S5 BIOLOGY

CHROMOSOME STRUCTURE AND CELL DIVISION.

THE CELL

The basic unit of structure and function of living organisms is the cell. According to cell theory new cells come only from pre-existing cells by cell division. The most important unit in the cell is the nucleus, which controls all the activities within the cell. It contains **chromosomes** which are important structures in the cell during cell division.

THE STRUCTURE OF CHROMOSOMES.

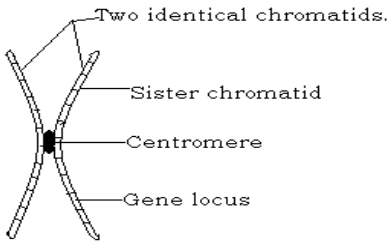
Chromosomes of the eukaryotic cells are composed of DNA, proteins and a small amount of RNA. The proteins present in the chromosome are known as histone. Histone binds strongly to DNA, taking the form of beaded sub-units on DNA chain called nucleosomes. This histone plays an important part in packaging of the DNA, the other non-histone proteins are the polymerase enzymes that catalyse the transcription and replication of nucleic acids.

Chromosomes carry hereditary material inform of DNA which determines the organisms characteristics and transmits these to subsequent generations. Each chromosome is made up of two strands called chromatids. The specific regions on the chromatids where the DNA or genes are located are referred to as **gene loci** or **gene locus**. Chromatids are held together at a point called the centromere. The centromere of the chromosome consists of a length of DNA that is never transcribed for protein synthesis. Chromatids of the chromosomes are held by centromere. Before cell divides, chromosomes exist as very long, thin, loosely coiled threads that spread through out the nucleus referred to as chromatin.

Chromatin is composed of coils of DNA bound to basic proteins called histones. DNA is wound around the histones which form bead-like structures called **nucleosomes** and in turn are regularly packed in the chromatin.

The term Chromatin means coloured material. It is easily stained. During nuclear division chromatins condense into more tightly coiled threads called chromosomes. Chromatins that remain tightly coiled and continues to stain intensely are called **heterochromatin.** While the loosely coiled chromatin that contain DNA and are genetically active during interphase are called **euchromatin**.

SIMPLE STRUCTURE OF A CHROMOSOME.



Each species has a particular number of chromosomes within their cells, for example Human cell has 46 chromosomes, fruit fly has 8, cats have 38, and dogs have 78 chromosomes. Most species have between 12 and 50 chromosomes in their cells. Within the cell the chromosomes exist as pairs (are paired) and are referred to as Homologous pairs. ***Homologous pairs of chromosomes*** are the pair of chromosomes with similar structures and contain genes which determine the same characteristics.

Species in which there are two sets of homologous chromosomes in the nucleus of the cell are referred to as **diploid**, given the symbol **2n**. Whereas organisms with only one set of chromosomes within the nucleus of the cell are referred to as **haploid**, give the symbol **n**. Most gametes are haploid. On the other hand organisms, organisms that have three or more sets of chromosomes within a nucleus of the cell are referred to as polyploids. They are given symbols 3n (Triploid), 4n (Tetraploid), 5n (pentaploids), etc.

- In diploids genetic variation is increased since each individual will have a mixture of characteristics from both parents.
- The harmful effects of one gene on one chromosome can be masked by the effects of another gene on another homologous chromosome.
- Diploid individuals have some advantages over their haploid counter parts in the following ways,

CELL DIVISION (CYTOKINESIS)

Is the process of division of the whole cell due to division of nucleus and then cytoplasm to form two daughter cells. This process begins with the nuclear division. There are two types of nuclear division.

- Mitosis.
- meiosis.

MITOSIS.

Is the process by which a cell nucleus divides to form two identical nuclei identical to the parent containing the same number (sets) of chromosomes to that of the parent. The daughter nuclei formed are diploid (2n).

Mitosis is the common type of cell division that occurs in body (somatic) cells. It results in rapid increase in cell numbers and it the means by which growth, replacement and repair of cells occur

in eukaryotes. Before starting to divide, a cell is at the **interphase** stage then after Mitotic cell division proceeds in four successive stages, which include,

- Prophase.
- Metaphase.
- Anaphase.
- Telophase.

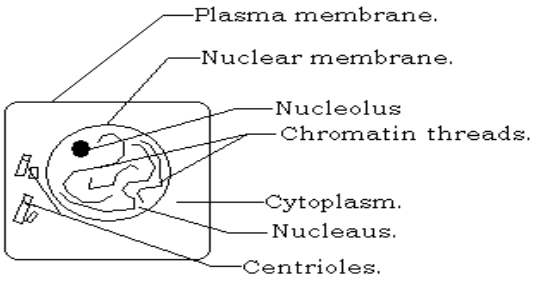
Note: A cell containing four chromosomes are used just for easy illustration of the mitotic cell division.

INTERPHASE.

Is the longest of these stages. The following events take place during this phase and they include,

- Synthesis of RNA.
- Synthesis of histone and non-histone proteins.
- DNA replication.
- Duplication of chromosomes which are long and thread like, invisible and exist as chromatins. At this stage the sister chromatids are joined along their length by centromere.
- Replication of organelles such as mitochondria, etc.
- Synthesis of energy inform of ATP molecules.

INTERPHASE.



PROPHASE.

Is the longest phase of the cell division. It is further divided into early and late stages of prophase.

Early prophase.

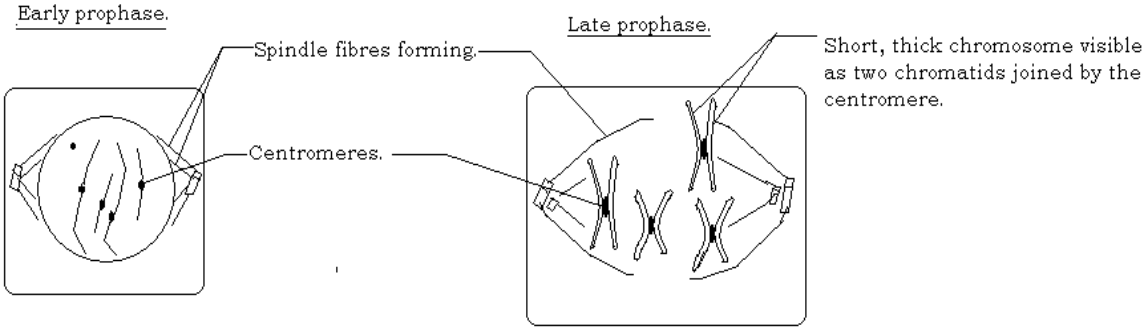
The events that occur in this stage include,

- Long, thin, thread like chromosomes begins to condense and contract.
- Nucleolus shrinks.
- Centrioles move to opposite poles of the cell.
- Spindle fibres start to form Short microtubules may be seen radiating from Centrioles called asters.

Late prophase.

The events that occur in this phase include,

- Chromosomes become shorter and thicker and become visible, each seen to consist of a pair chromatids joined at the centromere.
- Nucleolus disappears.
- Nuclear membrane breakdown, which ends the prophase.

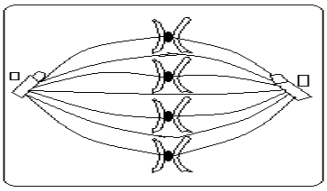


METAPHASE.

During this phase the following events take place,

- Nuclear breakdown is completed.
- Spindle fibre formation is completed.
- Each chromosome is attached on a single spindle fibre by the centromere, they form a single row of chromosomes at the equatorial plane.
- Chromatids draw apart at the centromere region.

METAPHASE.



ANAPHASE.

This is a very rapid stage. It has an early and a late stage,

Early Anaphase.

The events that take place include,

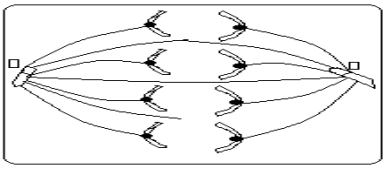
- The centromeres split into two and are pulled apart.
- The chromatids are separated and each chromosome pulled to opposite poles of the cell by the spindle fibres at the centromere.

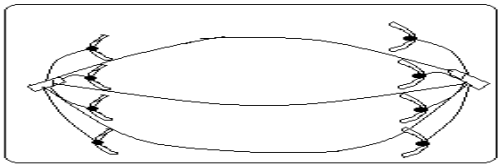
Late Anaphase.

During the late prophase the following events occur,

- Chromosomes reach opposite poles and converge at the poles.

Early AnaphaseLate Anaphase





TELOPHASE.

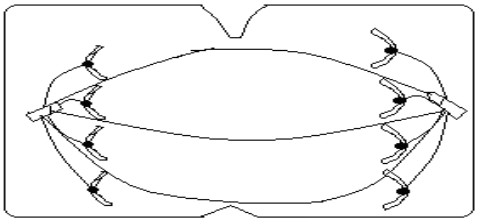
Early Telophase.

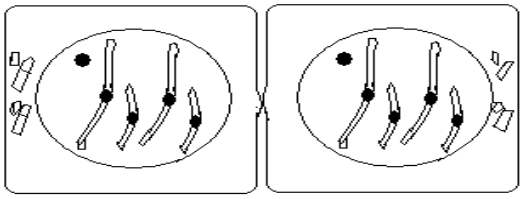
- The chromosomes have reached opposite poles of the cell and converge at the poles.
- The cell membrane starts to constrict across the middle.

Late Telophase.

- Constriction of the plasma membrane continues. In animal cell, it takes place by means of constriction of plasma membrane which cuts across the equator of the spindle. In plants, a new cell wall called the cell plate grows a cross the middle of the cell. They can also be deposited as scattered Golgi-bodies.
- Nuclear membrane and nucleolus reformed in each daughter cell.
- Spindle fibres disintegrate/ spindle fibres breakdown.
- Nucleolus reappears.
- The chromosomes become long, thin, thread like and disappear.
- The cell eventually divides to form two identical daughter cells.

Early Telophase. **Late Telophase.**





THE CELL CYCLE.

Is the sequence of events which occurs between one cell division and the next. It has three main stages,

- Interphase.
- Mitosis.
- and cell division.

INTERPHASE.

This is a period of synthesis and growth. It occupies the longest part of the cell cycle and also occurs in the following stages,

(i) The G1 stage.

In which synthesis of RNA and proteins occur.

(ii) The S stage.

In which DNA replication is completed and duplication of histone proteins and Chromosomes duplication occur. Chromosomes are thread like called chromatins.

(iii) The G2 stage.

In which synthesis and replication of organelles such as mitochondria occur. Synthesis of energy inform of ATP molecules also take place.

MITOSIS.

This is the process where the nucleus divides to form two nuclei identical to the parent nucleus, it occurs in four stages as described above. These include Prophase, Metaphase, Anaphase and Telophase.

CELL DIVISION.

This is the process of the division of the cytoplasm into two daughter cells. It is also referred to as **Cytokinesis**. This stage follows Telophase.

In animal cells, the cell surface membrane begins to inverginate to form furrows during Telophase. This occurs towards the region previously occupied by the spindle equator. Microfilaments in this region are said to be responsible for this. The cell surface membranes in the furrows eventually join up and completely separate the two cells.

In plant cells, the spindle fibres begin to disappear during Telophase, every where except in the region of equatorial plane. In this region the spindle fibres (microtubules) move outwards in diameter and increase in numbers to form a barrel-shaped region (phragmoplast). Microtubules, Ribosomes, Mitochondria, Endoplasmic Reticulum and Golgi apparatus are attracted to this region. Golgi apparatus produces a number of fluid filled vesicles. Along side microtubules all these materials fuse at the center of the cell to form a cell plate. The vesicles contribute to the new middle lamella and the cell walls of the new cells. They first form the primary cell walls which become thickened with cellulose to form secondary cell walls. In areas where the vesicles of the cell plate fail to fuse and the cytoplasm of the neighbouring daughter cells remain in contact, they form cytoplasmic channels which are lined by the cell surface membranes to form plasmodesmata.

DIFFERENCES BETWEEN MITOSIS IN PLANTS AND ANIMAL CELLS.

Plant cells	**Animal cells**
(i) No Centriole present. (ii) No asters formed. (iii) Cell division involve the formation of cell plate. (iv) Occur mainly at the meristem.	(i) Centrioles present. (ii) Asters formed. (iii) Cell division involve furrowing and cleavage of the cytoplasm. (iv) Occurs in tissues through out the body.

NOTE: Centrioles lie in the regions called centrosome which is responsible for making microtubules (spindle fibres). This explains why plants and fungi without Centrioles make spindles from microtubules. The function of the Centrioles is only to orientate the spindles, thus helping to determine in which plane the cell divides.

SIGNIFICANCE OF MITOSIS.

(i) Promotes growth. Mitosis is a type of cell division that takes place during growth of an Organism. Irreversible increase in size of an organism is due to repeated cell division by mitosis. For example of the development of a fertilized egg into adult tissues of human beings.

(ii) Means by which worn out cells are replaced.

(iii) Means by which some animals are able to regenerate the whole parts of their bodies.

(iv) For rapid multiplication of organisms

(v) Is the basis of asexual reproduction for some organisms.For example Binary fission in proctist, bacteria, Fragmentation in spirogyra etc.

(vi) Ensures continuity of species by maintaining the chromosome constitution as that of the parent (maintains diploid state). The features of mitosis which ensures that chromosome numbers are maintained include the following,

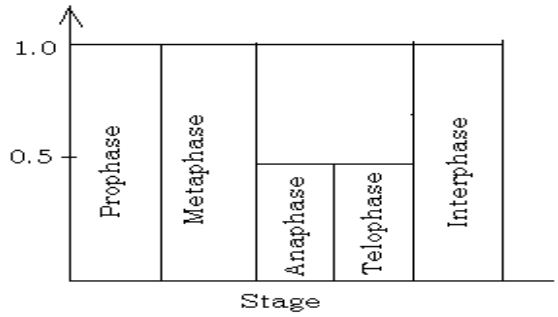
- Replication of chromosomes during Interphase, the parent cell will contain twice the normal number of chromosomes before mitosis begins.

- Each chromosome attaches on a single spindle fibre by the centromere and forms a single row at the equatorial plane. This ensures that chromosomes are distributed evenly between the two daughter cells.

(vii) Provides the means of distributing the hereditary materials equally between two cells. Yet the DNA constitution in each daughter cell is exactly as in that of the parent cell. This is because

before the cell divides, The DNA replicates and the amount of DNA doubles during interphase and is halved at Anaphase. Cells receive the same amount of DNA as in the parent cell.

THE DIAGRAM BELOW SHOWS CHANGES IN THE AMOUNT OF DNA NUCLEUS DURING MITOSIS.



MEIOSIS (MEIOTIC CELL DIVISION).

Is the process by which a cell nucleus divides to produce four daughter nuclei which are not identical to the parent nucleus, each daughter nuclei contain half the number of chromosomes of the original nucleus, they are therefore haploid, n. Meiosis is the process by which gametes are formed. These include formation of sperms and eggs (ova) in animals and formation of pollen grains and embryo sac and spores in plants. Meiosis consists of two successive divisions,

- The first meiotic division.
- and second meiotic division.

In the first meiotic division, the parent cell splits into two and in these stage homologous chromosomes are separated. And for this reasons it is referred to as a **reductive stage**.

In second meiotic division each of the products divides again to produce four daughter cells. In this stage the chromatids are separated to form chromosomes. Before a cell begins to divide, it is at interphase and then meiotic division proceeds in four stages of Prophase, Metaphase, Anaphase and Telophase. They occur in two successive stages and each phase is followed by symbols I or II indicating wether it belongs to the first or second meiotic division.

Note: A cell containing four chromosomes are used just for easy illustration of the meiotic cell division.

INTERPHASE I.

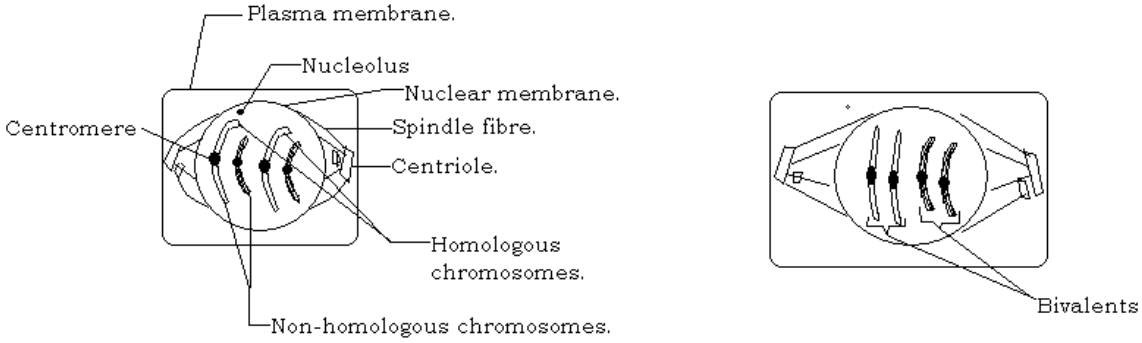
This stage is exactly similar to that which occurs in mitosis. Such similar events that take place are,

- Synthesis of RNA.
- Synthesis of histone and non-histone proteins.
- DNA replication.

- Duplication of chromosomes which are long and thread like, invisible and exist as chromatins. At this stage the sister chromatids are joined along their length by centromere.
- Replication of organelles such as mitochondria, etc.
- Synthesis of energy inform of ATP molecules.

PROPHASE I

Early prophase I ***Mid-prophase I***



Early prophase I.**Mid-prophase I**

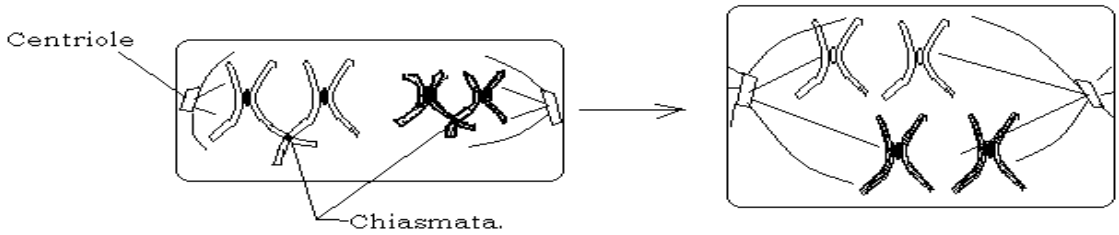
- Long thin, thread like chromosomes called chromatins begin to condense.
- Homologous chromosomes associate as they lie side by side to form a bivalent in a process called ***synapsis***.
- Nucleolus shrinks.
- Spindle fibres begin to form.
- Centrioles move to opposite poles of the cell.
- Homologous chromosomes intimately coil around one another.
- Nucleolus breaks down.

LATE PROPHASE I

- Chromosomes condense to short, thick structures and become visible as pair of chromatids held together by centromere.
- Homologous chromosomes previously coiled around one another repel each other apart slightly; the chromatids of the homologous chromosomes remain in contact at certain points known as ***chiasmata (singular chiasma).***
- Breakage at the chiasmata and re-union between the chromatids results into exchange of portions of chromatids between the two homologous chromosomes in a process known as ***crossing over***. This causes exchange of genes between the chromatids of the two homologous chromosomes, leading to a new gene recombination which is main causes of ***genetic variation***. So, Chiasmata have two functions, hold homologous chromosomes together while they move into position on spindles prior to segregation and leads to Crossing over causing increased genetic variation which is the basis for evolution of new species.

- The chromatids of homologous chromosomes continue to repel each other and Bivalents assume particular shapes depending upon number of chiasmata, one chiasma the shape of Bivalent is open cross, two chiasmata leads to ring shape, while three leads to loops at right angles.
- Nuclear membrane breaks down.

Late prophase I



Prophase I can further be classified into five sub-divisions.

- Leptotene.
- Zygotene.
- Pachytene.
- Diplotene.
- Diakinesis.

(i) Leptotene.

- Chromosomes appear as thin, thread like structure.
- Spindles start to form.

(ii) Zygotene.

- Nucleolus disappears.
- Bivalents formed in a process called synapsis.

(iii) Pachytene.

- Chromosomes become visible as a pair chromatids attached at the centromere.

-Chiasmata are formed.

(iv) Diplotene.

- Chromatids continue to move apart as they shorten and thicken.

– Crossing over occurs.

(v) Diakinesis.

– Shortening and thickening continues.

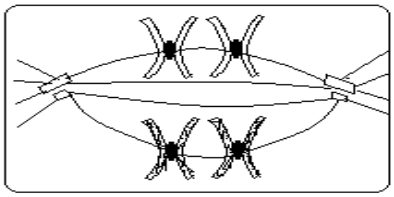
- Homologous chromosomes of have completely moved apart.
- Nuclear membrane breaks down.

METAPHASE I.

The chromosomal and other changes that take place during this stage include,

- Two homologous chromosomes attach and align by their centromere on the same spindle fibre. The arrangement is described as random and independent, and it leads to a new genetic recombination (gene reshuffling) that causes genetic variations.
- Two rows of chromosomes are formed at the equator. One chromosome of each Bivalent is directed towards one of the poles of the cell, while its homologous partner towards the other pole.
-

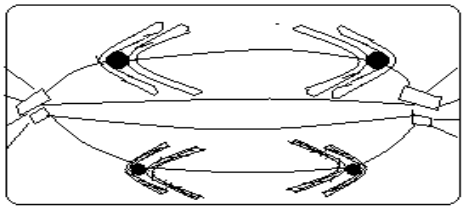
Metaphase I



ANAPHASE I

During this stage, chromosomal and other changes that take place include,
Spindle fibres pull back, Homologous chromosomes still attached on spindle by the centromere are pulled towards opposite poles of the cell, and this separates the homologous chromosomes into two haploid sets, one set at each end of the spindle.

Anaphase I

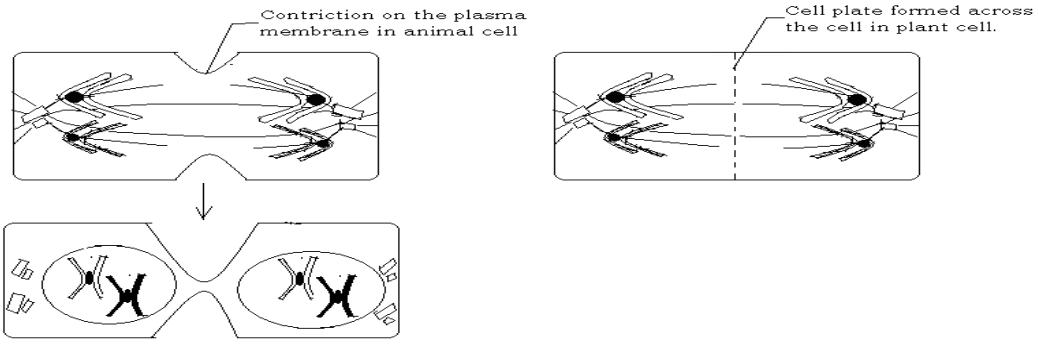


TELOPHASE I

- Homologous chromosomes reach the opposite poles.
- Spindles fibres disappear.
- In animal cells, the chromatids (chromosomes) uncoil and nuclear envelop membrane reforms at each opposite poles of the cell.
- In animal cells, the cell membrane constricts across the middle and cleavages. While in plant cells cell plates formation occurs.
- Nuclear membrane reforms.
- Centrioles split into two.
- Chromosomes (chromatids) uncoil.
- Nucleoli reappear.
- The cleavage of the cytoplasm occurs.

- Two daughter cells with two nuclei formed with half the number of chromosomes to that of the parent. The daughter cells are not identical that of the parents.

Telophase I



NOTE: - In many plants, there is no Telophase, cell wall formation and interphase,the cell passes straight from Anaphase I into Prophase II.

- Interphase II only occurs in animal cells. No further DNA replication and no chromosome duplication occurs. It is a very short process.

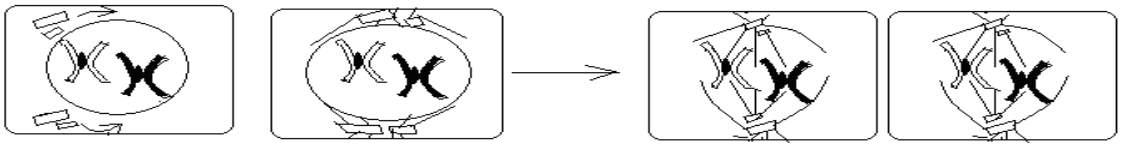
MEIOSIS II.

PROPHASE II.

The events that take place are,

- Nucleoli and nuclear membrane break down.
- Chromosomes shorten and thicken.
- Centrioles if present move to opposite poles of the cell
- New spindles form and are arranged at right angle to the spindles of meiosis.

PROPHASE II

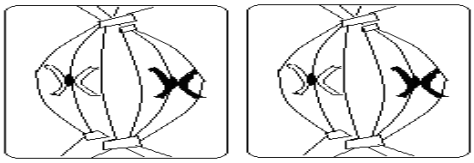


METAPHASE II

The chromosomal and other changes that take place during this stage include,

- Each chromosome attach on its own spindle fibre by the centromere and arrange themselves at the equator of the spindle.

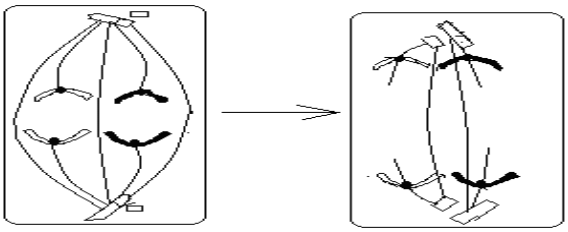
METAPHASE II



ANAPHASE II.

- Centromeres split.
- Chromatids are separated to form chromosomes and the chromatids (chromosomes) are pulled to opposite poles of the cell.

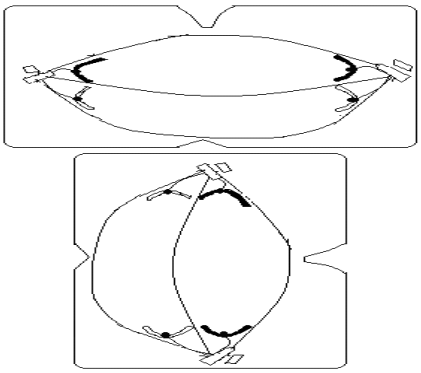
Anaphase II

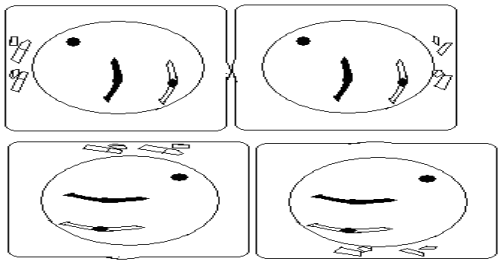


TELOPHASE II.

- The chromosomes have reached opposite poles of the cell and converge at the poles.
- The cells start to constrict across the middle.
- Constriction of the plasma membrane continues. In animal cell, it takes place by means of constriction of plasma membrane which cuts across the equator of the spindle. In plants, a new cell wall called the cell plate grows a cross the middle of the cell. They can also be deposited as scattered Golgi-bodies.
- Nuclear membrane and nucleolus reformed in each daughter cell. Each nucleus contain half the number of chromosomes of the parent nucleus, they are haploid.
- Spindle fibres disintegrate/ spindle fibres breakdown.
- Nucleolus reappears.
- The chromosomes become long, thin, thread like and disappear.
- The cell eventually divides to form four haploid cells not identical to the parent

TELOPHASE II ..





SIGNIFICANCE OF MEIOSIS.

(i) The process in which haploid gametes are formed for sexual reproduction. The fusions of the haploid gametes form diploid zygotes which ensure that chromosome numbers are normally kept constant in each generation. This prevents mutation of any kind.

(ii) Crossing over during prophase I, random and independent assortment of homologous chromosomes during metaphase I of meiosis which leads to new genes recombinations, causing an increased genetic variations which will result into offsprings with new characteristics which may better adapt them to the environment or may lead to evolution of new species.

DIFFERENCES BETWEEN MITOSIS AND MEIOSIS.

MITOSIS	**MEIOSIS**
PROPHASE. (i) No synapsis to form Bivalents.	**PROPHASE** (i) Synapsis to form Bivalents.
(ii) No chiasmata and crossing over occurs.	(ii) Chiasmata and crossing over occurs.
(iii) Takes Relatively shorter time	(iii) Takes relatively longer time.
(iv) Chromosomes shorten and thicken.	(iv) Chromosomes coil but remain longer than in mitosis.
METAPHASE. (V) Chromosomes form a single row at the equator.	**METAPHASE** (v) Chromosomes form two rows at the equator during meiosis I.
(vi) One chromosome attach at the equator.	(vi) Two chromosomes attach on a single spindle during metaphase I.
(vii) No random and independent	(vii) Random and independent assortment

Assortment of homologous chromosomes.	of homologous chromosomes occur.
ANAPHASE.	**ANAPHASE.**
(viii) Chromatids are separated and pulled to opposite poles of the cell.	(viii) Homologous chromosomes are separated and pulled to opposite poles of the cell during meiosis I.
(ix) Identical chromatids are separated.	(ix) Non-identical chromatids are separated.
(x) Centromeres pulled once towards opposite poles of the cell.	(x) Centromeres pulled twice towards opposite poles of the cell.
TELOPHASE.	**TELOPHASE.**
(xi) Same number of chromosomes present in daughter cells as parent cells. Daughter cells are Diploid, 2n.	(xi) Half the number of chromosomes present in daughter cells. Daughter cells are haploid,n.
(xii) Daughter cells formed are exact copies of the parent ones/ no variation	(xii) Daughter cells formed are not identical to the parent cells/ variation occurs.
(xiii) Two diploid daughter cells are formed.	(xiii) Four haploid daughter cells are formed.
OTHERS/ MITOSIS	**OTHERS/ MEIOSIS**
(xiv) Occurs in haploid, diploid or polyploid cells.	(xiv) Occurs in diploid or polyploid cells only.
(xv) Occurs mainly during formation of somatic (body) cells and some spores.	(xv) Occurs mainly during formation of gametes or spores.
(xvii) Fast process.	(xvii) Gradual process.
(xviii) Occurs in one phase.	(xviii) Occurs in two successive phases I and II.
(xix) One division of nucleus and one of chromosome.	(xix) Two divisions of nucleus and one of chromosome.

Qn. Compare processes of the first and second meiotic division.