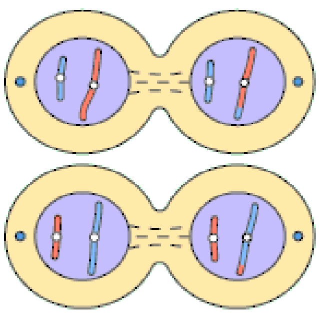
(h) Anaphase II



- Spindles contract further and completely separate the chromosomes into chromatids.
- Independent chromatids migrate to opposite poles being pulled by spindle fibres.
- During chromatid movement the centromere face opposite poles.
- Finally, chromatids reach their destination.

NB: Migration of chromatid requires energy provided by ATP hydrolysis.

(i) Telophase II



This is like telophase of mitosis, but in meiosis telophase II four haploid daughter cells are formed

- When chromatids arrive at the poles, a new nuclear membrane forms around each pole surrounding the chromatids.
- Nucleolus also forms.
- Chromatids become long, thin hence not easily seen as chromosomes.
- Spindle fibres disintegrate and disappear.

- Cytokinesis occurs to form four haploid daughter cells collectively called a **tetrad.**

NB:

In animals, meiosis occurs in germinal cells leading to production of gametes.

- In males, germinal cells are found in the testis and when they undergo meiosis, and Telophase II produces secondary spermatocytes.
- In females however, germinal cells are found in ovaries in which Telophase II produces a secondary Oocyte that matures into a functional egg/ovum.
- In flowering plants, meiosis occurs in Anther heads to produce pollen grains and in females: embryo sac / ovaries to produce eggs / ovules.

Spermatozoa and ova are haploid reproductive cells and Pollen grains and ovules may be haploid, diploid, triploid or tetraploid.

Significance of Meiosis

1. *Genetic variation*;

Meiosis provides opportunity for new combination of genes to occur in gametes and consequently in the off springs. This is possible in two ways.

2. *Crossing over*:

During crossing over in prophase I segments of chromatids are exchanged leading to formation of new gene combinations which are the basis of variation in the offspring.

3. *Independent assortment of chromosomes*;

At metaphase I of meiosis, random orientation of bivalents at the equator occurs resulting into formation of new gene combinations passed to gametes and finally to the off springs at fertilization hence genetic variation.

4. Sexual reproduction:

Meiosis leads to the production of gametes in plants and animals. The gametes formed are then used in sexual production.

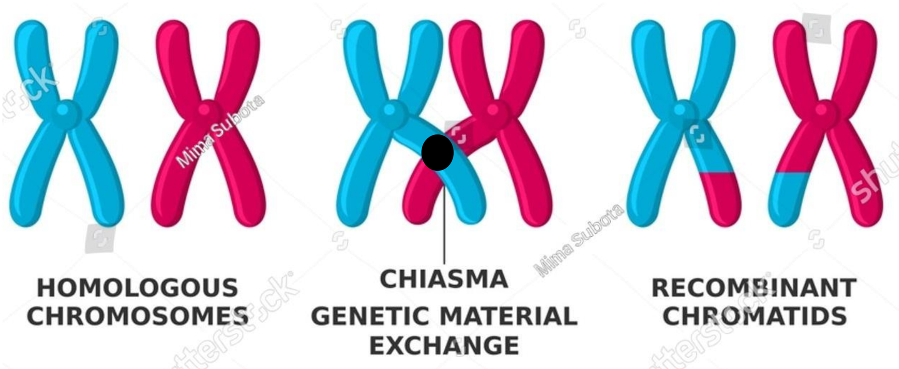
5. Maintenance of diploid state

Meiosis ensures that gametes formed are **haploid** in order to maintain **diploid** state of organisms after fertilization.

How meiosis causes almost infinite genetic variation / diversity

1. Meiosis produces haploid male and female gametes which fuse during fertilisation to create new combinations of parental genes.

2. Crossing over during prophase I of meiosis can separate and rearrange genes located on the same chromosome to form genetically non-identical gametes.



3. Independent assortment of homologous chromosomes on metaphase plate during metaphase I with respect to which paternal and maternal homologue is on either side forms different combinations of parental chromosomes in gametes. The number of possible combinations of maternal and paternal homologues is 2n, where n = the haploid number of chromosomes.

4. During Segregation / separation of homologues in anaphase I and sister chromatids at anaphase II, alleles for dominant or recessive traits go to opposite poles whereby only one of a pair of alleles goes into a single gamete.

COMPARISON OF MEIOSIS AND MITOSIS

Similarities; Both:

- Involve cytokinesis to form daughter cells from a parent cell
- Follow the same fundamental sequence of events i.e. Interphase, prophase, metaphase, anaphase, telophase.
- Include the breakdown of the nuclear membrane during prophase.
- Involve the separation of genetic material into two groups, followed by cell division.
- Involve the reformation of the nuclear membrane in each cell during telophase.
- Involve alignment of chromosomes on metaphase plate.

Differences

MEIOSIS	MITOSIS
Occurs in cells involved in sexual cycle	Occurs in somatic cells
Cells involved in meiosis are always diploid	Cells involved can be diploid or haploid
Daughter cells are genetically different	Daughter cells are genetically identical
Crossing over occurs	No crossing over
Homologous chromosomes pair up	No pairing of homologous chromosomes
Two divisions; meiosis I and meiosis II	One division involving Prophase, Metaphase, Anaphase, Telophase.
Four haploid cells are formed	Two diploid cells are formed
Chromosome number is reduced by half.	Chromosome number remains the same.
Homologous chromosomes line up along metaphase plate in tetrads	Chromosomes line up singly on metaphase plate
Cytokinesis occurs twice i.e. in Telophase I and in Telophase II.	Cytokinesis occurs once i.e. in Telophase.

Centromeres do not separate during anaphase I, but during anaphase II.	Centromeres split during anaphase.

Comparison between Mitotic prophase and meiotic prophase I

Similarities: In both:

1. chromatins condense to become visible chromosomes
2. spindle begin to form
3. nucleolus shrinks and disappears
4. nuclear envelope breaks down
5. centrioles migrate to opposite poles
6. sister chromatids are held together at the centromere.

Differences:

1. In mitotic prophase, no crossing over while it occurs in meiotic Prophase-I
2. In mitotic prophase, no chiasmata formation while it occurs in meiotic Prophase-I
3. In mitotic prophase, no synapsis while it occurs in meiotic Prophase-I
4. In mitotic prophase, no exchange/swapping of genetic material between non-sister chromatids while it occurs in meiotic prophase.