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STUDY MATERIAL

Cell cycle and Cell division

ENGLISH MEDIUM

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CELL CYCLE AND CELL DIVISION

01. INTRODUCTION

- **Introduction**
- **Cell Cycle**
- **M Phase**
- **Significance of mitosis**
- **Modifications of mitosis**
- **Meiosis**
- **Significance of Meiosis**
- **Differences between mitosis and meiosis**

- Growth and reproduction are characteristics of cells, indeed of all living organisms.
- All cells reproduce by dividing into two, with each parental cell giving rise to two daughter cells each time they divide. These newly formed daughter cells can themselves grow and divide, giving rise to a new cell population that is formed by the growth and division of a single parental cell and its progeny.
- In other words, such cycles of growth and division allow a single cell to form a structure consisting of millions of cells.
- Term mitosis was proposed by **Flemming**. Mitosis produced genetically identical cells, which are also similar to mother cell.

CAUSES OF MITOSIS

(A) Kern plasm theory : Hertwig proposed kern plasm theory. According to this theory mitosis occurs due to disturbance in Karyoplasmic Index (KI) or **Nucleocytoplasmic ratio** of cell.

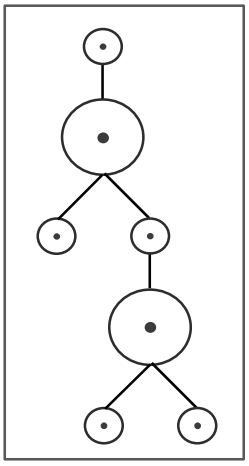
Karyoplasmic Index :

$$KI = \frac{V_n}{V_c - V_n}$$

V_n = Volume of nucleus

V_c = Volume of cell

$V_c - V_n$ = Volume of cytoplasm



- Karyoplasmic Index of small cell is high as they have less cytoplasm. Nucleus efficiently controls the activity of cytoplasm in small cells.
- In a large cell nucleus fail to control the activity of cytoplasm efficiently. To attain the control of nucleus on cytoplasm a large cell divides into two cells.

(B) Surface-Volume Ratio :

- Surface-volume ratio is also considered as a cause of cell division. When a cell grows in size its volumes increases more than its surface. So a stage will reach when the surface area of cell becomes insufficient to draw the materials from surrounding. At such critical stage, cell increases its surface volume ratio by division.

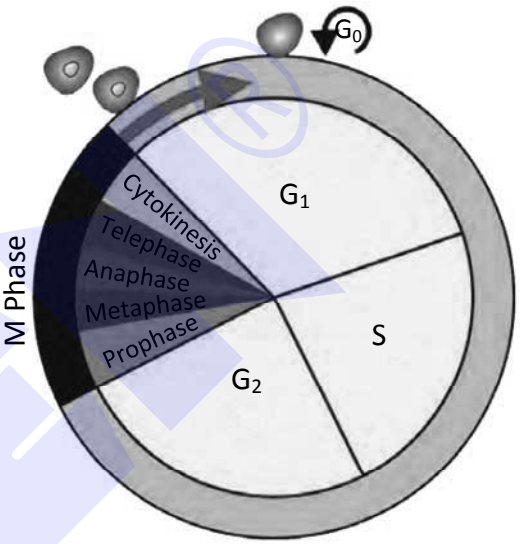
02. CELL CYCLE

- Cell division is a very important process in all living organisms. During the division of a cell, DNA replication and cell growth also take place.
- All these processes, i.e., cell division, DNA replication, and cell growth, hence, have to take place in a coordinated way to ensure correct division and formation of progeny cells containing intact genomes.

- The sequence of events by which a cell duplicates its genome, synthesises the other constituents of the cell and eventually divides into two daughter cells is termed **cell cycle**.
- **Cell growth (in terms of cytoplasmic increase) is a continuous process but DNA synthesis occurs only during one specific stage in the cell cycle.**
- The replicated chromosomes (DNA) are then distributed to daughter nuclei by a complex series of events during cell division. These events are themselves under genetic control.

PHASES OF CELL CYCLE

- A typical eukaryotic cell cycle is illustrated by human cells in culture. These cells divide once in approximately every 24 hours.
- The time period of cell cycle is varied from organism to organism and also from cell type to cell type Eg. :- Yeast can progress through the cell cycle in only about 90 minutes..



NCERT XI Page No. 163, Figure No. 10.1

Cell cycle involves **two stages** :-
Interphase
Division Phase/M-Phase

Interphase :- This is phase between two successive M-phase. In interphase cell grows in size and prepares itself for next division. Interphase is **most active phase** of cell cycle. The interphase last more than 95% of the duration of cell cycle.

- A series of metabolic changes occurs during interphase in cell. These changes were not visible under microscope, so some scientist termed interphase as **resting phase**. It is the time during which cell is preparing for division by undergoing both cell growth and DNA replication in an orderly manner.
- **Howard and Pelc** classified interphase into three sub stages :-

(i) G_1 – phase (I^{st} Gap phase) or Pre DNA synthesis phase or post mitosis gap phase :-

- G_1 phase corresponds to the **interval between mitosis and initiation of DNA replication**. During G_1 phase the cell is metabolically active and continuously grows but does not replicate its DNA.
- During G_1-**most of cell organelles increases in cell and cell** rapidly synthesizes different **types of RNA and proteins**. Due to availability of protein, synthesis of new protoplasm takes place in cell and it starts growing in size. Cell grows maximum in G_1 stage.

(ii) S – phase (DNA synthesis phase) :

- Replication of nuclear DNA and synthesis of **histone protein** takes place in s-phase. Replication of cytoplasmic DNA may occur in any stage of cell cycle.
- During this time the **amount of DNA per cell doubles**. If the initial amount of DNA is denoted as 2C then it increases to 4C. However, there is **no increase in the chromosome number**; if the cell had diploid or 2n number of chromosomes at G_1, even after S phase the number of chromosomes remains the same, i.e., 2n.
- S-phase marks the phase of DNA replication and chromosome duplication (DNA content in a chromosome become double).
- In animal cells, during the S phase, DNA replication begins in the nucleus, and the centriole duplicates in the cytoplasm.

(iii) G_2 – phase (2^{nd} Gap phase) or Post DNA synthesis phase or Pre mitosis gap phase :-

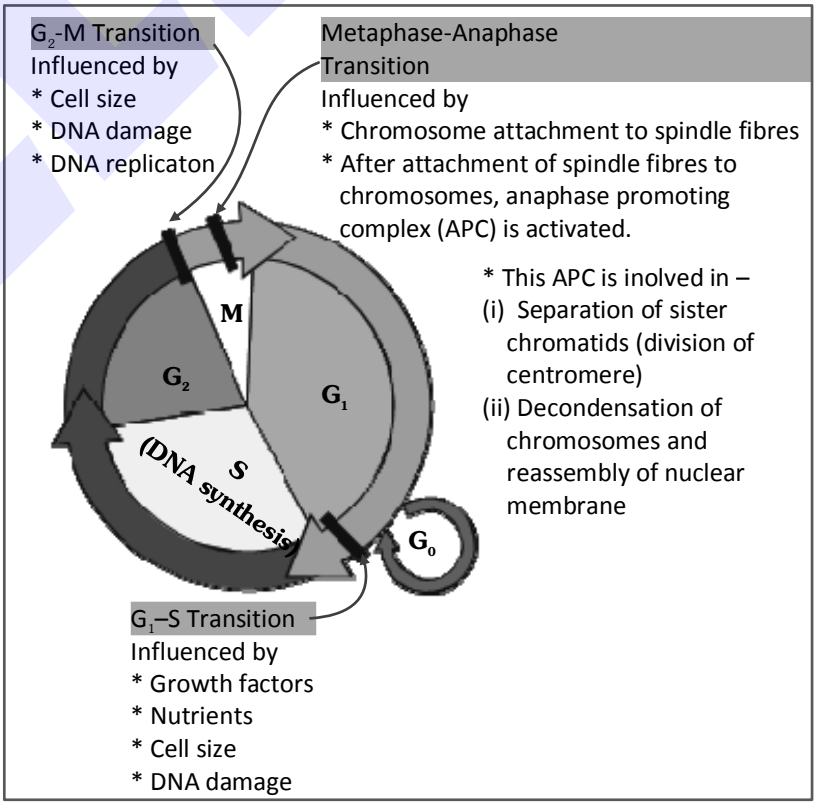
- **Final preparation** of M-phase occurs during this phase. Special proteins required for M-phase are synthesized in G_2 phase. eg. **Tubulin protein** (required for formation of spindle fibres). Cell growth continues.

G_0 phase -

- Some cells in the adult animals do not appear to exhibit division (e.g., heart cells) and many other cells divide only occasionally, as needed to replace cells that have been lost because of injury or cell death. These cells that do not divide further exit G_1 phase to enter an inactive stage called **quiescent stage (G_0)** of the cell cycle.
- Cells in this stage remain **metabolically active** but no longer proliferate (divide) unless called on to do so depending on the requirement of the organism.

CHECKPOINTS OF CELL CYCLE

- Cell cycle is running by a group of special proteins **"Cyclins and Cdks**. (Nurse, T.Hunt & Hartwell **2001** studied on *saccharomyces*)
- Kinase is an enzyme that removes a phosphate group from ATP & add to another protein. The kinases involved in the cell cycle are called **Cdks** because they are activated when they combined with key protein called **cyclin**.
- At some check points a kinase enzyme combines with cyclin & this moves the cell cycle forwardly.



- G_2 – M transition is triggered by maturation promoting factor (MPF) formed by M-cyclin + CDK.

03. MITOSIS PHASE (M-PHASE)

- **Division phase** or **M–phase** or mitosis phase lasts for only about an hour in the 24 hour duration of cell cycle of a human cell.
- The M-phase represents the phase when the actual cell division or mitosis occurs.
- In animals, mitosis or **equational cell division** is only seen in diploid somatic cell except in some social insects for example-male honey bee etc. Against this, the plants can show mitotic division in both haploid and diploid cells.
- This is the **most dramatic period** of the cell cycle, involving a major reorganisation of virtually all components of the cell. Since the number of chromosomes in the parent and progeny cells is the same, it is also called as **equational division**.
- Though for convenience mitosis has been divided into four stages of nuclear division, it is very essential to understand that cell division is a progressive process and very clear-cut lines cannot be drawn between various stages.
- The M-phase start with nuclear division, corresponding to the separation of daughter chromosomes (Karyokinesis) and usually ends with division of cytoplasm (cytokinesis).
- Karyokinesis is divided into the following four stages :-

(1) Prophase (2) Metaphase
(3) Anaphase (4) Telophase

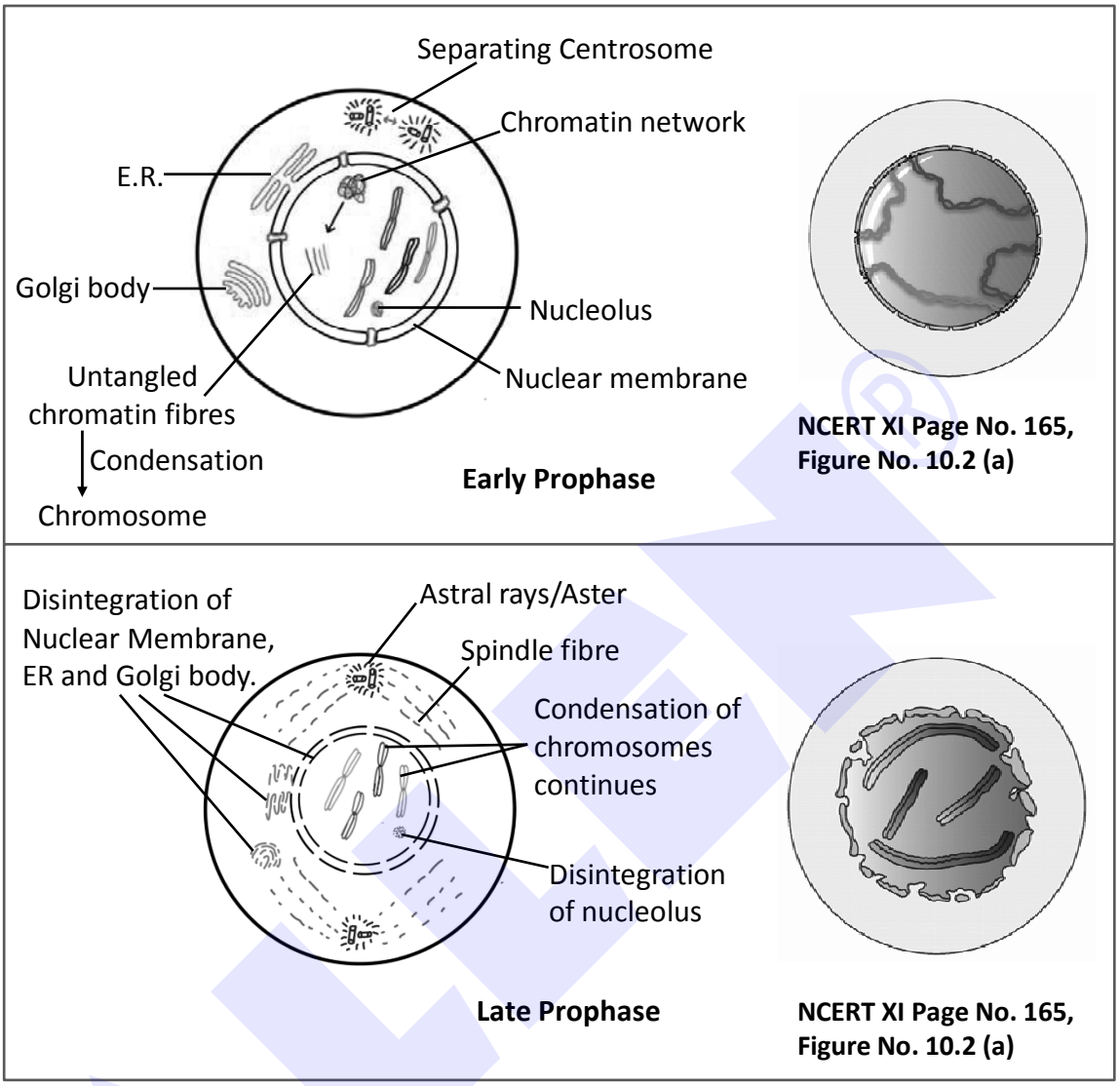
(1) PROPHASE

- Prophase which is the first stage of karyokinesis of mitosis follows the S and G_2 phases of interphase.
- In the S and G_2 phases the new DNA molecules formed are not distinct but interwined.
- Prophase is marked by the **initiation of condensation of chromosomal material**. The chromosomal material becomes untangled during the process of chromatin condensation.
- The centrosome, which had undergone duplication during S phase of interphase, now begins to move towards opposite poles of the cell.

Anastral and Amphiastral Mitosis : In plants, centrioles are absent and no asters are formed. Mitosis without asters is known as **anastral mitosis**. In animals, the asters are present and the mitosis is described as **amphiastral** or **astral mitosis**.

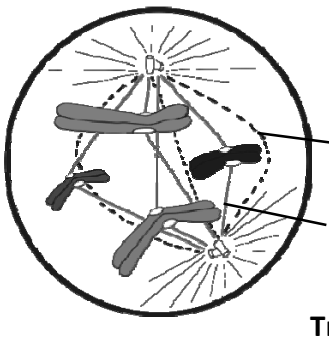
- The completion of prophase can thus be marked by the following characteristic events:
  - Chromosomal material condenses to form compact mitotic chromosomes. Chromosomes are seen to be composed of two chromatids attached together at the centromere.
  - **Centrosome which had undergone duplication during interphase, begins to move towards opposite poles of the cell. Each centrosome radiates out microtubules called aster. The two asters together with spindle fibres forms mitotic apparatus.**

- Cell at the end of prophase when viewed under the microscope, do not show **golgi complexes, endoplasmic reticulum, nucleolus** and **nuclear envelope.**

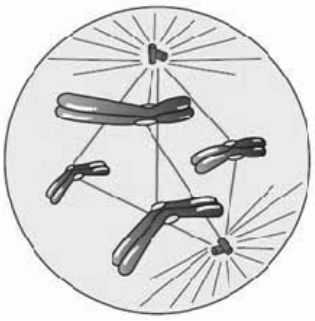


(2) METAPHASE

- The complete disintegration of the nuclear envelope marks the start of the second phase of mitosis, hence the chromosomes are spread through the cytoplasm of the cell.
- By this stage, condensation of chromosomes is completed and they can be observed clearly under the microscope. **This then, is the stage at which morphology of chromosomes is most easily studied.**
- At this stage, metaphase chromosome is made up of two sister chromatids, which are held together by the centromere. Small disc-shaped structures at the surface of the centromeres are called **kinetochores**. **These structures serve as the sites of attachment of spindle fibres (formed by the microtubules) to the chromosomes that are moved into position at the centre of the cell.**



Transition to Metaphase



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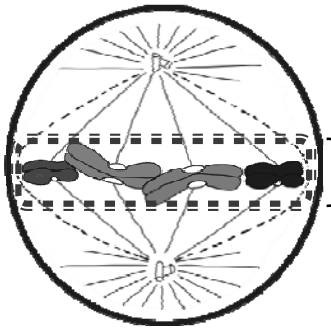
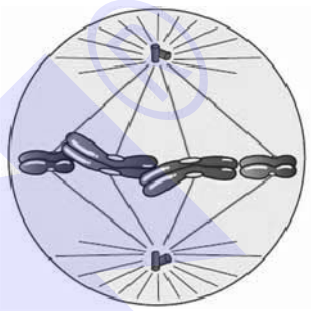


Metaphase



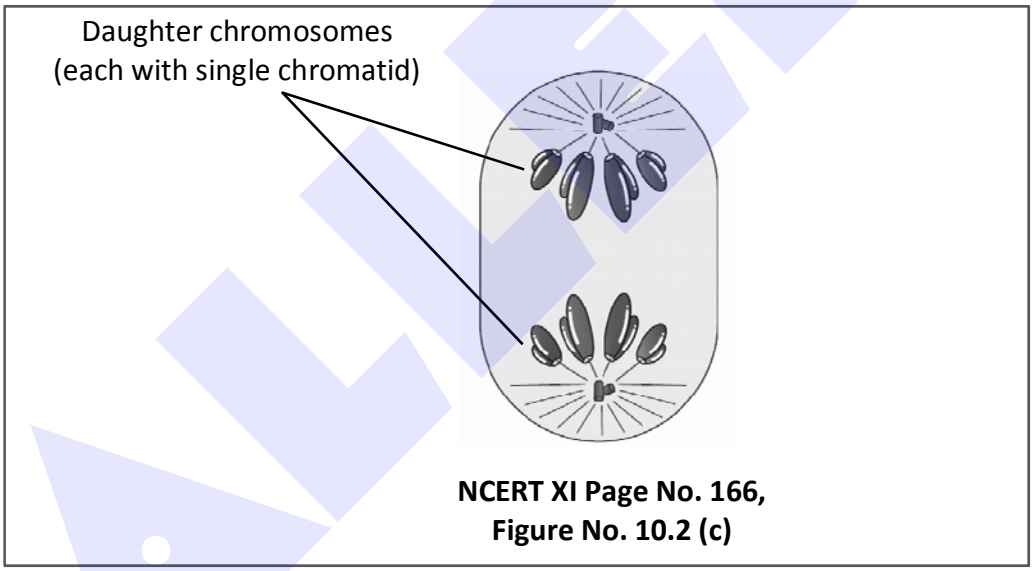
NCERT XI Page No. 165, Figure No. 10.2 (b)

- Hence, the metaphase is characterised by all the chromosomes coming to lie at the equator with one chromatid of each chromosome connected by its kinetochore to spindle fibres from one pole and its sister chromatid connected by its kinetochore to spindle fibres from the opposite pole. The plane of alignment of the chromosomes at metaphase is referred to as the **metaphase plate**.
- Chromosomal fibres (discontinuous/kinetochore fibres which run from pole to centromere) and supporting fibres (continuous/non-kinetochore fibres which run from pole to pole) arrange in cell.
- Centromere lies at equator and arms of chromosomes remain directed towards poles.
- The key features of metaphase are:
  - Spindle fibres attach to kinetochores of chromosomes.
  - Chromosomes are moved to spindle equator and get aligned along metaphase plate through spindle fibres to both poles.

(3) ANAPHASE

- At the onset of anaphase, each chromosome arranged at the metaphase plate is split simultaneously and the two daughter chromatids, now referred to as daughter chromosomes of the future daughter nuclei.
- **Number of chromosome become double** in cell.
- **The two new daughter chromosomes begin moving toward opposite ends of the cell as their spindle fibres shorten due to depolymerisation of tubulin protein towards kinetochoric end.**
- As each chromosome moves away from the equatorial plate, the centromere of each chromosome is towards the pole and hence at the leading edge, with the arms of the chromosome trailing behind.

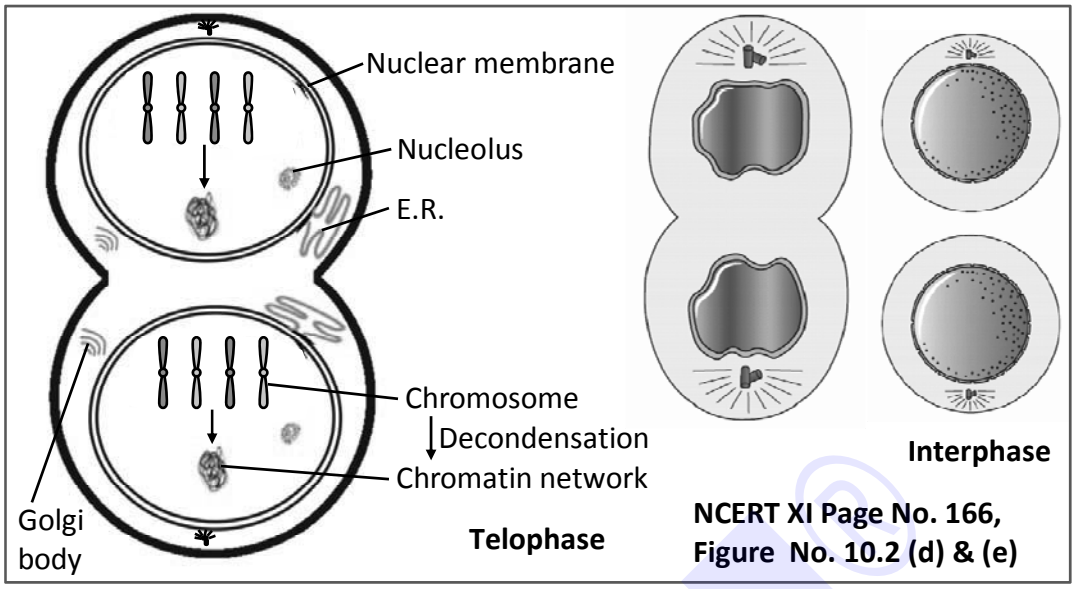
  Anaphase stage is characterised by the following key events:
  - Centromeres split and chromatids separate.
  - Chromatids (now referred as chromosomes) move to opposite poles.



NCERT XI Page No. 166,
Figure No. 10.2 (c)

(4) TELOPHASE OR REVERSE PROPHASE

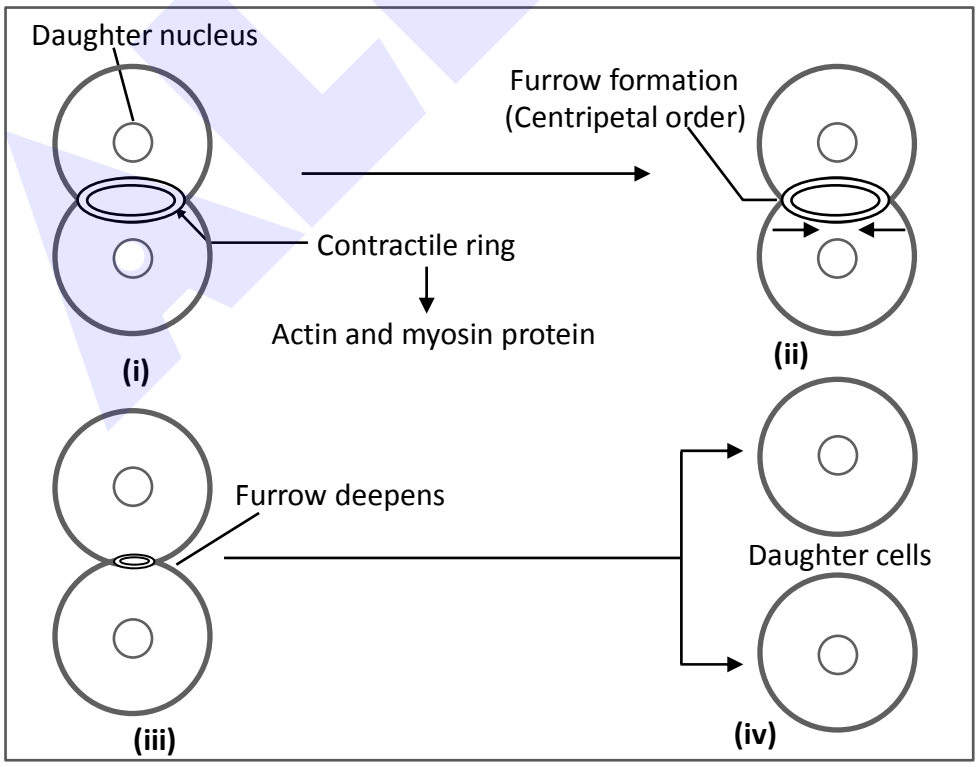
- At the beginning of the final stage of karyokinesis, i.e., telophase, the chromosomes that have reached their respective poles decondense and lose their individuality. The individual chromosomes can no longer be seen and chromatin material tends to collect at each of the two poles. This is the stage which shows the following key events:
  - Chromosomes cluster at opposite spindle poles and their identity is lost as discrete elements.
  - Nuclear envelope develops around the chromosome clusters at each pole forming two daughter nuclei.
  - Nucleolus, Golgi complex and ER reform.



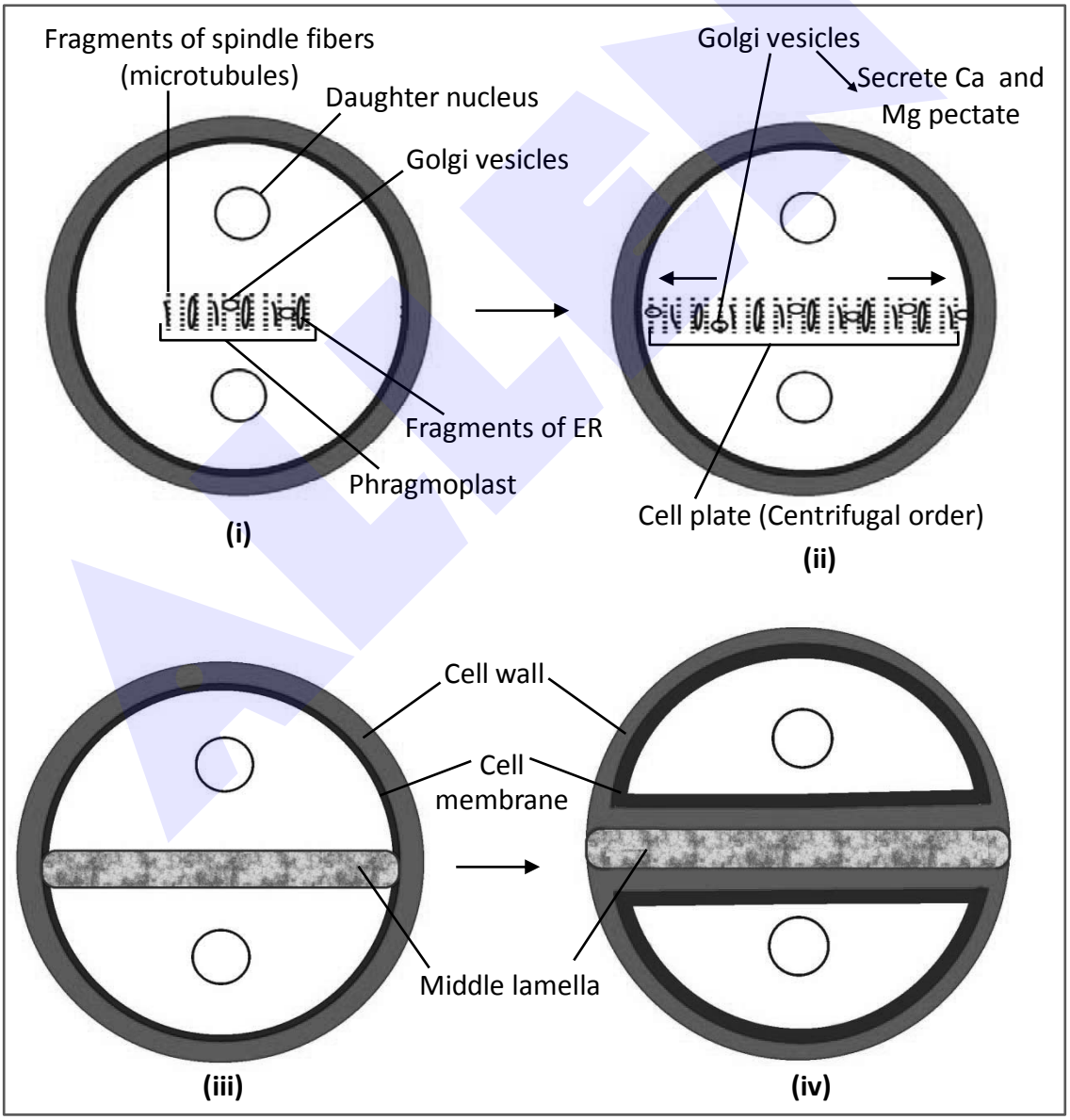
NCERT XI Page No. 166, Figure No. 10.2 (d) & (e)

(5) CYTOKINESIS

- Mitosis accomplishes not only the segregation of duplicated chromosomes into daughter nuclei (Karyokinesis) but the cell itself is divided into two daughter cells by the separation of cytoplasm called cytokinesis at the end of which cell division gets completed.
- At the time of cytoplasmic division, organelles like mitochondria and plastids get distributed between the two daughter cells.
- In **animals** cytokinesis occurs by **constriction & furrow formation.** At the periphery of the equator a contractile ring is formed that is made up of actin and myosin protein. Due to interaction between actin and myosin, ring contract, thus a furrow forms from outside to inside in cell. Furrow deepens continuously and ultimately a cell divides into two daughter cells. In animals cytokinesis occurs in **centripetal order.**



- **Cytokinesis in plants** takes place by **cell plate formation** because constriction is not possible due to presence of a relatively inextensible cell wall. Many golgi vesicles and spindle microtubules arrange themselves on equator to form **phragmoplast.** Fragments of ER may also deposit in phragmoplast. Membranes of golgi vesicles fuse to form a plate like structure called **cell plate**. Golgi vesicles secret calcium and magnesium pectate due to which cell plate is modified into middle lamella. In plants, cytokinesis occurs in **centrifugal order** (cell plate formation is from center to periphery).
- In some organisms **karyokinesis is not followed by cytokinesis as a result of which multinucleate condition arises leading to the formation of syncytium** (e.g., **liquid endosperm in coconut)**.



04. SIGNIFICANCE OF MITOSIS

- Mitosis usually results in the production of diploid daughter cells with identical genetic complement.
- The growth of multicellular organisms is due to mitosis. **Development of an organism** occurs by mitosis. Every organism starts its life from a single cell i.e. zygote. Repeated mitosis in zygote leads to the formation of the whole body.
- Cell growth results in disturbing the ratio between the nucleus and the cytoplasm. It therefore becomes essential for the cell to divide to restore the nucleo-cytoplasmic ratio.
- A very significant contribution of mitosis is cell repair. The cells of the upper layer of the epidermis, cells of the lining of the gut, and blood cells are being constantly replaced.
- Mitotic divisions in the meristematic tissues – the apical and the lateral cambium, result in a continuous growth of plants throughout their life.

05. MODIFICATIONS OF MITOSIS

- **Free nuclear division :-** Karyokinesis is not followed by cytokinesis as a result of which multinucleated condition arises.
- **Endomitosis :-** This is duplication of chromosomes without division of nucleus. Endomitosis leads to polyploidy. i.e. Increase in number of set of chromosomes. Colchicine induces polyploidy in plants. Colchicine is a mitotic poison as it arrests the formation of spindle fibres.
- **Endoreduplication :-** The polytene chromosomes are formed by the process of endoreduplication. In endoreduplication, the chromatids replicate but do not get seperated. This process is also known as polyteny.

AMITOSIS : It is a simple method of cell division which is also called **direct cell division**. In this division there is no differentiation of chromosomes and spindle. The nuclear envelope does not degenerate. The nucleus elongates and constricts in the middle to form two daughter nuclei. This is followed by a centripetal constriction of the cytoplasm to form two daughter cells. eg. Prokaryotes and some unicellular eukaryotes.

Golden Key Points

- During the division of a cell, DNA replication and cell growth also take place.
- The sequence of events by which a cell duplicates its genome, synthesise the other constituents of the cell and eventually divides into two daughter cells is termed cell cycle.
- The interphase lasts more than 95% of the duration of cell cycle.
- S phase marks the phase of DNA replication and chromosome duplication.
- In prophase, chromosomal material (Chromatin) condenses to form compact mitotic chromosomes.
- In metaphase, spindle fibres attach to kinetochores of chromosomes.
- In anaphase, centromeres split and chromatids separate.
- In animal cell cytokinesis occurs by furrow formation and in plant cell it occurs by cell plate method.
- A very significant contribution of mitosis is cell repair.

BEGINNER'S BOX

INTRODUCTION, CELL CYCLE, MITOSIS PHASE (M-PHASE), SIGNIFICANCE OF MITOSIS, MODIFICATIONS OF MITOSIS

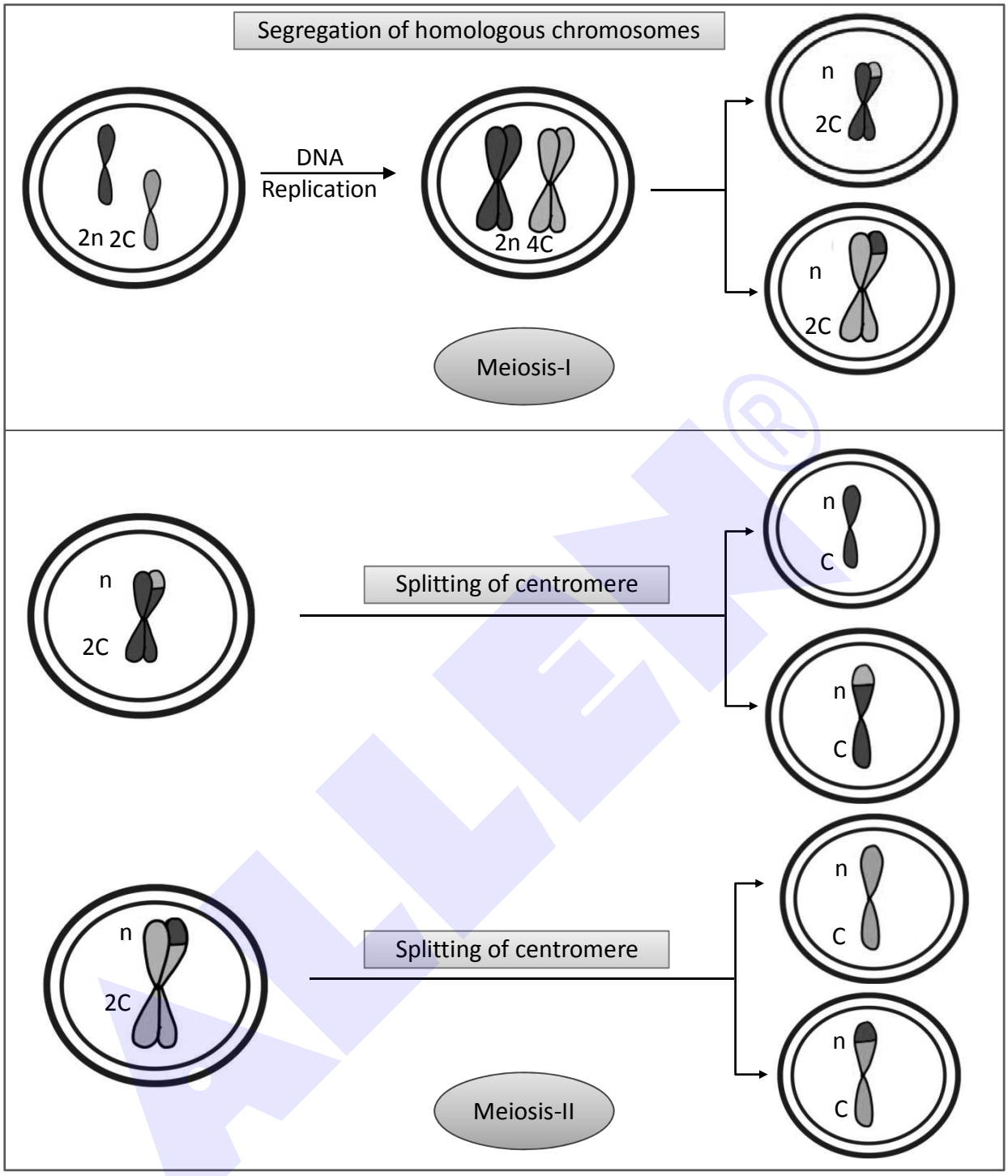
1. First gap phase in cell cycle is :-
   (1) interval between mitotic phase and initiation of DNA replication phase
   (2) interval between DNA replication phase and DNA separation phase
   (3) interval between karyokinesis and cytokinesis
   (4) interval between DNA replication phase and second gap phase
2. The two chromatids of a metaphase chromosome represent :-
   (1) replicated DNA to be separated at anaphase
   (2) replicated DNA to be separated at prophase
   (3) replicated DNA to be separated at telophase
   (4) replicated DNA to be separated at interphase
3. A cell that is entering the M-phase of cell cycle is :-
   (1) always haploid and with duplicated chromosomes
   (2) either haploid or diploid and with duplicated chromosomes
   (3) either haploid or diploid and with duplicated or unduplicated chromosomes
   (4) always diploid and with unduplicated chromosomes
4. A cell examined during prophase of cell cycle contained 100 units of DNA and 50 chromosomes. What would be the number of DNA and chromsomes in anaphase of this cell cycle?
   (1) 200 DNA & 100 chromosomes
   (2) 100 DNA & 50 chromosomes
   (3) 100 DNA & 100 chromosomes
   (4) 50 DNA & 25 chromosomes
5. Which type of chromosome is present in the prophase of cell cycle?
   (1) 2 chromatid (2) 1 chromatid (3) 4 chromatid (4) 8 chromatid

06. MEIOSIS

- "Term meiosis" was proposed by Farmer and Moore.
- The specialised kind of cell division that reduces the chromosome number by half results in the production of haploid daughter cells. This kind of division is called **meiosis.**
- Meiosis ensures the production of haploid phase in the life cycle of sexually reproducing organisms whereas fertilisation restores the diploid phase. Meiosis occurs during gametogenesis, leads to the formation of haploid gametes.

  The key features of meiosis are as follows :

  - Meiosis involves two sequential cycles of nuclear and cell division called **meiosis I** and **meiosis II** but only a single cycle of DNA replication.



(1) MEIOSIS I

- Heterotypic division or **reduction division**. It leads to reduction in chromosome numbers. **Division of chromosomes does not occurs** in meiosis-I, only **segregation or disjunction of homologous chromosomes** takes place.
- Meiosis I is initiated after the parental chromosomes have replicated to produce identical sister chromatids at the S phase.
- Meiosis I involves pairing of homologous chromosomes and **recombination** between their non sister chromatids.

(2) MEIOSIS II

- This is a homotypic division because it does not leads to any change in chromosome number.
- **Division of chromosome** or centromere occurs during meiosis II.
- Four haploid cells are formed at the end of meiosis II. All the four **daughter cells** produced by meiosis are **genetically different** from each other and also differ from the mother cell.
- **In meiosis, division of nucleus takes place twice but division of chromosome occurs only once in anaphase of meiosis-II.**

Meiotic events can be grouped under the following phases :

Meiosis I	Meiosis II
Prophase I	Prophase II
Metaphase I	Metaphase II
Anaphase I	Anaphase II
Telophase I	Telophase II

- **Interphase –** same as in mitosis

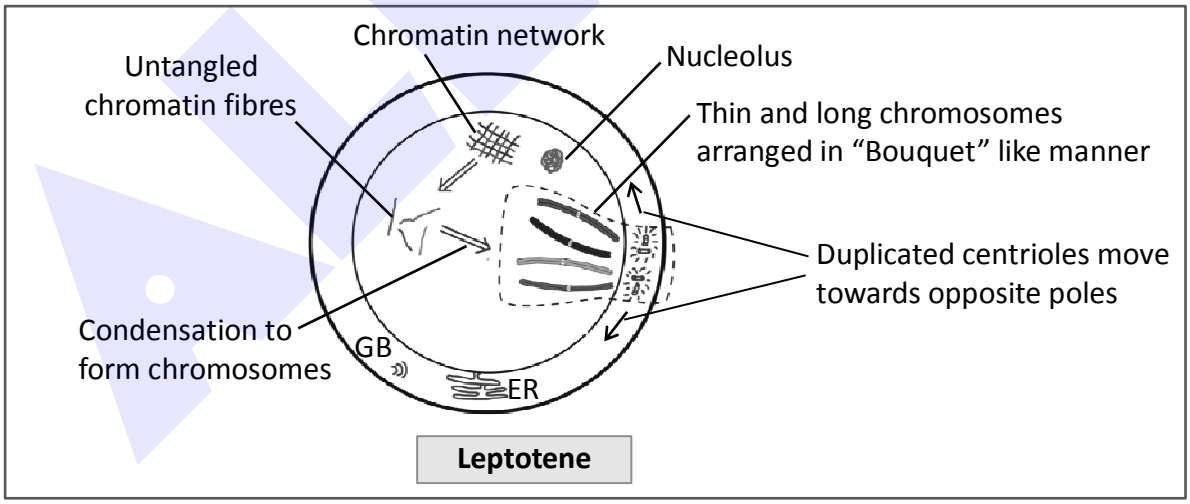
(1) MEIOSIS-I

(A) Prophase – I :

- Typically longer and more complex when compared to prophase of mitosis. **Prophase I is classified in five sub stages based on chromosomal behaviour :**

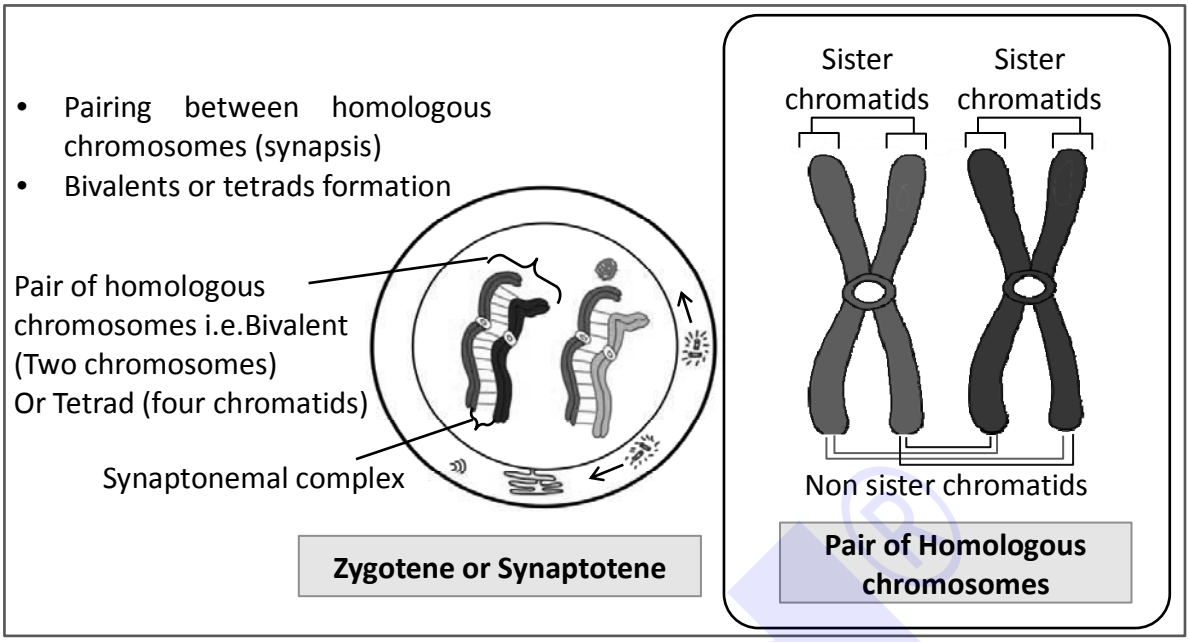
(i) Leptotene ⇒ Chromatin threads condense to form chromosomes. Chromosomes are **longest & thinnest**. Chromosomes become gradually visible under the light microscope.

- All the chromosomes in nucleus remain directed towards centrioles, so group of chromosomes in nucleus appears like a bouquet. **(Bouquet stage)**



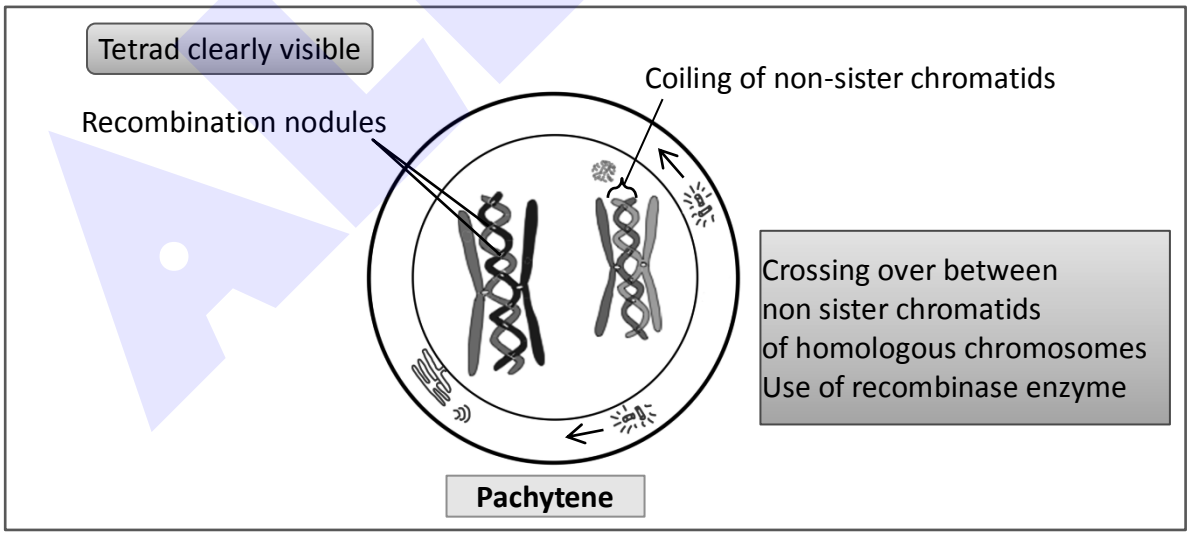
(ii) Zygotene or Synaptotene : Zygotene is characterized by pairing of homologous chromosomes **(Synapsis).** Pairs of homologous chromosomes are called **Bivalents** or **tetrads**. However these are more clearly visible at next stage (pachytene). A structure develops in between homologous chromosomes, which is termed as **synaptonemal complex**.

- The first two stages of prophase I is relatively short lived compared to the pachytene.



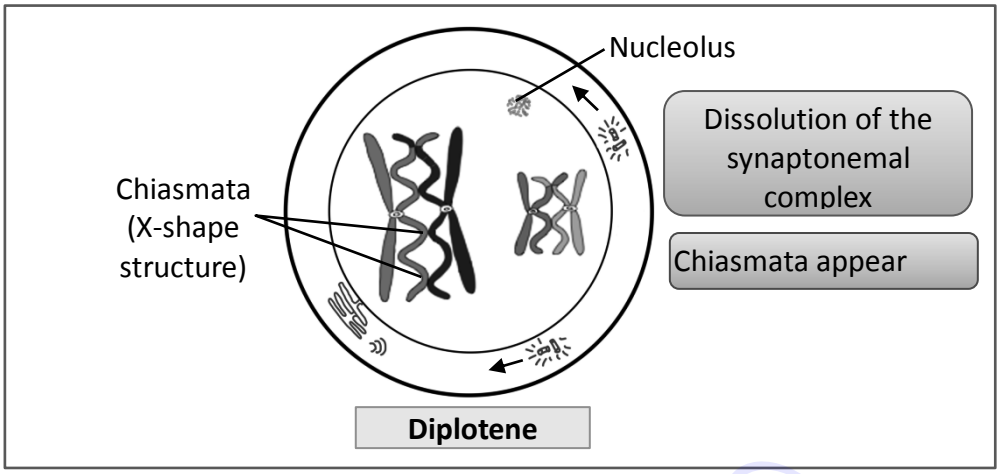
(iii) Pachytene (Thick thread) :

- During this stage, the four chromatids of each bivalent chromosomes become distinct and clearly appeared as tetrad.
- **Recombination nodules** between non sister chromatids of homologous pair develop and these non sister chromatid exchange their parts i.e. **crossing over**.
- Crossing over leads to recombination of genetic material on the two chromosomes.
- Crossing over is an enzyme mediated process and the enzyme involved is called **recombinase** (Endonuclease + ligase)
- Recombination between homologous chromosomes is completed by the end of pachytene, leaving the chromosomes linked at the sites of crossing over.



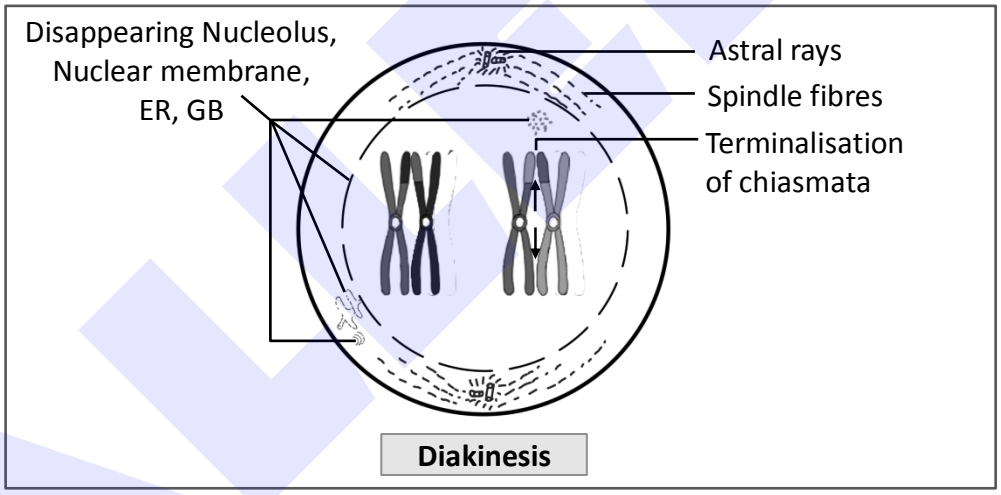
(iv) Diplotene : The beginning of diplotene is recognised by the dissolution of the synaptonemal complex and the tendency of the recombined homologous chromosomes of the bivalents to separate from each other except at the sites of crossovers. These X-shaped structures, are called **chiasmata**.

- **Diplotene** may last long up to months or years in oocytes of some vertebrates (Dictyotene stage).



(v) Diakinesis : It is final stage of meiotic prophase I. Marked by **terminalization** of chiasmata (Chiasmata open in zip like manner).

- Chromosome are fully condensed and meiotic spindle is assembled to prepare the homologous chromosomes for separation.
- By the end of diakinesis nucleolus disappear and the nuclear envelop also breaks down.
- Diakinesis represents **transition to metaphase**.



(B) Metaphase I :

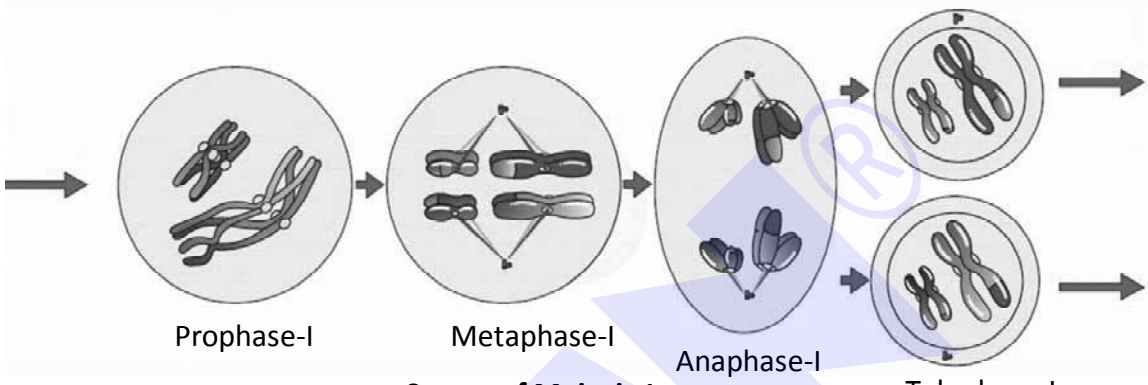
- The bivalent chromosomes align on the equatorial plate. The microtubules from the opposite poles of the spindle attach to the kinetochore of homologous chromosomes.
- Two types of spindle fibres appear in the cell :-
  (i) Chromosomal / Kinetochore Spindle fibres
  (ii) Supporting / Continuous / non-kinetochore Spindle fibres

(C) Anaphase I :

- Due to shortening of kinetochore/chromosomal fibres homologous chromosomes separate from each other and move towards the opposite poles. Sister chromatids remain associated at their centromeres (i.e. chromosomes remain in double chromatid condition)
- Anaphase I is characterised by **segregation** or **disjunction** of chromosomes. **Division of centromere is absent.**

(D) Telophase I :

- The nuclear membrane and nucleolus reappear. Although in many cases the chromosomes do undergo some dispersion, but they do not reach the extremely extended state of the interphase nucleus.
- Cytokinesis follows telophase-I and a diploid (2n) cell divides into two haploid (n) daughter cells. This is called as **dyad of cells.**



Stages of Meiosis-I

NCERT XI Page No. 169, Figure No. 10.3

- Gap between meiosis I and meiosis II is called **Interkinesis**. Preparations of meiosis II occur during interkinesis. It is like interphase of mitosis but **replication of DNA is absent** in interkinesis.
- Interkinesis is generally short lived. Interkinesis is followed by prophase-II, a much simpler prophase than prophase-I.

(2) MEIOSIS-II

(A) Prophase II :

- Meiosis II is initiated immediately after cytokinesis, usually before the chromosomes have fully elongated. In contrast to meiosis I, meiosis II resembles a normal mitosis. The nuclear membrane disappears by the end of prophase II. The chromosomes again become compact.

(B) Metaphase II :

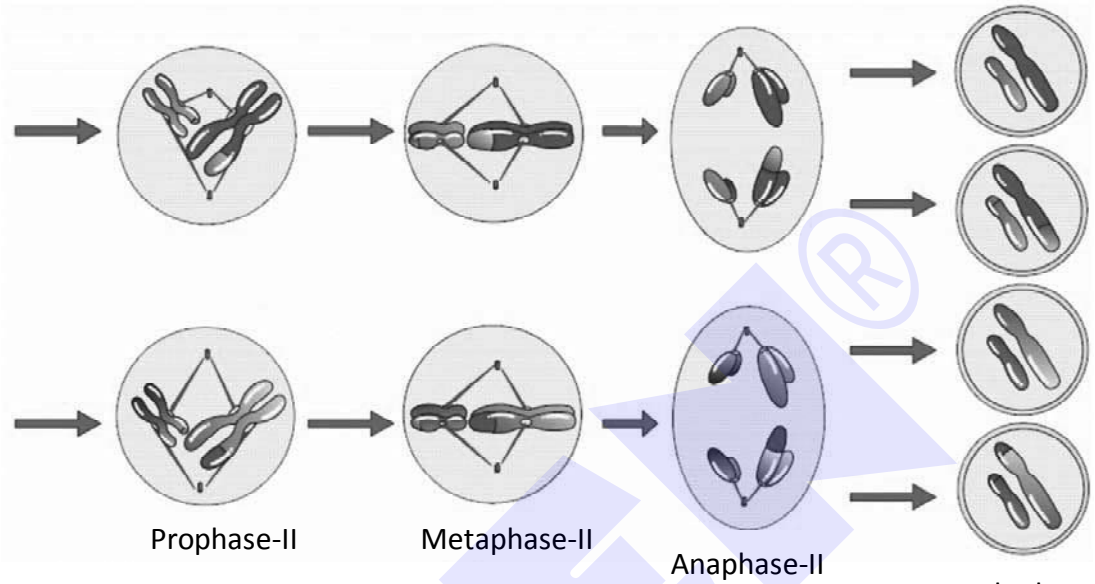
- At this stage the chromosomes align at the equator and the microtubules from opposite poles of the spindle get attached to the kinetochores of sister chromatids.

(C) Anaphase II :

- It begins with the simultaneous splitting of the centromere of each chromosome (which was holding the sister chromatids together), allowing them to move toward opposite poles of the cell by shortening of microtubules attached to kinetochores.

(D) Telophase II :

- Meiosis ends with telophase II, in which the two groups of chromosomes once again get enclosed by a nuclear envelope; cytokinesis follows resulting in the formation of **tetrad of cells** i.e., four haploid daughter cells.



Stages of Meiosis-II

NCERT XI Page No. 170, Figure No.10.4

07. SIGNIFICANCE OF MEIOSIS

(1) Meiosis is the mechanism by which **conservation of specific chromosome number** of each species is achieved across generations in sexually reproducing organisms, even though the process, per se, paradoxically, results in reduction of chromosome number by half.

(2) It also **increases the genetic variability** in the population of organisms from one generation to the next. **Variations are very important for the process of evolution.**

★ Golden Key Points ★

- Prophase-I further subdivide into five phases based on the chromosomal behaviour.
- Meiosis ensures the production of haploid phase in the life cycle of sexually reproducing organisms.
- Meiosis involves pairing of homologous chromosomes and recombination between them.
- Chiasmata formation is the result of crossing over.
- Meiosis increases the genetic variability in the population from one generation to next.

08. DIFFERENCES BETWEEN MITOSIS AND MEIOSIS

S.No.	Mitosis	Meiosis
	1. GENERAL	
1.	The division occurs in somatic cells.	It occurs in reproductive cells.
2.	Both diploid and haploid cells show mitosis.	Meiosis is found only in diploid cells.
3.	It is a single division.	It is a double division.
4.	Mitosis produces two cells	Meiosis produces four cells.
5.	It does not introduce variation.	Meiosis introduces variations due to gene exchange.
6.	Number of chromosome same as mother cells.	Chromosome number reduced (halved).
7.	It is required for growth, repair and healing.	Meiosis involved in only sexual reproduction.
	2. PROPHASE	
8.	It is simpler.	Prophase - I is complicated.
9.	Bouquet stage and synapsis absent.	Bouquet stage and synapsis occurs.
10.	Crossing over does not occur and chiasmata are not seen.	Crossing over and chiasmata formation occurs.
	3. METAPHASE	
11.	Centromeres are present over the equator or metaphase plate while arms facing towards the poles.	Centromeres projects towards the poles.
	4. ANAPHASE	
12.	Centromere divides during anaphase.	Division of centromere is absent in anaphase -I
13.	Chromosomes have single chromatid.	Chromosome has two chromatids in anaphase -I
14.	The two chromatids of a chromosome separate and become daughter chromosomes.	Chromatids do not separate in anaphase-I
15.	Chromosomes moving towards the opposite poles are similar	Chromosomes are dissimilar.
	5.TELOPHASE	
16.	Chromosomes become completely decondensed to form chromatin network	Chromosomes not completely decondensed to form chromatin network
	Daughter cells posses same genetic constitution as in mother cell.	All four daughter cells are differ from each other and also from mother cell.

S.No.	Mitosis	Meiosis – II
1.	An interphase occurs prior to mitosis.	Interkinesis is present prior to meiosis-II
2.	S-phase present.	S-phase absent.
3.	Daughter cells formed after mitosis resemble to mother cell.	Differ from mother cell, quantitatively and qualitatively.

BEGINNER'S BOX

MEIOSIS, SIGNIFICANCE OF MEIOSIS, DIFFERENCES BETWEEN MITOSIS AND MEIOSIS

1. Synaptonemal complex is a nucleoprotein structure. It is visible or found from-
   (1) zygotene to pachytene (2) leptotene to diplotene
   (3) zygotene to metaphase (4) pachytene to diplotene
2. Which one of the following is correctly matched?
   (1) Leptotene - formation of bivalents (2) Diplotene - chiasmata appear
   (3) Pachytene - chiasmata terminalisation (4) Zygotene - formation of bouquet
3. In which stage of meiosis, chromosomes are thin, long, thread like?
   (1) Zygotene (2) Leptotene
   (3) Pachytene (4) Diakinesis
4. Meiosis involves-
   (1) one nuclear division and one chromosome division
   (2) two nuclear divisions and one chromosome division
   (3) one nuclear division and two chromosome divisions
   (4) two nuclear divisions and two chromosome divisions
5. In meiosis, centromeres of chromosomes divide during-
   (1) anaphase of meiosis-II (2) metaphase of meiosis-I
   (3) anaphase of meiosis-I (4) prophase of meiosis-II

BEGINNER'S BOX

ANSWER KEY

INTRODUCTION, CELL CYCLE, MITOSIS PHASE (M-PHASE), SIGNIFICANCE OF MITOSIS, MODIFICATIONS OF MITOSIS

Que.	1	2	3	4	5
Ans.	**1**	**1**	**2**	**3**	**1**

MEIOSIS, SIGNIFICANCE OF MEIOSIS, DIFFERENCES BETWEEN MITOSIS AND MEIOSIS

Que.	1	2	3	4	5
Ans.	**1**	**2**	**2**	**2**	**1**

ESSENCE

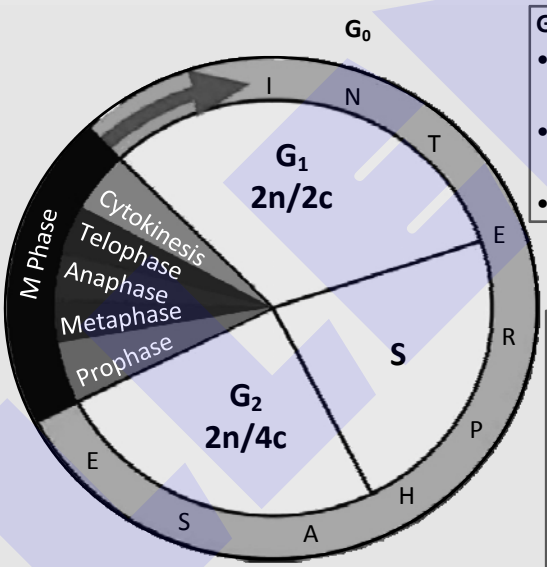
Cytokinesis
- Division of Cytoplasm
- Furrow method [centripetal] in animal cell
- Cell plate method [centrifugal] in plant cell

Telophase (T)
- ER, Golgi apparatus, Nucleolus, Nuclear membrane reform
- Chromosomes decondense and lose their individuality

Quiescent stage (G_0 phase)
- Cells remain metabolically active but no longer proliferate unless called on to do so.
- Heart cells remain in permanent G_0
- Cell exit G_1 phase

Interphase
- Phase between two successive M-phase
- More than 95% duration of cell Cycle
- Preparation for division/M-phase

Anaphase (A)
- Centromeres split
- Sister chromatids separate
- Number of chromosomes become double
- Daughter chromosomes move towards opposite poles



G_1 phase
- Interval between mitosis and initiation of DNA replication.
- Cell is metabolically active and continuously grows
- Most of the organelles duplicate

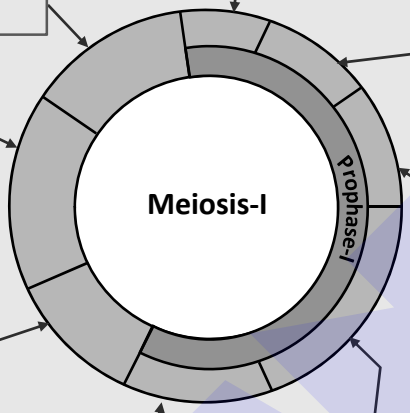
Metaphase (M)
- Condensation of chromosome completed.
- Suitable for study of morphology of chromosome
- Spindle fibres attach with Kinetochore
- Chromosomes lie at the equator

S phase
- Replication of DNA
- Centriole duplication (In cytoplasm of animal cell)
- Synthesis of histone proteins
- Chromosome number remains same but DNA content become double

Prophase (P)
- Condensation of chromatin material starts
- Replicated centrioles start to move towards opposite poles.
- Initiation of the assembly of spindle fibres
- At the end Golgi apparatus, ER, nucleolus and nuclear membrane disappeared

G_2 phase
- Protein formed for formation of spindle fibres
- Cell growth continues

M-Phase
- Actual phase when division occurs
- Most dramatic period
- Reorganisation of virtually all components of the cell
- Starts with karyokinesis and ends with cytokinesis



• Telophase-I
- Nuclear membrane and nucleolus reappear
- Chromosomes decondense but do not reach the extremely extended state of the interphase nucleus

Leptotene
- 'Bouquet stage'
- Chromosome become visible under light microscope
- Compaction of chromosome starts

Zygotene
- Formation of synaptonemal complex
- Pairing of homologous chromosomes
- Pairing is called synapsis
- Pair of homologous chromosomes is called bivalent/tetrad

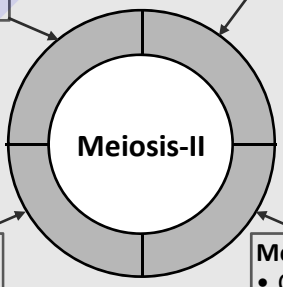
Anaphase-I
- Homologous chromosomes separated
- Sister chromatids remain associated

Metaphase-I
- Bivalent chromosomes align on equatorial plate
- Spindle fibres attach to the pair of homologous chromosomes

Pachytene
- Tetrads are clearly visible
- Formation of recombination nodules
- Crossing over occurs between non-sister chromatids of the homologous chromosomes
- Recombinase enzyme involved in crossing over
- At the end, recombination completed, leaving the chromosomes linked at the sites of crossing over

Diakinesis
- Marked by terminalisation of chiasmata
- Chromosomes are fully condensed
- Spindle is assembled to prepare the homologous chromosomes for separation
- Nucleolus disappear and nuclear envelope also breaks down

Diplotene
- Dissolution of synaptonemal complex
- Homologous chromosomes separate from each other except at the sites of cross overs
- X-shaped structures called chiasmata are visible
- This phase can lasts for month or years in some vertebrate's oocytes.

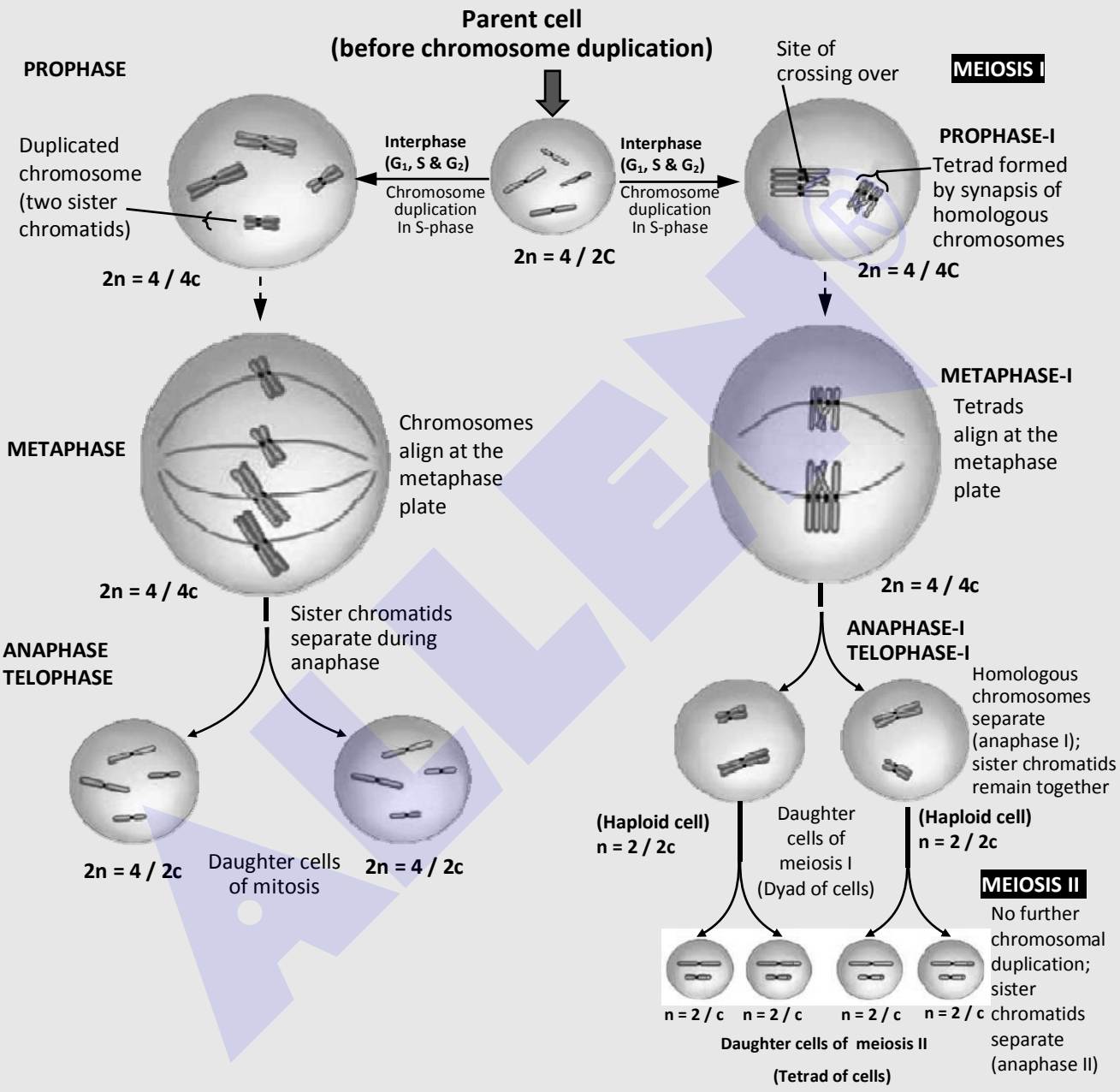


Telophase-II
- Meiosis ends with telophase-II
- Two groups of chromosomes once again get enclosed by a nuclear envelope.

Prophase-II
- The nuclear membrane disappears
- The chromosomes again become compact.

Anaphase-II
- Begins with the simultaneous splitting of centromere of each chromosome allowing daughter chromosomes to move towards opposite poles of the cells.

Metaphase-II
- Chromosomes align at the equator
- The microtubules from opposite poles of the spindle get attached to the kinetochore of sister chromatids.


Parent cell
(before chromosome duplication)
2n = 4 / 2C
PROPHASE
Duplicated chromosome (two sister chromatids)
2n = 4 / 4c
Interphase (G_1, S & G_2)
Chromosome duplication In S-phase
Interphase (G_1, S & G_2)
Chromosome duplication In S-phase
Site of crossing over
MEIOSIS I
PROPHASE-I
Tetrad formed by synapsis of homologous chromosomes
2n = 4 / 4C
METAPHASE
Chromosomes align at the metaphase plate
2n = 4 / 4c
METAPHASE-I
Tetrads align at the metaphase plate
2n = 4 / 4c
ANAPHASE
TELOPHASE
Sister chromatids separate during anaphase
2n = 4 / 2c
Daughter cells of mitosis
2n = 4 / 2c
ANAPHASE-I
TELOPHASE-I
Homologous chromosomes separate (anaphase I); sister chromatids remain together
(Haploid cell)
n = 2 / 2c
Daughter cells of meiosis I (Dyad of cells)
(Haploid cell)
n = 2 / 2c
MEIOSIS II
No further chromosomal duplication; sister chromatids separate (anaphase II)
n = 2 / c
n = 2 / c
n = 2 / c
n = 2 / c
Daughter cells of meiosis II
(Tetrad of cells)