Unit-II : Cell-Biology - II

(1) Chromosomes :-

(chrom - color, soma - body).

Chromosomes are thread-like structures present in the nucleus & which become visible during cell-division. They carry genes or units of heredity. Chromosomes were discovered by Strausberger (1875). The name chromosome was coined by Waldeyer (1888) to darkly-stained bodies of nucleus.

The eukaryotic chromosomes are classified into autosomes & sex-chromosomes. The autosomes have nothing to do with determination of sex. They are more in number. The sex-chromosomes determine sex of their bearer. They are two in number & are of two types :- X-chromosomes & Y-chromosomes.

Morphology of chromosomes :-

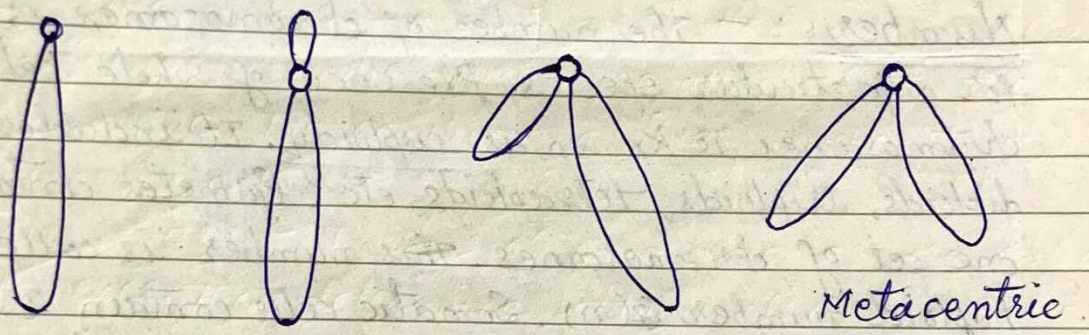
Number :- The number of chromosomes is constant for a particular species. Presence of whole sets of chromosomes is known as euploidy. It includes haploids, diploids, triploids, tetraploids, etc. Gametes contain only one set of chromosomes. This number is called as haploid number (n). Somatic cells contain 2 sets of chromosomes (2n). Triploids have three sets of chromo-somes (3n) & tetraploids have 4 sets (4n).

In higher plants, only a few species have more than 15 chromosomes (haploid). In most animals, there are upto 50 chromosomes.

Size :- The size of chromosomes varies from species to species & is constant for a particular species. The length of chromosome varies from 1 μ (some fungi) to 30 μ (Trillium). All chromosomes of a species may be of same size or vary in size. Plants have large-sized chromosomes than animals. Among plants, monocots have large-sized chromosomes than dicots. The largest chromosomes are lampbrush chromosomes of certain vertebrate oocytes & polytene chromosomes of certain dipteran insects.

Shape :—

The shape of chromosomes is changable from phase to phase in the process of cell-division. In the resting phase or interphase stage of a cell, the chromosomes occur in the form of thin, thread-like structures called chromatin fibres/threads. During metaphase and anaphase, the chromosomes become thick & filamentous. Each chromosome contains a clear zone, known as centromere or kinetochore. The centromere divides the chromosome into 2 parts, each part is called chromosome arm. The position of centromere varies in different chromosomes. On the basis of position of centromere, the chromosomes are of 4 types/shapes:



Telocentric Acrocentric Sub-metacentric

Fig: Different shapes of chromosomes

1. Telocentric :— These are rod-shaped chromosomes, having centromere at proximal end.
2. Acrocentric :- These are rod-shaped chromosomes, having centromere near one end. So, one arm is very short & other is long.
3. Sub-metacentric :- These chromosomes are "J" or "L"-shaped. The centromere occurs near the centre, & thus the two arms are unequal.
4. Metacentric :- These chromosomes are "V"-shaped. The centromere occurs in the centre & thus two equal arms are formed.

Structure of chromosome. :-

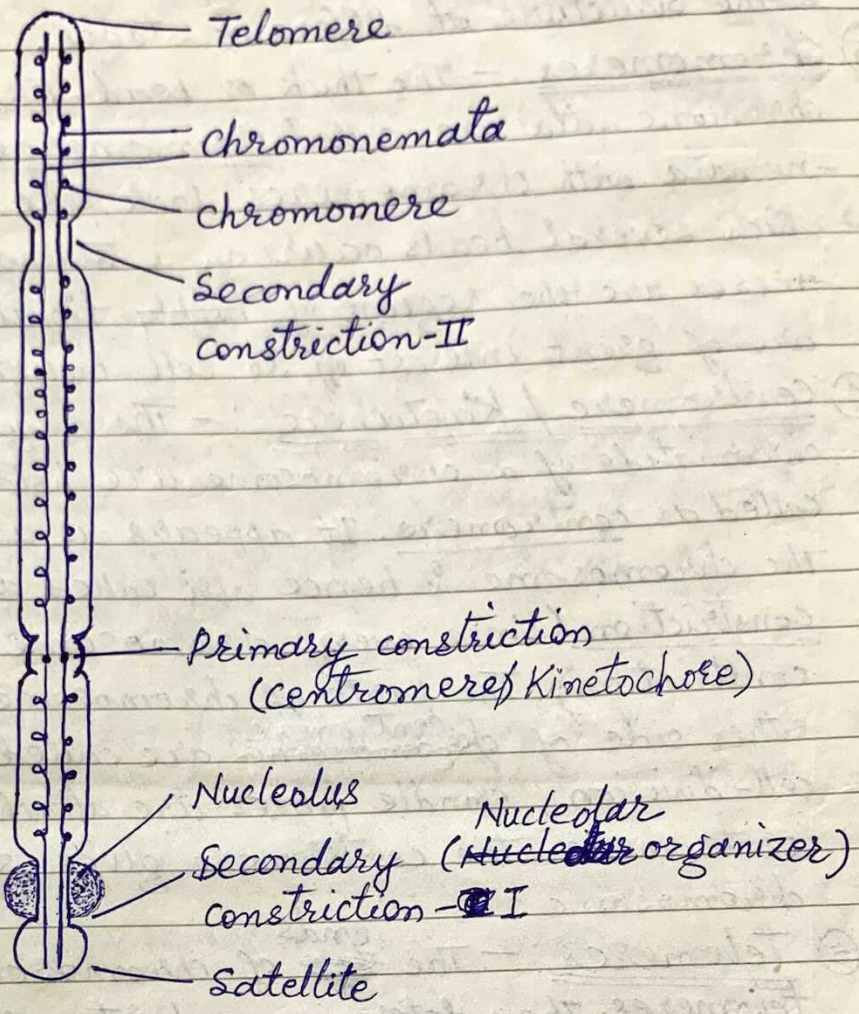


Fig :- Structure of a typical chromosome.

A chromosome consists of different parts, as follows →

(1) Chromatids :- Each metaphase chromosome shows two identical parts, known as chromatids. The two chromatids are fused together at a point, called centromere. Since the two chromatids are produced through replication of a single chromatid, they are called as sister chromatids.

(2) Chromonemata :- Internally, the chromosome contains → two identical, spirally coiled filaments, called as chromonemata. The chromonemata may be two, four or more in number, according to species. They are spirally coiled with each-other. During cell-division, chromonemata become

condensed to form chromatids. So, the chromo--nemata & chromatids are the two names of the same structure at different stages.

③ Chromomeres :- The thick or bead-like-structures of chromonemata are called chromomeres. The chromo--nemata with chromomeres look like necklace in which several beads occur on a string. The chromo--meres are the regions of ~~highly~~ tightly-folded DNA & are of great interest to cell biologists.

④ Centromere / Kinetochore :- The region where two chromatids of a chromosome are held together, is called as centromere. It appears as a constriction in the chromosome & hence also called as primary constriction (since every chromosome has this constriction). The parts of chromosome lying on either side of centromere are called arms. During cell-division, spindle fibres are attached to the centromere. The centromere gives shape to the chromosome.

⑤ Telomeres :- The ends of chromosomes are called Telomeres. They determine polarity of chromosomes & therefore prevent the fusion of other chromosome to them. If a chromosome breaks, the broken ends can fuse with each other due to lack of telomere

⑥ Secondary constriction :- In addition to the primary constriction, the chromosome possesses a second constriction, called secondary constriction. It plays a vital role in formation of nucleolus & hence also called nucleolar organizer.

⑦ Satellite :- Sometimes, the chromosomes bear round, elongated or knob-like appendage called as satellite. The chromosome with satellite is called as SAT chromosome. Prefix SAT stands for 'Sine Acid Thymonucleinico (without thymonucleic acid or DNA), because the chromosome on staining shows deficiency of DNA in the nucleolar organiser region. There are at least 2 SAT chromo--somes in each diploid nucleus.

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Functions of a Typical chromosome :—

- The chromosomes are most important components of the cell.
- They control all the cell biological & genetical activities of a species.
- They control the heredity. They carry genes from parents to offsprings.
- They are vital for cell-division process & responsible for cell division, replication & creation of daughter cells.

(*) Study of Karyotype & idiogram of human beings :—

(A) **Karyotype** :- The sequential arrangement of all the chromosomes of an individual, is called as karyotype. It gives the number, shapes and sizes of chromosomes of the individual. All the members of a species of a plant or animal have chromosomes with certain constant characters.

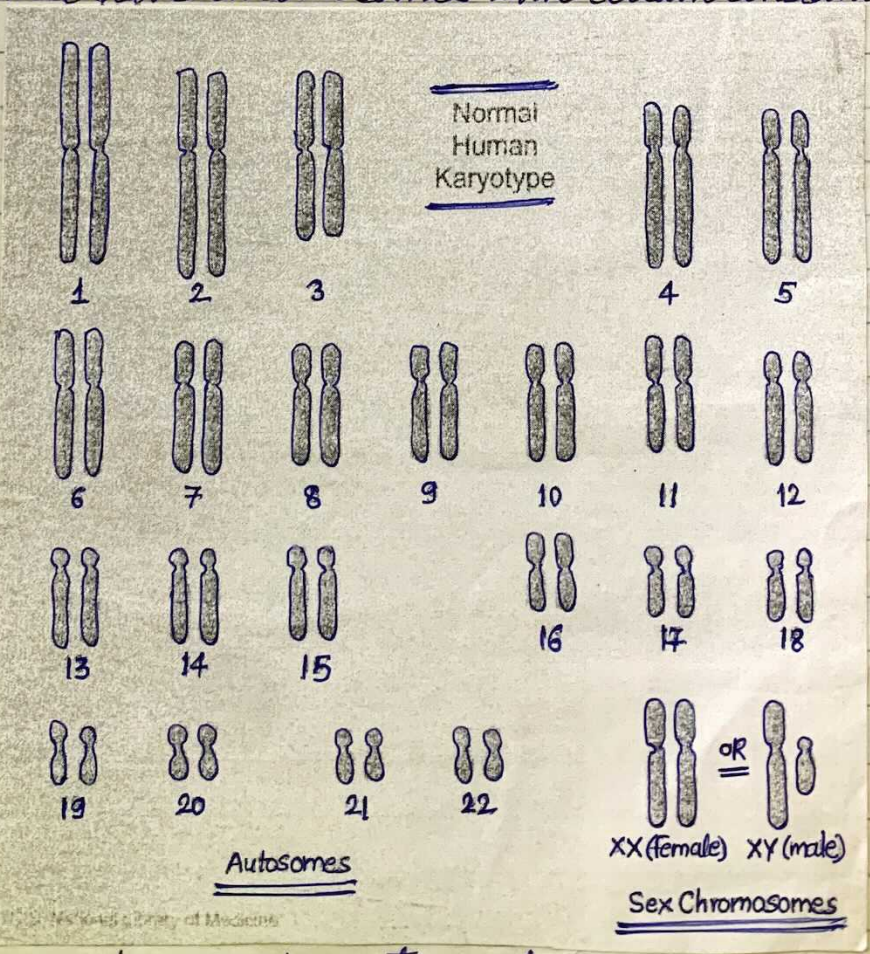
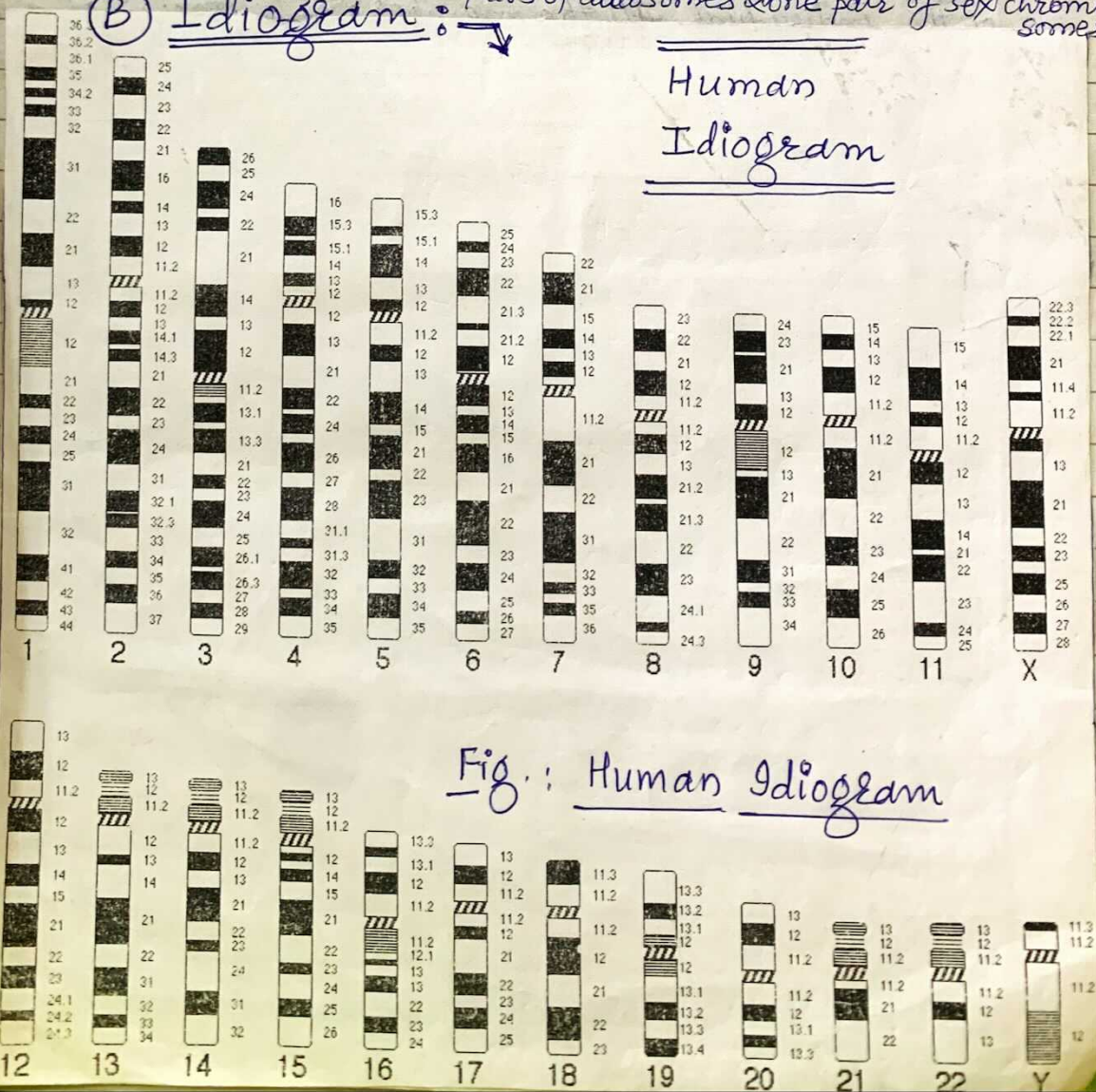


Fig :- The human karyotype showing 22 pairs of autosomes & one pair of sex-chromosomes.

The Karyotypes of different species are ~~com~~ compared to know evolutionary relationship. A karyotype also suggests primitive or advanced features of an organism. Karyotype may be symmetric or asymmetric.

Human karyotype is prepared from White blood cells ie. leucocytes. Metaphase nuclei are photographed and the individual chromosomes are cut out and arranged in descending order of their size. Thus, the longest chromosome is placed at first and the smallest chromosome is placed at last. The sex-chromosomes are placed separately after the autosomes & hence placed at extreme right. Each chromosome in a karyotype is given a serial number according to its position. The sex chromosomes are labelled as X and Y. The Y-chromosome is shorter than the X-chromosome. In karyotype of human male, X & Y chromosomes are seen, while in case of human female, two X-chromosomes are observed. Karyotype of an individual represents karyotype of the concerned species. Human karyotype shows 22 pairs of autosomes & one pair of sex chromosomes.

(B) Idiogram:



Human Idiogram

Fig.: Human Idiogram

The diagrammatic representation of a karyotype is called as idiogram. In idiogram, karyotype is represented diagrammatically, showing all morphological features of the chromosomes. As a rule, idiogram is prepared for haploid chromosome complement of a species.

⋆ Giant chromosomes :-

(1) Polytene chromosomes / Salivary gland chromosomes

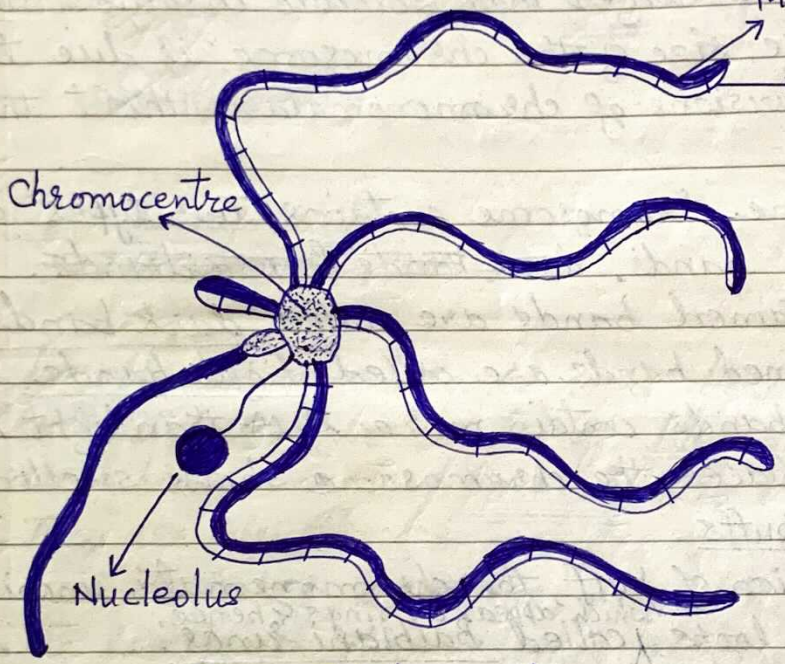


Fig. :- Polytene chromosome.

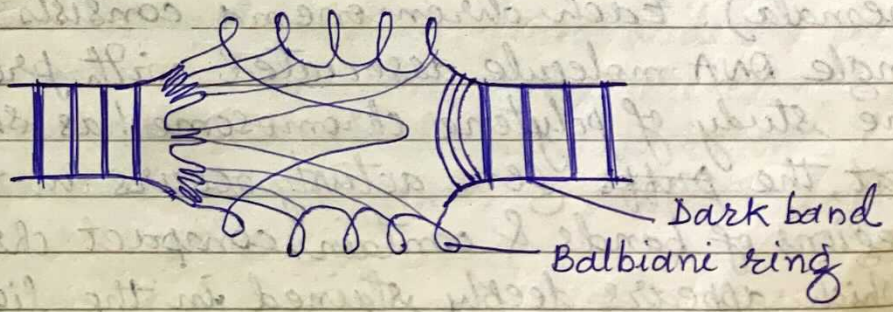


Fig. :- Puff

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→ Polytene chromosomes were discovered by Balbiani (1881) in the salivary glands of chironomous larvae & hence called as salivary gland chromosomes.
→ They are also found in guts, trached, & fat body cells of many insects of order Diptera.
→ The polytene chromosome contains many chromonemata in it & hence named as polytene chromosome (poly - many, tene - strand).
→ In Drosophila melanogaster, polytene chromosome is 1000 times larger than somatic chromosome.
→ The large size of the chromosome is due to repeated divisions of chromonemata without their separation.
→ The polytene chromosome contains two types of transverse bands, ~~dark bands & interbands~~.
→ Darkly-stained bands are called dark bands & lightly-stained bands are called light bands.
→ The dark bands contain more DNA than light bands.
→ At some places, the chromosome shows swellings, called as puffs.
→ In the region of puff, the chromonemata uncoil & form many loops, which appear as rings & hence, called Balbiani rings.
→ The puff is related with ~~mRNA~~ synthesis of mRNA and proteins.

→ The salivary gland chromosome is formed by about 1000 - 4000 unit chromatids (Chromo - nemata). Each chromonema consists of a single DNA molecule associated with protein.
→ The study of polytene chromosome has shown that, the ~~puffs~~ gene activity occurs in the regions of bands & contain conspact chromatin which appears deeply stained in the light microscope.
→ In chironomous, many types of puffing patterns have been observed. i) Some bands do not puff at all. ii) Others undergo puffing, but there is no connection.

between puffing & moulting. iii) Puffing begins at commencement of moulting. iv) Puffing begins some time after the commencement of moulting. v) Puffs are present during intermoult stage, but become larger during metamorphosis.

(2) Lampbrush chromosomes :—

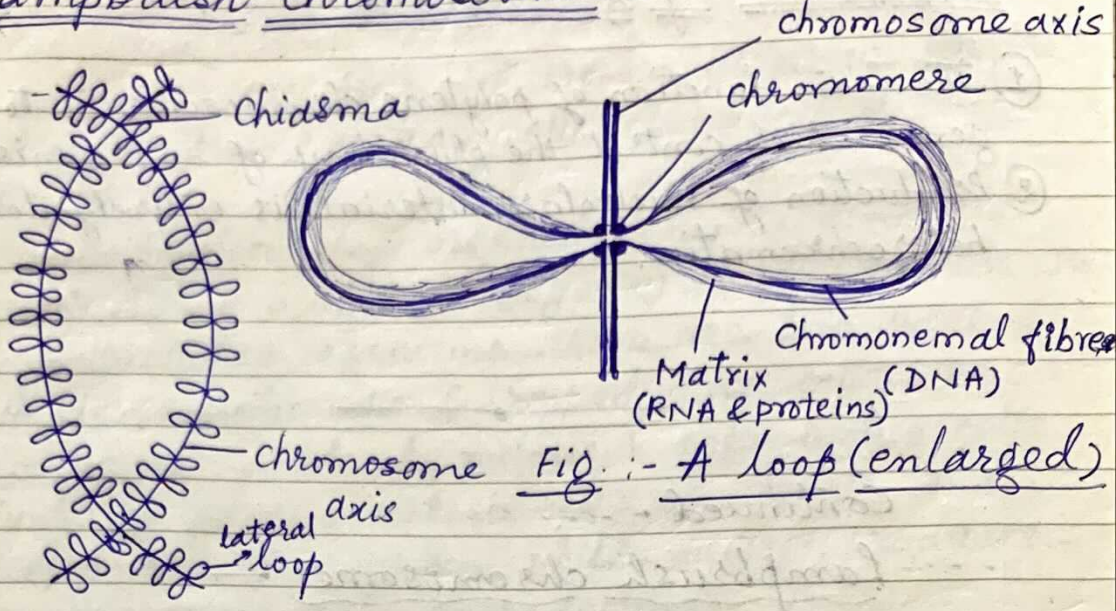


Fig :- A loop (enlarged)

Fig :- Lampbrush chromosome

→ Lampbrush chromosomes were discovered by ~~Ruckert (1892) in oocytes of~~ Flemming (1882) in amphibian oocytes / Ruckert (1892) in oocytes of shark.
→ They are also found in oocytes of many vertebrates, such as fishes, reptiles, amphibians & birds.
→ The lampbrush chromosomes are much larger than polytene chromosomes.
→ They appear as brushes once used for cleaning glass chimneys of kerosene lamps & hence called lampbrush chromosomes.
→ Each chromosome of a pair consists of a main axis composed of two chromatids. Hence, 4 chromatids are present.
→ The main axis contains many thickenings called chromomeres. They are found in pairs, one for each filament.
→ From each chromomere, a pair of lateral loops is developed.
→ The loop consists of an axial fibre, made up of DNA.
→ The axial fibre is surrounded by a matrix, which is composed of RNA and proteins.
→ The homologous chromosomes have points of contact known as chiasmata. —:PTO:—

⊛ Significance of giant chromosomes :-

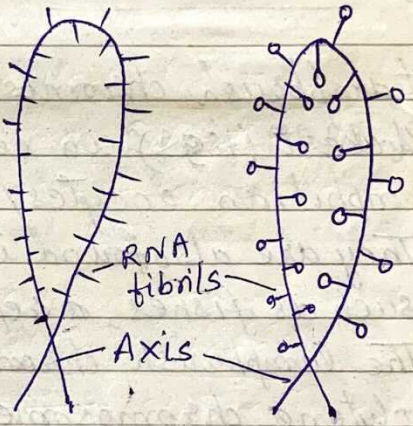
(1) The main function of polytene chromosome is to carry genes which control the physiology of an organism.
(2) Production of nucleolar material is entirely done by heterochromatin.

Continued - - - -

- - - - Lampbrush chromosome —

- The loops are of two types: typical & special. Most of the loops are typical.

(a) The typical loop consists of a central axis, from which are given off RNA fibrils of progressively increasing lengths. This makes the loop thicker on one side.



Typical loop Special loop

(b) The special loop has a marked symmetry & granules at the end of the fibrils.

- The study of lampbrush chromosome shows that, gene activity occurs on loops.
- As the chromosome is highly elastic, it can be stretched to about 2.5 times its original length.
- At the diplotene stage of meiosis in oocytes of amphibians, lampbrush chromosomes are seen. It is considered to be an adaptation to the intense metabolic & synthetic activities of the oocytes. This modified diplotene stage is called as dictyate stage.

⊛ Cell Division ⊛

The process by which new cells arise by the division of pre-existing cells, is called as cell-division.

In multicellular organisms, new individuals develop from a single cell (zygote) by cell-division. In the multicellular organisms, there are two types of cells, viz :- somatic cells & reproductive cells. The somatic cells divide by mitosis & reproductive cells divide by meiosis. Mitosis helps in growth and development of organism, while meiosis produces gametes & spores in reproduction.

The cell which undergoes division is called as mother cell, while newly formed cells are called as daughter cells.

Cell Cycle :-

"The cell cycle is the sequence of events occuring in the life of a cell". It is a period from the begining of one cell-division to the begining of next cell-division. The period required to complete one cell cycle is called as generation time.

The cell cycle consists of two phases, viz :- ⊛ interphase & M-phase.

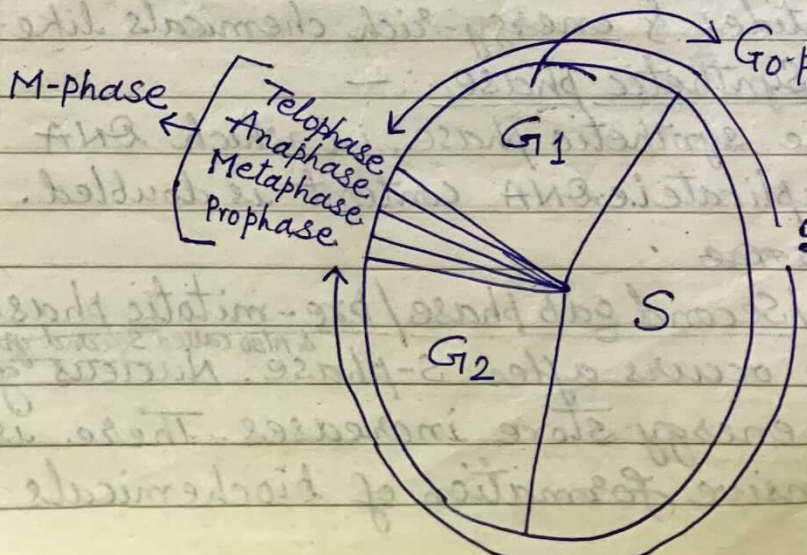


Fig. : Cell cycle.

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(1) Interphase :— (Inter - in between, phase - state)

It is the interval between two successive divisions of a eukaryotic cell. It is a non-dividing phase. Previously, it was called resting phase, but metabolically, it is very active phase.

Three important processes occur in interphase
(i) Synthesis & storage of energy-rich compounds (ATP).
(ii) Replication of DNA.
(iii) Synthesis of histones & other nuclear proteins.

During interphase, nuclear envelope is intact & nucleolus is present. The chromosomes are diffused, & invisible.

Interphase is longest phase in cell-cycle & divided into three sub-stages, as G_1, S and G_2 phase.

(a) G_1-phase / First gap phase / Post-mitotic phase :—

G_1-phase occurs immediately after previous division. It is called first gap phase, since no DNA synthesis takes place during it. It is also called first growth phase because it involves the synthesis of RNA, proteins etc., which lead to growth of nucleus. Cell size is also increased. Nucleus also grows to a smaller extent. There is intensive formation of biochemicals & cell organelles like mitochondria, plastids, endoplasmic reticulum, Golgi complex, ribosomes, RNAs, proteins, amino acids, nucleotides & energy-rich chemicals like ATP.

(b) S-phase / Synthetic phase :—

It is the synthetic phase, in which DNA molecules replicate i.e. DNA content is doubled.

(c) G_2-phase / Second gap phase / pre-mitotic phase :—

This phase occurs after S-phase. Nucleus grows in size. The energy store increases. There is again intensive formation of biochemicals

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including RNAs and proteins. Mitochondria, plastids, endoplasmic reticulum, Golgi complex etc. are also formed. Centrosome replicates (in animal cells).

② M-phase (Mitotic/Meiotic phase) :-

It is the phase of cell-division. Division may be mitosis / meiosis. M-phase involves separation & distribution of chromosomes into daughter cells. There is also distribution of cell-organelles and cytoplasm.

M-phase consists of following two phases :-

(a) Karyokinesis ie. the division of nucleus, &

(b) Cytokinesis. ie. the division of cytoplasm.

G_0-phase :- It is the stage of G_1-phase, during which cell cycle is arrested & stopped for indefinite period.

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(1) Mitosis (Equational division)

Mitosis is the process of cell-division in which chromosomes are duplicated & distributed equally in two daughter cells. Mitosis results in the formation of two diploid daughter cells, from a diploid parent cell. As the daughter cells resemble mother cell genetically, mitosis is also called as equational division. Mitosis occurs in somatic cells & results in growth & development of organisms.

Mitosis is divided into karyokinesis (division of nucleus) and cytokinesis (division of cytoplasm).

(A) Karyokinesis :-

Karyokinesis is the division of nucleus. It involves four stages, viz.: prophase, metaphase, anaphase and telophase.

(1) Prophase :- (pro ~~tase~~ - first, phase - stage).

→ This is the longest mitotic phase. In the begining, chromosomes appear thin & thread-like. ~~later~~ The nuclear membrane & nucleolus are ~~intact~~ distinct.

Later the chromosomes become short & thick due to condensation. Each chromosome consists of two sister chromatids joined to each-other by centromere.

~~The centromere~~ In animal cell, the centrosome now divides into two centrioles which move two opposite poles.

Disappearance of nuclear envelope and nucleolus marks the end of prophase. As the nuclear envelope disappears, nucleoplasm and cytoplasm get mixed.

(2) Metaphase :- (Meta ÷ Middle, phase - stage).

At the late prophase, microtubules extend in

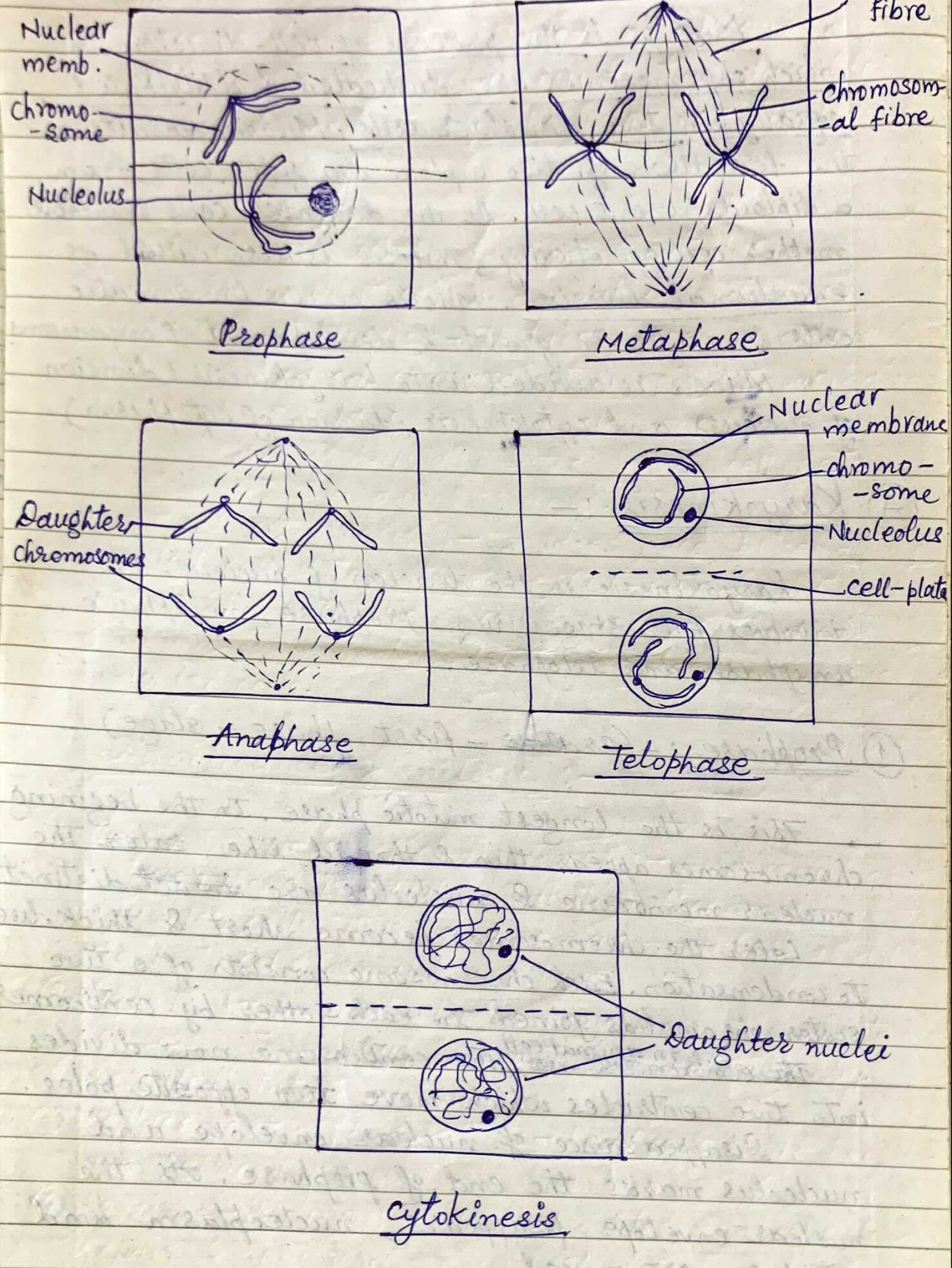


Fig. : Stages of mitosis in plant cell.

all directions from centrioles and called asters. Centrioles & asters are found in cells of animals & and lower plants. This type of mitosis is called as astral mitosis. Mitosis in higher plants does not involve centrioles & asters & called anastral mitosis.

From the centrioles & asters, bipolar spindle apparatus is formed. The central broader part is called equator & narrow ends are called poles. The microtubules (fibres) which form the spindle are called spindle fibres. The spindle fibres which run from pole to pole are called as continuous fibres. The spindle fibres which are attached to centromere of chromosome are called discontinuous / chromosomal fibres.

During metaphase, the chromosomes become very short & thick. They are brought on the equator of the spindle apparatus. Centromere of each chromosome is connected to both the spindle poles by separate spindle fibres (Continuous / chromosomal fibres). Centromeres of all chromosomes lie over the equator to form metaphasic plate or equatorial plate.

(3) Anaphase :- (Ana - up, phase - stage).

During anaphase, centromere of all chromosomes spits, sothat the sister chromatids are separated. The sister chromatids with their own centromere are called as daughter chromosomes.

The daughter chromosomes are pulled towards spindle poles in the region of their centromere. As a result, centromeres are found to lead, while arms trail behind. The anaphasic movement of the chromosomes is due to shortening (Contraction) of chromosomal (discontinuous) fibres. Movement of daughter chromosomes continues till they reach the poles.

④ Telophase :- (Telo - end, phase - stage).

This is the last stage of karyokinesis. The chromosomes become long & thin. Nuclear membranes and nucleoli reappear & as a result, two daughter nuclei are formed. The spindle fibres get disappeared.

(B) Cytokinesis :-

Cytokinesis is the division of cytoplasm. Cytokinesis in plant cells & animal cells differs.

Animal cell cytokinesis :- It takes place by cleavage or furrow & called cleavage cytokinesis. Invagination of plasma membrane forms a cleavage / furrow, which deepens centripetally & the mother cell gets divided into two daughter cells.

Plant cell cytokinesis :- It takes place by cell-plate & called cell-plate cytokinesis. Cell-plate formation begins in the centre of cell & proceeds towards periphery & the mother cell gets divided into two daughter cells.

Significance of mitosis :-

① Constant number of chromosomes :- As a result of mitosis, there is equal distribution of chromosomes to daughter cells. Thus, chromosome number of all the body cells remains constant.

② Growth :- In multicellular organisms, the zygote develops into embryo & finally into an adult by repeated mitotic divisions.

③ Replacement of body cells :- Dead cells of the body are replaced by new cells thro' mitosis.

④ Repair & Healing :- Mitosis provides new cells for repair & regeneration of lost parts & healing of wounds.

⑤ Asexual reproduction :- In many organisms, asexual reproduction takes place by mitosis.

(2) Meiosis (Reduction division)

Meiosis is the cell-division which involves reduction of diploid chromosome number to half, in the daughter cells. Meiosis results in the formation of four haploid daughter cells, from a diploid parent cell. Since meiosis reduces the number of chromosomes to half; it is also called reduction division.

Meiosis occurs in plants during sporogenesis. In animals, it occurs during gametogenesis.

Meiosis is divided into karyokinesis (division of nucleus) and cytokinesis (division of cytoplasm).

Homologous chromosomes :- The diploid organism, which reproduces sexually; is developed from a diploid ($2n$) zygote. During fertilization, zygote ($2n$) is formed from fusion of haploid (n) male gamete & haploid (n) female gamete. Thus, a diploid individual receives two sets of chromosomes — one from male gamete (paternal set) & other from female gamete (maternal set). For every chromosome in a paternal set, there is a similar chromosome in the maternal set. Such similar chromosomes from materal and paternal sets which form pairs during meiosis, are called as homologous chromosomes. Thus, all chromosomes have their homologues.

Meiosis consists of two successive divisions — Meiosis - I and Meiosis - II. The time period between Meiosis - I and Meiosis - II is called as Interkinesis.

(A) Meiosis – I :–

It is the first division of meiosis, in which a diploid cell divides into two haploid daughter cells. As diploid number is reduced to haploid, meiosis – I is also called reduction division.

Meiosis – I is divided into 4 stages – Prophase – I, metaphase – I, anaphase – I & telophase – I.

(1) Prophase – I :– It is longest phase in meiosis & divided into five sub stages – leptotene, zygotene, pachytene, diplotene & diakinesis.

(i) Leptotene / Leptonema (Leptos – thin, tene – thread) :– The chromosomes are thin, elongated & thread – like. They are scattered in the nucleus. Nuclear membrane & nucleolus are prominent. In animal cells, centrioles are formed. They form asters. In plant cells, asters and centrioles are not formed.

(ii) Zygotene / Zygonema (Zygon – pair, tene – thread) :– During this stage the chromosomes become shorter & thicker. This phase is characterised by the pairing of homologous chromosomes, which is called synapsis. (The paternal & maternal chromosomes are paired). In each pair, one chromosome is paternal & other is maternal. The pair of homolo. chro. is called bivalent.

(iii) Pachytene (Pachy – thick, tene – thread) :–

In this stage, the chromosomes become shorter, thicker & more distinct. The pachytene stage is marked by crossing over, resulting into recombination of characters. Each chromosome of bivalent is made up of two chromatids. The two chromatids of the same chromosome are called sister chromatids while the chromatids of different chromosomes are called as non – sister chromatids. Crossing over occurs between non – sister chromatids of a bivalent by breakage & reunion with the help of

enzymes. The phenomenon of exchange of segments of non-sister chromatids of homologous chromosomes is called as crossing over". It results in the recombination of genes.

(iv) Diplotene / Diplonema (Diplos - double, tene - thread):
In this stage, the homologous chromosomes start separating from each-other. However, separation is not complete. They remain attached at the point of crossing over. This point is called as chiasma (Plural - chiasmata) (chiasma = cross).

(v) Diakinesis (Dia - across, kinesis - movement) :-
The chromosomes condense & become shorter & thicker. They move towards periphery. The chiasmata are shifted towards the end of chromosomes. This movement of chiasmata is known as terminalisation. In case of animal cells, asters reach the poles. The nuclear membrane & nucleolus disappear. The spindle apparatus begins to appear.

② Metaphase - I :-
The bivalents are arranged at the equator of the spindle. There are two types of spindle fibres. The discontinuous fibres run pole to pole, while continuous fibres are attached to centromere of chromosomes & also called chromosomal fibres.

③ Anaphase - I :-
The homologous chromosomes of each bivalent separate & move towards opposite poles. This is due contraction of chromosomal fibres. Thus, paternal & maternal chromosomes get separated. Each pole receives half the number of chromosomes. Thus, in Anaphase - I, actual reduction in chromosome number occurs.

④ Telophase - I :- At each pole, the chromosomes become thin, elongated & thread-like. The nuclear

membrane & nucleolus reappear & hence, two daughter nuclei with haploid chromosome number are formed. The spindle apparatus disappears.

Cytokinesis :- It may or may not be present. If present, it occurs by cell plate in plant cells and cleavage / furrow in animal cells. It produces two daughter cells having haploid nucleus.

(B) Meiosis - II :-

It is the second division of meiosis - I. After this division, number of chromosomes remains same as after Meiosis - I. Hence, it is called as equational division.

Meiosis - II is divided into 4 stages - Prophase - II, Metaphase - II, anaphase - II & telophase - II

(1) Prophase - II :- The chromosomes again become shorter & thicker. Each chromosome has two sister chromatids, joined by a centromere. The nuclear membrane and nucleolus disappear. In animal cell, centrioles & asters are developed. Spindle apparatus begin to appear.

(2) Metaphase - II :- The spindle apparatus is completely formed. The chromosomes are arranged on the equator. The centromere of each chromosome is connected to each pole by chromosomal fibres.

(3) Anaphase - II :- The centromere of each chromosome divides longitudinally. The separated sister chromatids are called daughter chromosomes. They move to opposite poles by shortening of the spindle fibres. After the end of anaphase - II, each pole contains haploid number of chromosomes.

④ Telophase-II :- The chromosomes form the group at each pole. They become thin, elongated & thread-like. The nuclear membrane & ~~nucleolus~~ nucleolus reappears. The spindle apparatus disappears. Thus, four daughter nuclei are formed, which contain haploid number of chromosomes. The chromosomes of daughter nuclei differ from each-other, because of the process of crossing over in prophase-I.

Cytokinesis :- Cytokinesis occurs by cell-plate formation in plant cells & by cleavage/furrow in animal cells.

Significance of meiosis :-

① ~~Reduction~~ Maintenance of chromosome number :- Meiosis reduces chromosome number from diploid to haploid. During fertilization, haploid gametes fuse and again diploid number is established. Thus, chromosome number is maintained by meiosis.

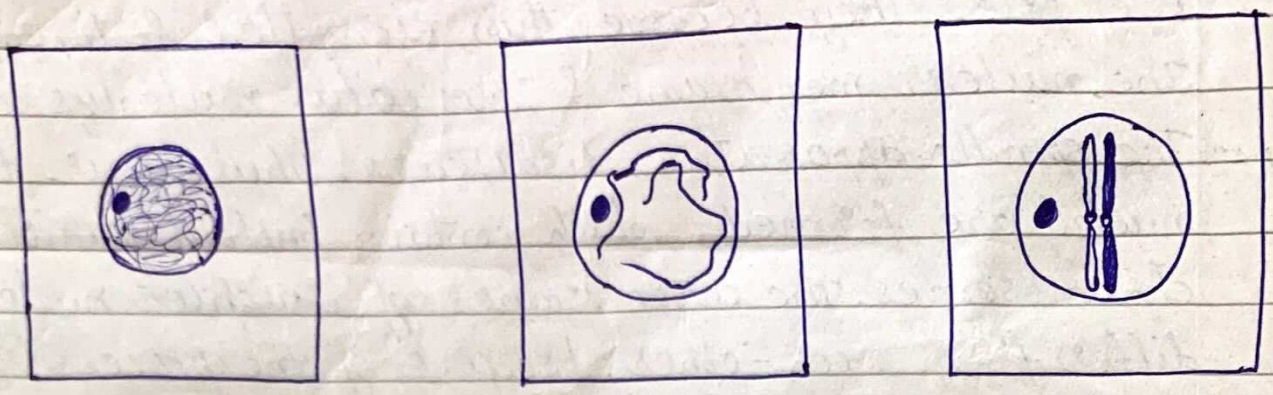
② Recombination :- Recombination of genes occurs during crossing over in pachytene of prophase-I.

③ Variations :- Recombination of genes causes variations in offsprings.

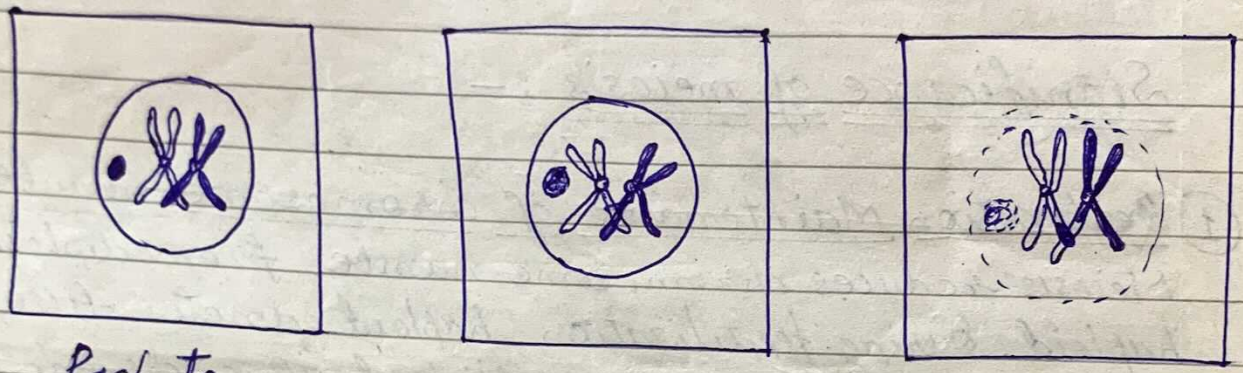
④ Evolution :- Variations in offsprings over the generations result in organic evolution.

⑤ Formation of spores & gametes :- Due to meiosis, spores are formed in asexual reproduction and gametes during sexual reproduction.

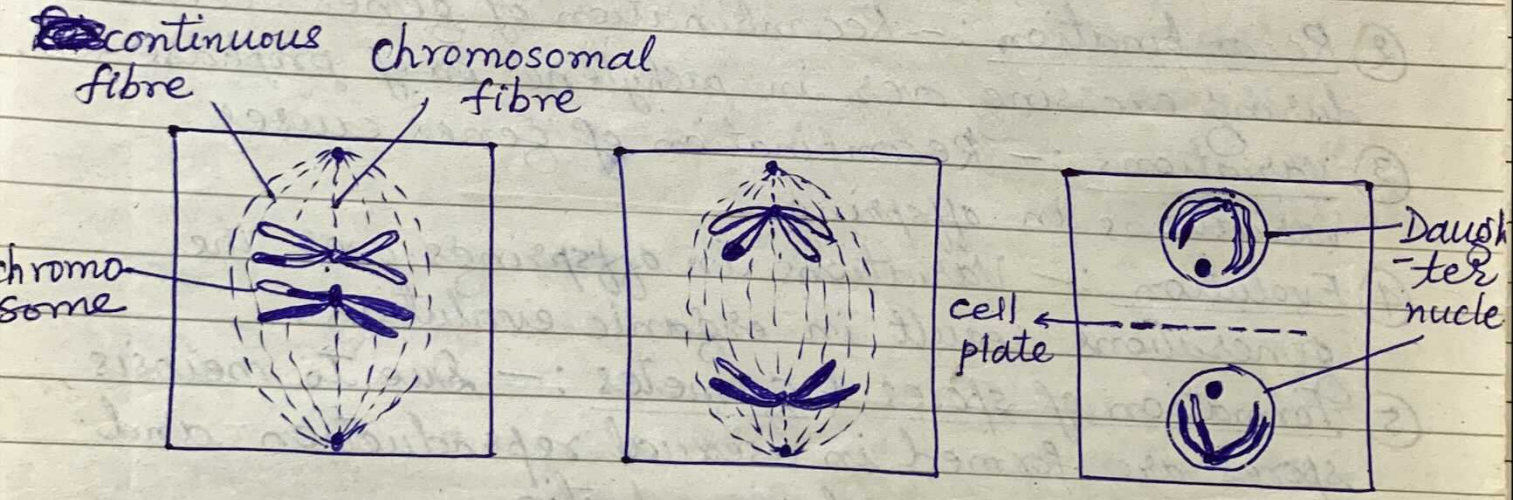
← P.T.O →



Interphase Leptotene Zygotene

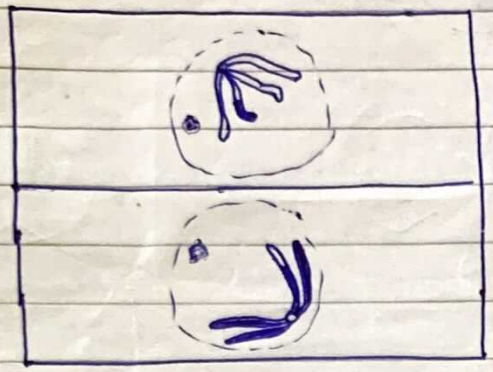


Pachytene Diplotene Diakinesis

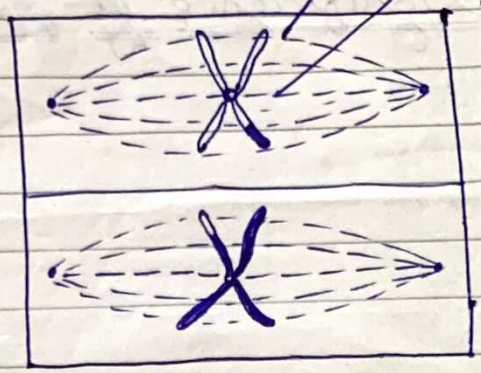


Metaphase-I Anaphase-I Telophase-I

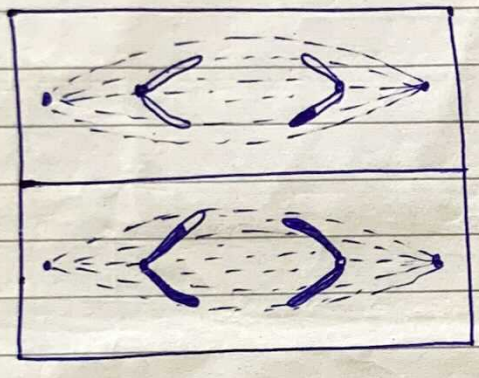
Fig.: Stages of Meiosis-I in plant cells



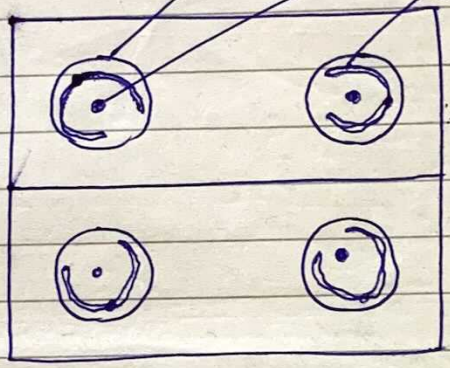
Prophase – II



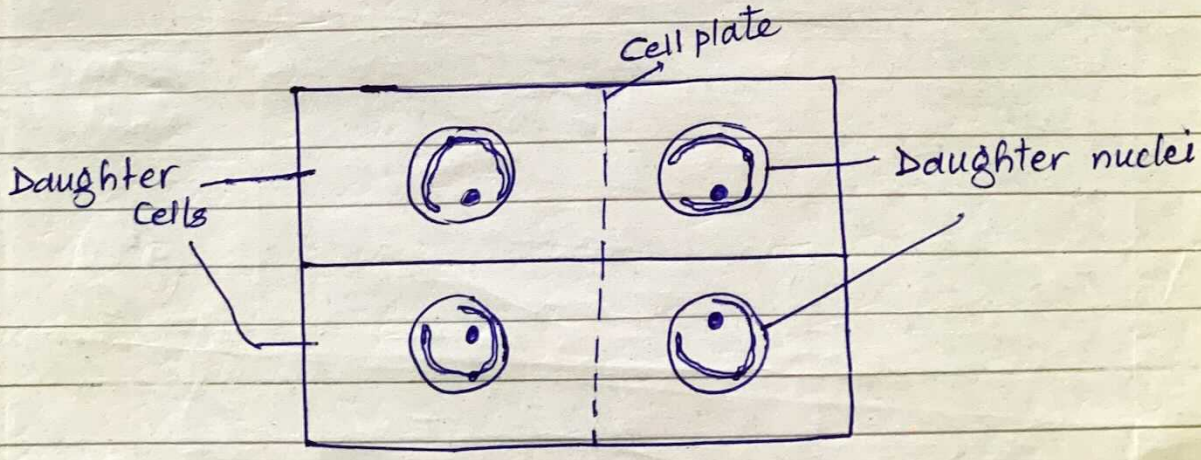
Metaphase – II



Anaphase – II



Telophase – II



Cytokinesis

Fig.: Stages of Meiosis – II in plant cell