Cell Cycle and Cell Division

INTRODUCTION

- Cell division is a very important process in all living organisms.
- All cells reproduce by dividing into two where each parental cell gives rise to two daughter cells each time.
- During the division of a cell, DNA replication and cell growth take place in a coordinated way to ensure that the progeny cells receive intact genomes.
- All life forms whether unicellular or multicellular start their life with a single cell.
- Hammerling and Boveri have pointed out the role of nucleus in heredity. Strasburger (1873) stated that nuclei arise from pre-existing nuclei. He also explained the process cell division in plant cells.
- Flemming in 1882 first of all described cell division in animal cells and coined the term 'mitosis' (*mitos* — divisible).
- Strasburger and Winiwarter in 1900 studied meiosis in rabbits.
- Farmer and Moore in 1905 gave the term 'meiosis' for the cell division in which the number of chromosomes become half, in daughter cells.
- Although cell growth (in terms of cytoplasmic increase) is a continuous process but DNA synthesis occurs only during one specific stage in the cell cycle i.e., synthetic phase.
- The replicated chromosomes are then distributed to daughter nuclei by a complex series of events during cell division. These events are under genetic control.
- The continuity of life mainly depends on cell division.

CELL DIVISION

Division of the parent cell into daughter cells is called cell division.

- **Types of Cell Division:** Cell division is of three types— Amitosis, mitosis and meiosis.

Definition

Cell Division: Formation of daughter cells from the parent cell.

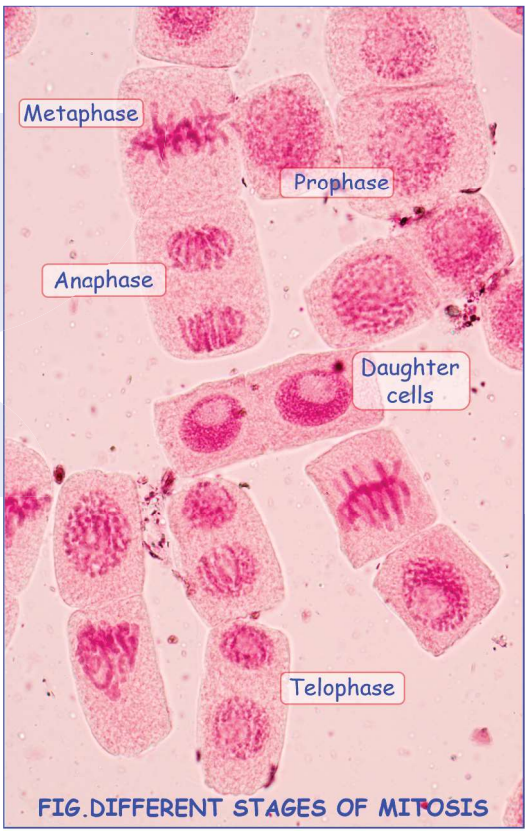

FIG.DIFFERENT STAGES OF MITOSIS

Rack Your Brain

All multicellular organisms start their life as single cell. Justify.

- **Amitosis (Direct Cell Division):** In this process, the nucleus of a cell lengthens and a constriction appears. The nucleus becomes dumb-bell shaped and then divides into two. Thus, they do not necessarily pass through any phase. This type of division mainly takes place in unicellular organisms.
- **Mitosis (Indirect Cell Division):** Mitosis is also known as Somatogenesis (taking place in somatic cells or body cells) or Equational Division (daughter cells have equal number of chromosomes) or Homotypic Division (division completing in one sequence only) or Karyokinesis (division mainly concerns the division of nucleus) or Indirect Cell Division (cell passes through many phases before its complete division). Mitosis cell division is a continuous process. Each new formed cell passes through a cycle called 'cell cycle' before entering the next mitotic division.
- **Meiosis (Reductional Cell Division):** It occurs in the reproductive cells or germ cells of higher organisms which reproduce sexually. This division gives rise to haploid cells called gametes. Meiosis helps in restoring the chromosome number in a sexually reproducing organism. The process of meiosis cell division may be discontinuous in some cases (e.g., meiosis cell division in oocytes of some vertebrates).

Previous Year's Question

Number of mitosis divisions required to produce 128 cells from a single cell is—
(1) 7
(2) 14
(3) 16
(4) 32

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Mitogen: A substance (agent or factor) which triggers cell division.
Cytokinin (phytohormone) is a common plant mitogen.

Rack Your Brain

Why amitosis is called direct cell division.

CELL CYCLE

- 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.
- The duration of cell cycle can vary from organism to organism and also from cell type to cell type.
- The cell cycle of a somatic cell involves two basic phases—

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Cell growth results in disturbed nucleo-cytoplasmic ratio. To restore this nucleo-cytoplasmic ratio the cell indergo mitotic division.

- **A long interphase**
- **A short M phase, or mitotic phase.**

- Approximately, every 24 hours a human cell (typical eukaryotic cell) divides once. So, the duration of human cell cycle is 24 hours.
- In cell cycle of human cell the interphase lasts more than 95 per cent of the duration and the M phase lasts for about an hour.
- In Yeast, the cell cycle completes in only about 90 minutes.
- The M Phase represents the phase when the actual cell division or mitosis occurs and the interphase represents the phase between two successive M phases.

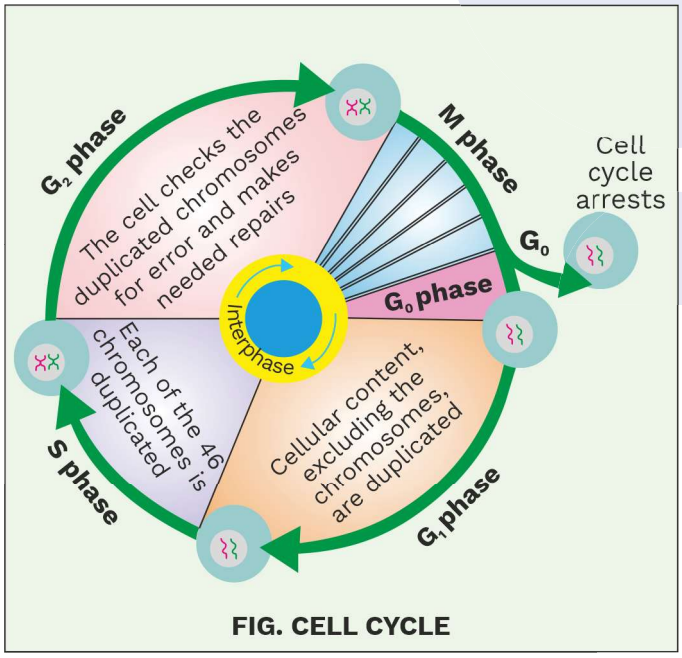

FIG. CELL CYCLE

Rack Your Brain

What triggers a cell to divide?

Previous Year's Question

If after mitotic division cell activity is restricted to G_1 phase of the cell cycle, then the conditon is known as

(1) G_2 phase
(2) G_0 phase
(3) S-phase
(4) M-phase

INTERPHASE

- It is the phase between two successive M phases (divisions).
- Interphase, also called 'resting phase', is the most active phase; though the cell does not divide in the phase, it prepares itself and restores all the important constituents for daughter cells (such as ATP, DNA, RNA, etc.).

Rack Your Brain

Why it is essential for the cells to enter G_0 phase?

- The cell is preparing for division by undergoing both cell growth and DNA replication in an orderly manner.

The interphase is divided into three phases:

- G_1 phase (Gap 1 phase)
- S phase (Synthesis phase)
- G_2 phase (Gap 2 phase)

- **G_1 Phase or First Growth Phase or Post Mitotic Phase**
  - New formed cells grow in size and are metabolically active.
  - Active synthesis of RNA and proteins.
  - Active in physiological functions.
  - No replication of DNA occurs.
- **S Phase or Synthetic Phase**
  - DNA is synthesised after its replication.
  - During this time the amount of DNA per cell doubles, so the DNA in diploid cell (2C) can be denoted as 4C.
  - In animal cells, the duplication of centrosome takes place in the cytoplasm. Two centrioles are formed.
  - Each chromosome carries a duplicate set of genes.
  - Each chromosome consists of two chromatids joined together at a point called centromere. So, the number of chromosomes remains the same, i.e., 2n (in a diploid cell).
- **G_2 Phase or Second Growth Phase or Pre-Mitotic Phase**
  - Synthesis of RNA and proteins.
  - Preparation of cell to undergo M phase (mitotic phase).
  - Cell contains double amount of DNA.
  - Energy pools (ATPs) are formed.
  - Cell growth continues.

Rack Your Brain

A plant cell has 2n = 8 chromosomes. What will be the number of DNA molecules in this cell during S phase of interphase?

Previous Year's Question

Which one is present on a chromosome?

(1) Centrosome
(2) Centromere
(3) Nucleus
(4) Golgi body

Gray Matter Alert!!!

Mitosis was first observed by Strasburger (1875) in plant cells.

G_0 PHASE OR QUIESCENT STAGE (Inactive Stage)

- Some cells after M phase do not enter interphase to repeat the cell cycle.
- Hence, they enter G_0 phase where the cell grows in size and gets differentiated to perform specialised function.
- In this phase cells remain metabolically active but do not proliferate.
- For example, **heart cells** in the adult animals do not 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.

Definition

G_0 Phase: Phase that arrests the cell cycle and no further division takes place in the cell.

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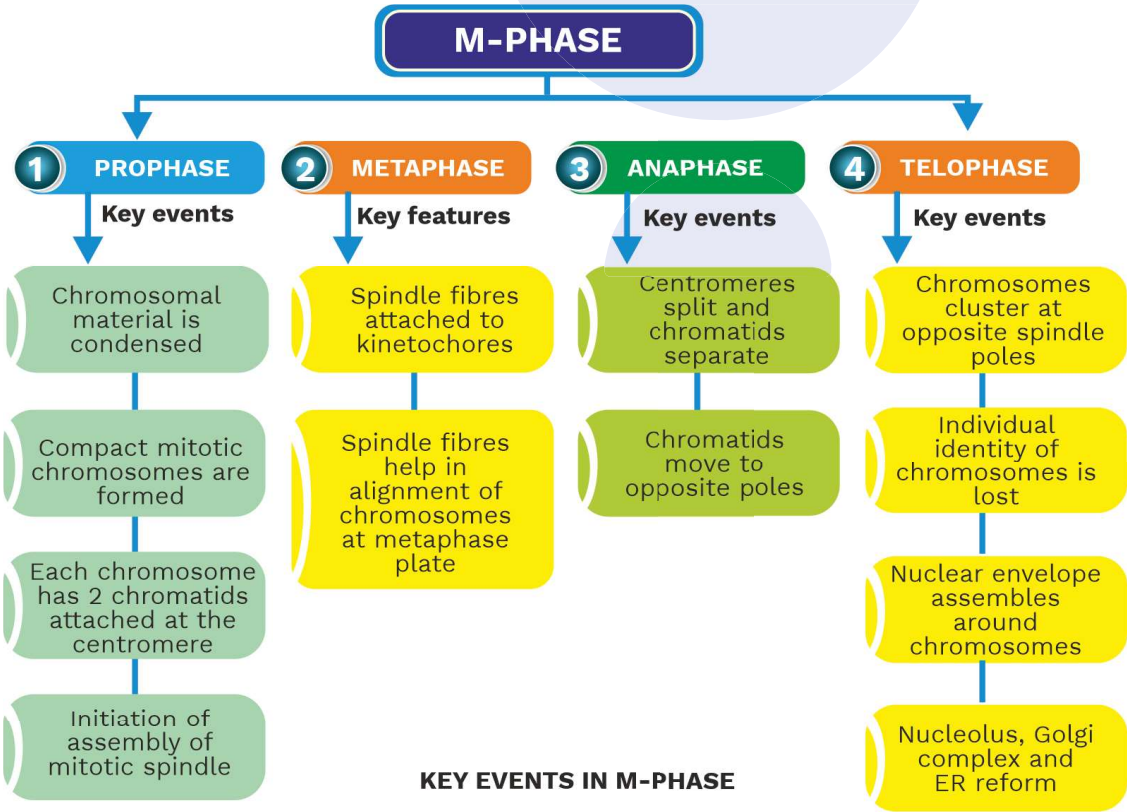
Flemming (1880) coined the term 'Mitosis'.

M Phase (Mitotic Phase)



KEY EVENTS IN M-PHASE

- The M Phase starts with the nuclear division, corresponding to the separation of daughter chromosomes (karyokinesis) and usually ends

with division of cytoplasm (cytokinesis).

- M phase helps in reorganisation of all components of the cell.
- It is called equational division as the number of chromosomes in the parent and progeny cells is the same.
- In animals, mitotic cell division is only seen in the diploid somatic cells.

Exception: Male honey bees (drones) are haploid organisms and all cells in their body divide by mitosis.
Plants show mitotic divisions in both haploid and diploid cells.

KARYOKINESIS

- The Karyokinesis is divided further into four phases:
  - Prophase
  - Metaphase
  - Anaphase
  - Telophase

Rack Your Brain

What are the terms used for the cells with one set of chromsomes and two sets of chromsomes?

Previous Year's Question

The stage of mitosis in which the chromosomes move towards the poles is
(1) Prophase
(2) Metaphase
(3) Anaphase
(4) Telophase

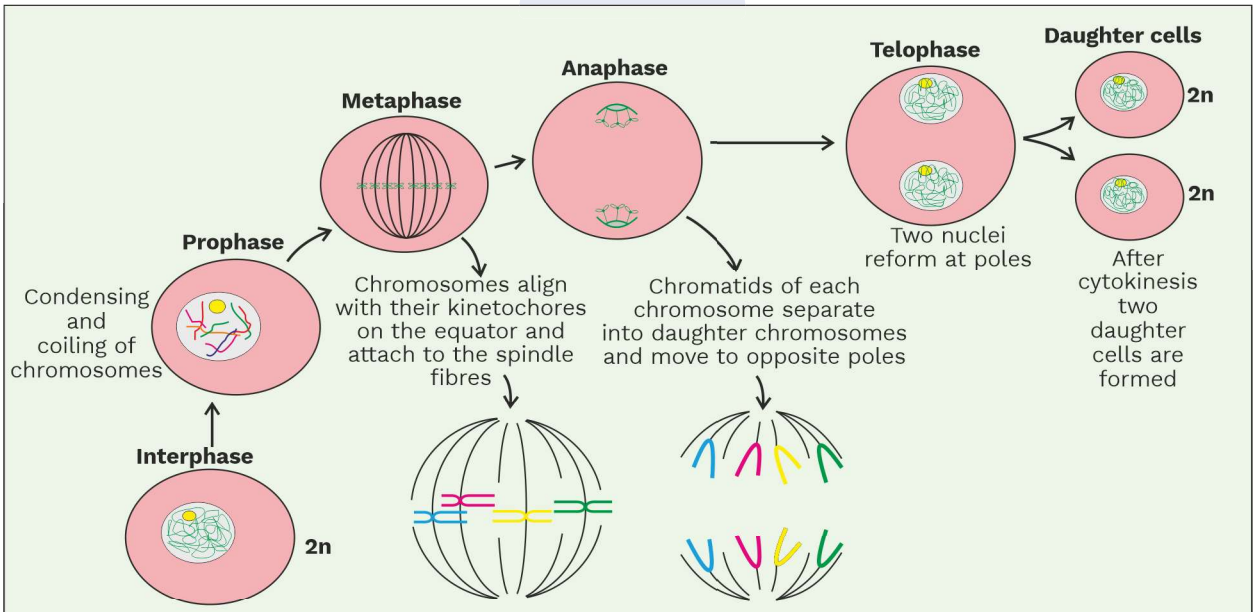


FIG. MITOSIS IN ANIMAL CELL

Prophase: It is the longest phase in mitotic cell division. This phase can be divided into three sub-phases— early prophase, mid prophase and late prophase.

- **Early Prophase**
  - During early prophase chromatin fibres start to condense, shorten and thicken, chromatin reticulum disappears.
  - Coiling and spiralization of chromatin helps untangling of the chromatin.
  - The centrosome, which had undergone duplication during S Phase of interphase, now begins to move towards opposite poles of the cell.
  - Proteins surrounding the chromatin lose water and chromosome appear like a ball of wool called **Spireme Stage.**
- **Mid Prophase**
  - At mid prophase, the chromosomes containing two chromatids are called **dyad**.The two chromatids are attached to each other by **centromere** (**primary constriction**).
  - At centromere region each chromatid has a disc like structure called kinetochore. To this **kinetochore** the spindle fibres from opposite poles join.
- **Late Prophase**
  - Chromosomes continue to become short and thick till the end of the prophase.
  - Nucleoli degenerate.
  - Nuclear envelope breaks into small vesicles.
  - At the end of the prophase golgi complexes, endoplasmic reticulum disappear.
  - The two asters lie opposite to each other to form spindle fibres (in animal cells).
- **Metaphase**
  - Nuclear membrane completely degenerates and disappears, this marks the beginning of metaphase
  - Spindle apparatus is formed.

Previous Year's Question

Number of chromatids at metaphase in a chromosome is

(1) Two each in mitosis and meiosis
(2) Two in mitosis and one in meiosis
(3) Two in mitosis and four in meiosis
(4) One in mitosis and two in meiosis

Definition

Dyad: Univalent chromosome is called a dyad which has two sister chromatids held together at the centromere region.

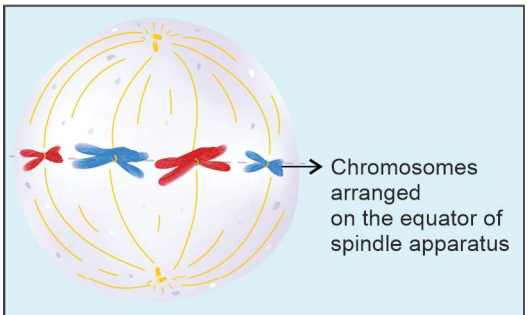


FIG. MATAPHASE

- Chromosomes become arranged at the equator of the spindle and lie in the centre of the cell. One chromatid of each chromosome connected by its kinetochore to spindle fibres from one pole and its sister chromatid is connected by its kinetochore to spindle fibres from the opposite pole
- Condensation of chromosomes is completed and they become most condensed; thickest and shortest and quite visible.
- Nucleoli completely degenerate and disappear.
- In animal cell spindle is astral and in plants, it is anastral.
- The plane of alignment of the chromosomes at metaphase is referred to as the metaphase plate.

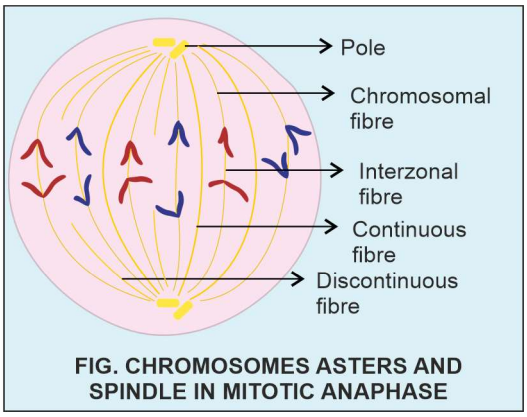


FIG. CHROMOSOMES ASTERS AND SPINDLE IN MITOTIC ANAPHASE

Note: Metaphase chromosome is made up of two sister chromatids, which are held together by the centromere.

Spindle fibres possess the proteins having sulphur containing amino acids .

Definition

Sister Chromatids: Chromatids of the same chromosome.

Previous Year's Question

Each chromosome at the anaphase stage of a bone marrow cell has
(1) Two chromatids
(2) One chromatid
(3) Several chromatids
(4) No chromatids

- **Anaphase**
  - Each chromosome splits or separates at centromere and chromatids separate.
  - Chromosomes divide along longitudinal axis.
  - Separated chromatids are now referred to as daughter chromosomes.
  - The separated chromatids, start moving towards opposite poles (the centromere of each chromosome remains directed towards the pole and hence at the leading edge, with the arms of the chromosome trailing behind).
  - Chromatids remain attached to each other by interzonal fibres.
  - The shape of the chromosomes become V, L, J and I shaped. The arms remain towards centre and centromere towards poles.

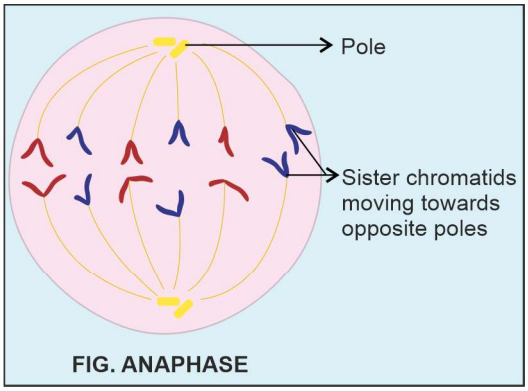


FIG. ANAPHASE

- **Telophase**
  - Nuclear membrane reappears around each group of chromosomes that have reached their respective poles.
  - Spindle fibres disappear.
  - Chromosomes are reorganised in each nucleus by decondensing and their identity is lost.
  - Chromosomes elongate and form chromatin fibre thus, lose their individuality (as discrete elements).
  - Each nucleus contains the same number of chromosomes as the parent cell.
  - Chromosomes cluster at opposite spindle poles. Nuclear envelope develops around the chromosome clusters at each pole forming two daughter nuclei.
  - Nucleolus, golgi complex and endoplasmic reticulum reform.

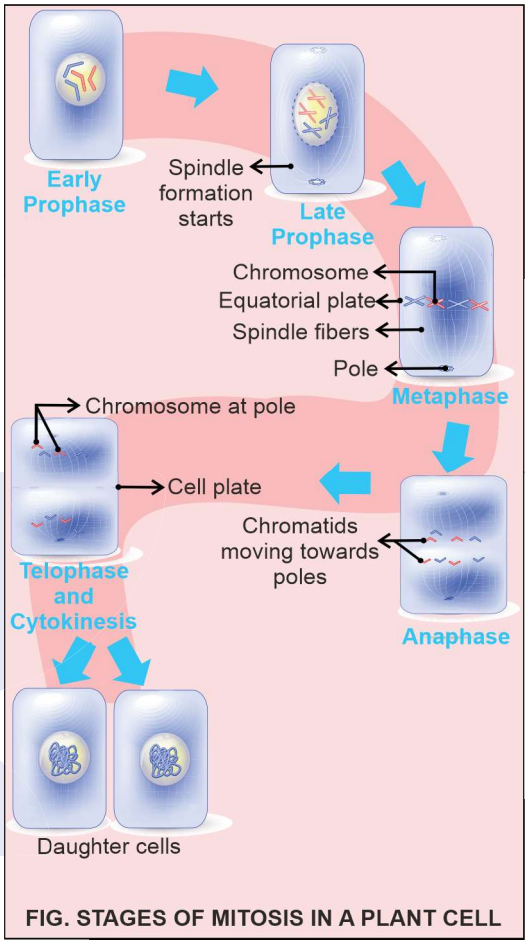


FIG. STAGES OF MITOSIS IN A PLANT CELL

CYTOKINESIS (Division of Cytoplasm)

- Generally, cytokinesis takes place immediately after the nuclear division
- During cytokinesis, organelles like mitochondria and plastids (in plant cells) get distributed between the two daughter cells.

Exception: Cytokinesis may not occur immediately after karyokinesis in some cases.

Types of Cytokinesis.

- **Cleavage Method**
  - It is the characteristic of lower plants. The cytoplasm splits centripetally. Pectin, hemicellulose and cellulose are deposited in the furrow. It results in the formation of two daughter protoplasts.
  - In an animal cell, cytokinesis occurs by furrow formation in the plasma membrane. The furrow gradually deepens and ultimately joins in the centre dividing the cell cytoplasm into two parts thus, two cells are formed.

Previous Year's Question

Chromosomes separate during
(1) Early prophase
(2) Early metaphase
(3) Early anaphase
(4) Early telophase.

- **Cell Plate Method**
  - Plant cells are enclosed by a inextensible cell wall, so cytokinesis takes place by the cell plate formation.
  - In this process, the spindle persists for some time and is known as **phragmoplast**.
  - Small vesicles of golgi apparatus are collected and fuse at the equator of phragmoplast and form two sheets. It encloses matrix which forms cell plate (middle lamella).
  - The formation of the new cell wall begins with the formation of a simple precursor, called the cell-plate that is actually the middle lamella between the walls of two adjacent cells.
  - In plant cells, new cell wall formation starts in the centre of the cell and grows outward to meet the existing lateral walls. This process takes place in higher plants.

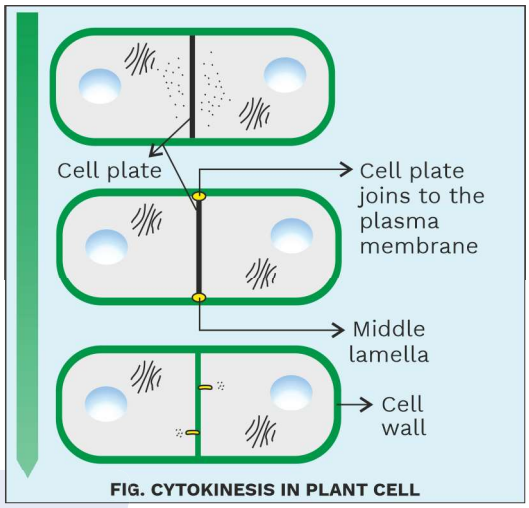


FIG. CYTOKINESIS IN PLANT CELL

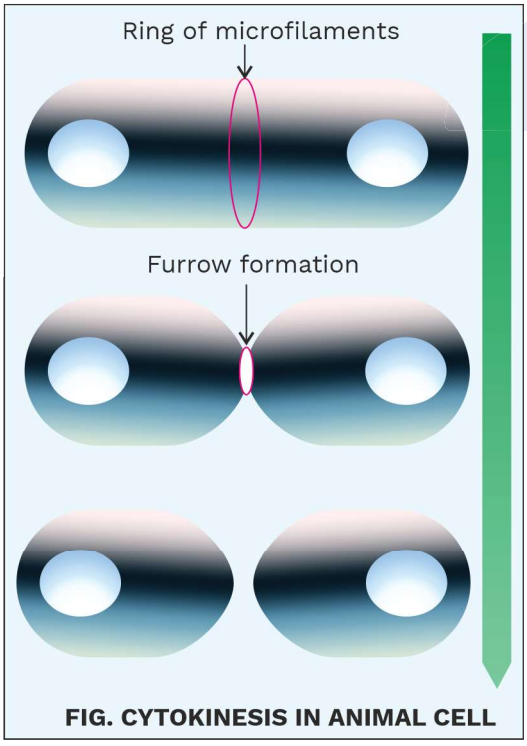


FIG. CYTOKINESIS IN ANIMAL CELL

Gray Matter Alert!!!

Phragmoplast: Spindle that persists during cytokinesis in plant cells.

Previous Year's Question

Anastral mitosis is found in —
(1) All living organisms
(2) Higher plants
(3) Higher animals
(4) Lower animals

SIGNIFICANCE OF MITOSIS

- It is the type of multiplication in unicellular organism.
- It maintains the Kern-Plasma-Relation or karyoplasmic ratio of the cell.
- DNA, Proteins, RNA, etc., are synthesised in this process.
- It is a method for replacing old worn out cells.
- Any type of wound or injury is healed by this process.
- It plays an important role in the regeneration of a part of organism.
- It is responsible for growth of living organism.

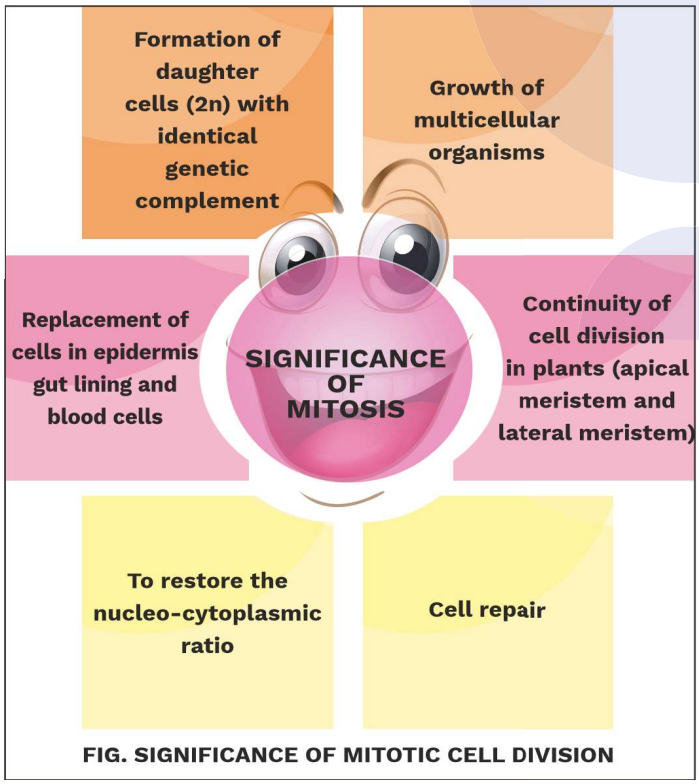


FIG. SIGNIFICANCE OF MITOTIC CELL DIVISION

Note: In some cases, 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).

Gray Matter Alert!!!

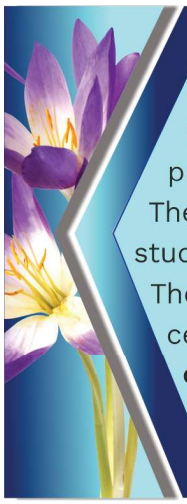
Kern-Plasma-Relation or karyoplasmic ratio: It states that their is a definite relation between mass of nuclear material and the cytoplasm of the cell.
This theory was put forward by Hertwig in the year 1903.

Rack Your Brain

Why is colchicine referred as a mitotic poison?

Gray Matter Alert!!!

Anastral mitosis: Mitosis in which spindle forms but no centrioles or asters are observed. It occurs typically in higher plants
Astral mitosis: Mitosis in which spindle forms by centrosome and asters are observed.
In some animals mitotic spindle has two asters, this is called amphiastral mitosis. While in some animals mitotic spindle has only one aster. It called monoastral mitosis.



Colchicine—The Mitotic Poison

Colchicine is an alkaloid obtained from the corms of Autumn crocus (*Colchicum autumnale*). The alkaloid inhibits the formation of spindle by preventing assembly of microtubules.

The cell division is arrested and the cell which are at metaphase stage are used to study chromosome structures.

The chromosomes can be allowed to duplicate but they remain within the same cell, increasing the number of chromosomes. Such cells are called **Polyploid cells,** these are used to develop new varieties and species of plants. Colchicine induced polyploidy is used to produced variants of agricultural and horticultural crops.

MEIOSIS (REDUCTIONAL DIVISION)

- The process of meiosis is completed in two broad sequences:
  - **Heterotypic division** (Meiosis I)
  - **Homotypic division** (Meiosis II)
- But only a single cycle of DNA replication occurs in meiosis.
- Four haploid cells are formed at the end of Meiosis II.
- Meiotic events can be grouped under the following phases—

Meiosis I

- Prophase I
- Metaphase I
- Anaphase I and Telophase I
- Interkinesis

Meiosis II

- Prophase II
- Metaphase II
- Anaphase II
- Telophase II

DIFFERENT STAGES IN LIFE CYCLE OF ORAGANISMS WHEN MEIOSIS OCCURS

- Sporic Meiosis (Meiosis occurring during spore formation).

Gray Matter Alert!!!

Farmer and Moore (1905) introduced the term 'Meiosis'.

Rack Your Brain

Meiosis is essential in sexually reproducing organisms. Justify.

Definition

Crossing Over: Exchange of genetic material between non-sister chromatids of homologous chromosomes (usually during the pachytene stage of Prophase-I in meiotic cell division).

- Gametic Meiosis (Meiosis occurring during gametogenesis or gamete formation in animals).
- Zygotic Meiosis (Meiosis occurring during germination of zygote as in lower plants).

HETEROTYPIC DIVISION:

Meiosis I is initiated after the parental chromosomes have replicated to produce identical sister chromatids at the S phase of interphase.

Meiosis I involves pairing of homologous chromosomes and recombination between non-sister chromatids of homologous chromosomes.

Phases In Heterotypic Division.

- **PROPHASE I:** It is longer and more complex phase in comparison to prophase of mitosis. It is subdivided into the following five phases based on chromosomal behaviour, i.e., **leptotene, zygotene, pachytene, diplotene** and **diakinesis**.
  - **Leptotene (Leptonema)—Thread like stage**
    - Chromatin fibres continue to condense and coil throughout leptotene.
    - Nucleus increases in size.
    - Chromatids are not visible due to nucleoprotein complex between them.
    - The number and size of chromosomes are same in homologous chromosomes.
    - Chromosomes first appear as fine single thread and then contract and become thick. These are visible under the light microscope.
    - The compaction of chromosomes continues throughout the leptotene stage.
  - **Zygotene (Zygonema)—Pairing stage (Synapsis)**
    - Homologous chromosomes (one paternal and other maternal) get paired. This process is called synapsis. **Synapsis** is

Previous Year's Question

Segregation of Mendelian factors (Aa) occurs during
(1) Anaphase I
(2) Diplotene
(3) Zygotene
(4) Anaphase II

Definition

Homologous chromosomes: The chromosomes which are similar in size, shape and nature of inherited characters. In each pair, one is the paternal chromosome and the second one is the maternal chromosome.

Definition

Synapsis: The pairing of two homologous chromosomes.

accompanied by the formation of complex structure called synaptonemal complex.
- Nucleolus increases in size.
- Centrioles start moving apart in animal cells.
- Each pair of synapsed homologues is called **bivalent** or a **tetrad**.
- Pairing may start at one point or more points along the length of homologous chromosome.

Note: Leptotene and zygotene are relatively short-lived phases in comparison to pachytene phase.

- **Pachytene (Pachynema)—Crossing over stage**
  - Chromosomes of bivalent become shorter and thicker.
  - Chromatids of each chromosome become distinct and visible because of dissolving of nucleoprotein core.
  - During this phase chromosome synapsis is accompanied by the formation of complex structure called synaptonemal complex.
  - The complex formed by synapsed homologous chromosome is called a **bivalent** or **tetrad** (having four chromatids).
  - This phase is characterised by the appearance of recombination nodules (**chiasmata**) at which exchange of non-sister chromatids of homologous chromosomes takes place (cross over).
  - Crossing over is also an enzyme-mediated process and the enzyme involved is called **recombinase**.
  - Nicking (untwisting of DNA strands) occurs by enzyme **endonuclease** and re-annealing by **ligase** (once exchange of DNA segments is completed).

Definition

Tetrad: Association of a pair of homologous chromosomes (four sister chromatids) visible in the pachytene stage is called a tetrad (in meiotic cell division).

Definition

Chiasmata: The points at which crossing over takes place between homologous chromosomes (during the Pachytene stage of Prophase-I in meiotic cell division).

Previous Year's Question

In which stage the chromosomes appear as thin long threads?
(1) Zygotene
(2) Leptotene
(3) Pachytene
(4) Prophase

Definition

Bivalent: A pair of homologous chromosomes which lie closely during the zygotene stage of Prophase-I.

- Crossing over is the exchange of genetic material between two non-sister chromatids of the homologous chromosomes.
- Recombination between homologous chromosomes is completed by the end of pachytene, leaving the chromosomes linked at the sites of crossing over.

- **Diplotene (Diplonema)**
  - The beginning of diplotene is recognised by the dissolution of the synaptonemal complex.
  - Homologous chromosomes continue to condense and separate except at chiasmata, giving rise to X-shaped structure.
  - These X-shaped structures are called **chiasmata**.
  - Chiasmata may be terminal or interstitial and lately disappear.
  - Chromosomes become shorter and thicker by coiling.
  - In **oocytes** of some vertebrates, diplotene can last for months or years.
- **Diakinesis (Separating State or Terminalisation Stage)**
  - Nuclear membrane and nucleolus disappear.
  - Chiasmata move towards the end of the chromatids, it is called terminalisation.
  - Chromosomes are fully condensed and are thick.
  - The meiotic spindle is assembled to prepare the homologous chromosomes for separation.
  - By the end of diakinesis, the nucleolus disappears and the nuclear envelope also breaks down.
  - Diakinesis phase represents transition to metaphase.

Definition

Non-sister Chromatids: Chromatids of different chromosomes.

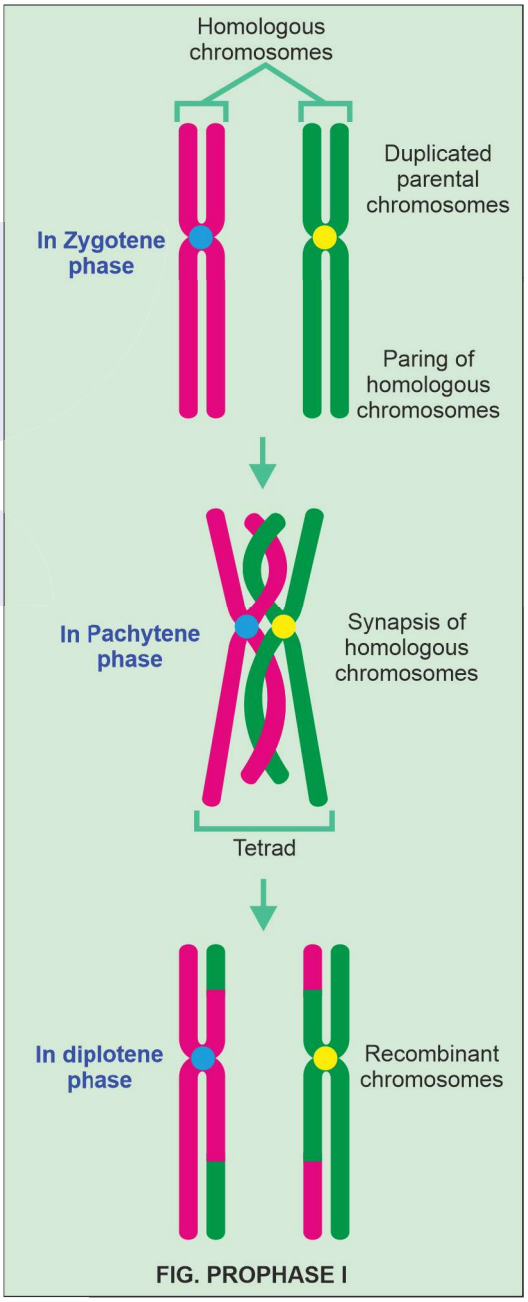


FIG. PROPHASE I

Note: During diakinesis ability of the chromosomes to get stained with basic dyes reappears.

- **METAPHA SE I**
  - Spindle formation is completed.
  - The bivalent chromosomes align on the equatorial plate.
  - The microtubules from the opposite poles of the spindle attach to the kinetochore of homologous chromosomes.
  - Chromosomes get arranged in a way that their centromere face towards poles and the arms towards equator.
  - Centromeres of homologous chromosomes are attached by interzonal fibres.
  - Chromosomes are thickest and shortest.
- **ANAPHASE I**
  - Centromere of homologous chromosomes separate from each other.
  - One chromosome of each homologous pair moves to the opposite poles (haploid chromosomes showing reduction).
  - Disjunction of homologous chromosome takes place.
  - Chromosomes consist of two chromatids attached to the centromere (unlike mitosis).
- **TELOPHASE I**
  - Nuclear membrane reappears around each group of chromosome, and the cell at this stage is called **dyad of cells**.
  - Chromosomes elongate progressively but are not in extremely extended state of interphase nucleus.
  - Nucleolus is formed (by satellite chromosome).
  - Polar groups of chromosomes arrange as haploid nuclei.
  - Interphase does not exist.

INTERKINESIS

- The stage between the two meiotic divisions is called interkinesis and is generally short lived.

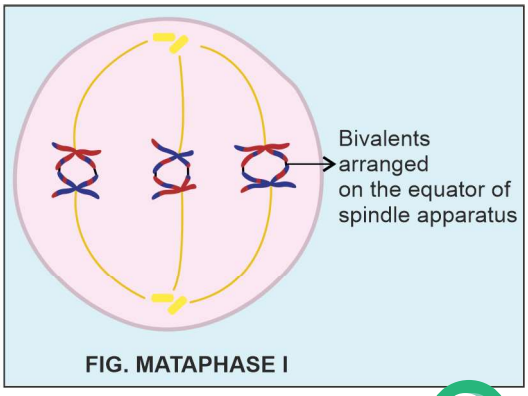


FIG. MATAPHASE I

Previous Year's Question

Zygotic meiosis takes place in
(1) *Marchantia*
(2) *Pinus*
(3) *Chlamydomonas*
(4) *Dryopteris*

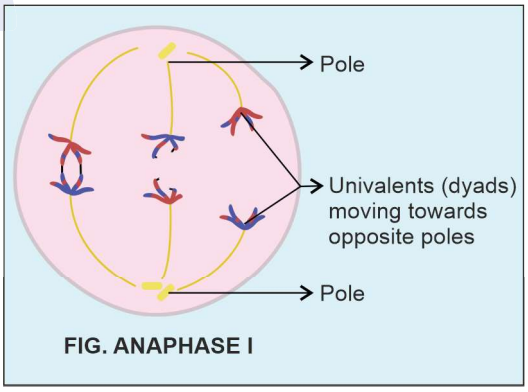


FIG. ANAPHASE I

Gray Matter Alert!!!

Disjunction: The separation of homologous chromosomes towards the opposite poles during the Anaphase-I of meiotic cell division.

- There is no replication of DNA during interkinesis.
- Interkinesis is followed by Prophase II of Mieosis II (Homotypic division).

HOMOTYPIC DIVISION

(All the stages of this category resemble to mitotic cell division)

- **Prophase II**
  - Nuclear envelope starts degenerating and disappears at the end of this phase.
  - Nucleolus also disappears slowly and slowly and is lost at the end of this phase.
  - Chromosomes are again compact.
  - In animal cells, the spindle starts to form.
  - Both the daughter nuclei formed after Telophase I undergo various phases of karyokinesis.
- **Metaphase Ii**
  - Nuclear membrane and nucleolus completely disappear.
  - Achromatic dipolar spindle is formed.
  - 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.
  - Chromosomes are arranged in a way that their centromere lie at the equator and their arms facing the poles.
  - Chromosomes are quite visible.
- **Anaphase Ii**
  - Two chromatids of a chromosome separate completely from centromere(splitting of centromere occurs)
  - Daughter chromosome (separated chromatids) move towards respective poles by shortening of microtubules attached to kinetochores.
  - The centromeres of chromatids are joined by interzonal fibres.
  - Two groups of chromosomes (total four groups) are produced.

Previous Year's Question

In meiosis, the chromatids separate during
(1) Anaphase I
(2) Metaphase I
(3) Anaphase II
(4) Metaphase II

Gray Matter Alert!!!

Aster: Star-like structure consisting of centriole pairs and radiating microtubular fibrils.

Rack Your Brain

In haplontic life cycle, which type of meiosis will take place?

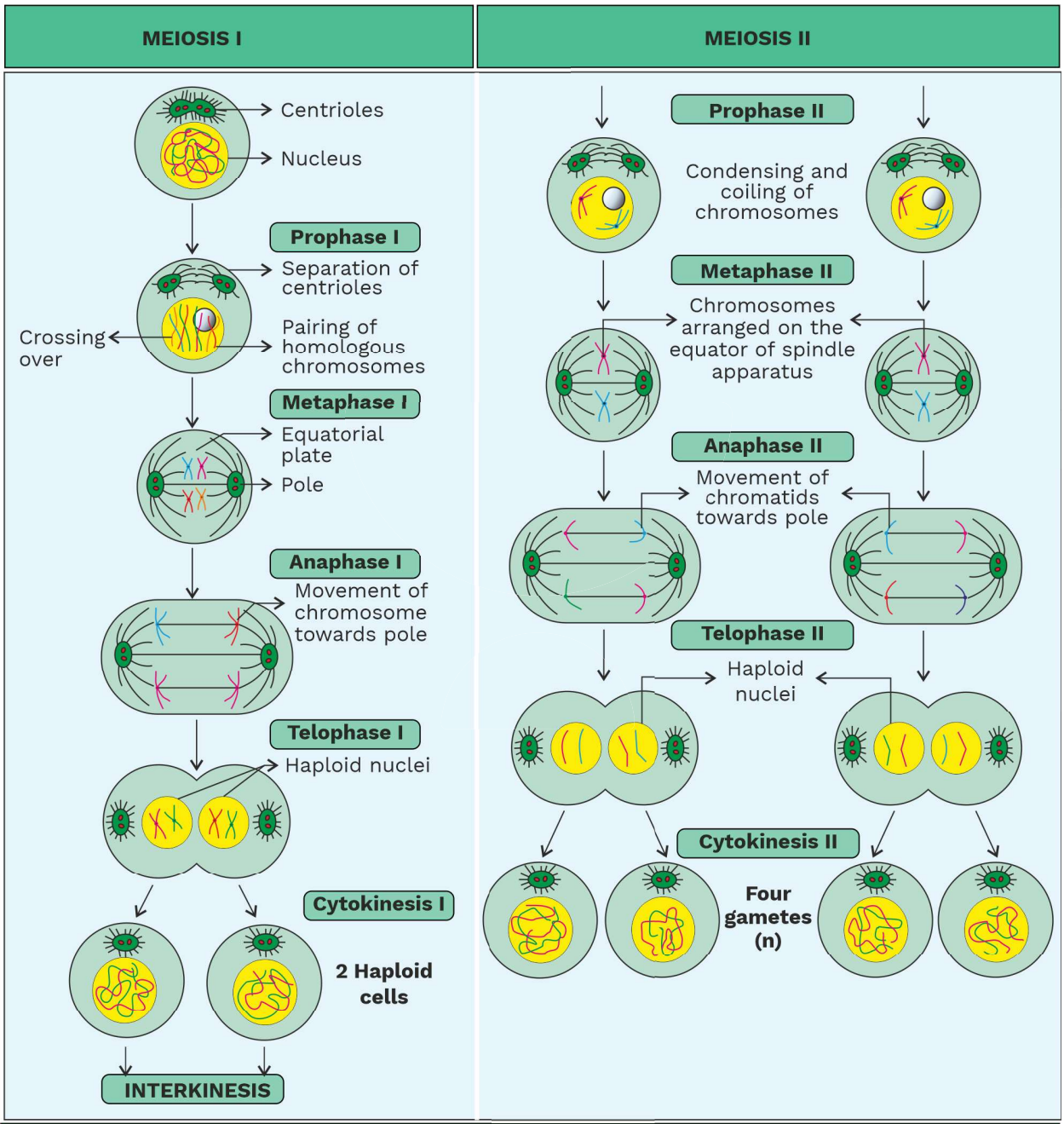


FIG. MEIOSIS CELL DIVISION IN ANIMAL CELL

- **Telophase Ii**
  - Nuclear envelop is formed around each group of chromosome.
  - A nucleolus reappears in each group of chromosome.
  - Four groups of chromosomes are arranged into four nuclei (four cells are produced).
  - Spindle fibres degenerate and become invisible.
  - Tetrad formation takes place (four haploid daughter cells are formed).
  - Meiosis ends with Telophase II.

CYTOKINENSIS II

- Cytokinesis follows resulting in the formation of tetrad of cells, i.e., four haploid cells.
- The cytoplasmic contents are equally divided among all the four cells called gametes in diploid organisms.

Note: Gametes are always haploid.

SIGNIFICANCE OF MEIOSIS

- It maintains and restores the definite number of chromosomes in sexually reproducing organism.
- It is essential for sexual reproduction by providing haploid chromosomes in the gametes.
- It is the main cause of variation in the progeny which may result in the improvement of the race.
- It leads to induced mutation which may be useful or harmful.

SPECIFIC OR UNUSUAL CELL DIVISIONS

- **Endomitosis or Endoduplication:** In this process chromosomes replicate without the division of nucleus. Thus, chromosomes number is increased.
- **Polyteny:** Chromosomes replicate continuously without their separation and thus, a gliant chromosome with many chromatids is formed.

Rack Your Brain

Assertion: Meiosis I is called heterotypic division.
Reason: It halves the chromosome number in the daughter nuclei.

(1) Both Assertion and Reason are true and the Reason is the correct explanation of the Assertion.
(2) Both Assertion and Reason are true but the Reason is not the correct explanation of the Assertion.
(3) Assertion is true statement but the Reason is false.
(4) Both Assertion and Reason are false statements.

Previous Year's Question

Colchicine influences
(1) DNA replication
(2) Organisation of spindle
(3) Chromosome condensation
(4) Chromosome division

This type of chromosome is called polytene chromosome. For example, salivary chromosome of *Drosophila* may contain 1000 chromatids.

- **Amitosis:** In *Amoeba* and white blood corpuscles (WBCs), the nucleus divides without the formation of spindle. The genetic material of these daughter nuclei is distributed unequally. This type of division is called amitosis.
- **Karyokinesis:** In *Ulothrix, Rhizopus* and *Gnetum,* the nuclear membrane does not disintegrate completely during mitosis. A spindle is formed internally and after Anaphase, this nuclear membrane constricts in the middle to produce daughter nuclei. This process is called Karyokinesis.

Gray Matter Alert!!!

Intra-nuclear spindle: Spindle formed inside the nucleus like in Amoeba, fungi and many algae.

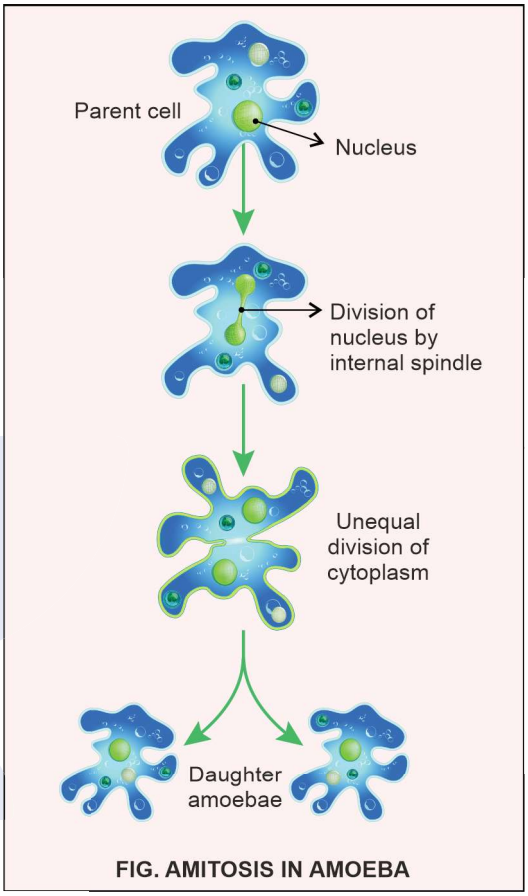


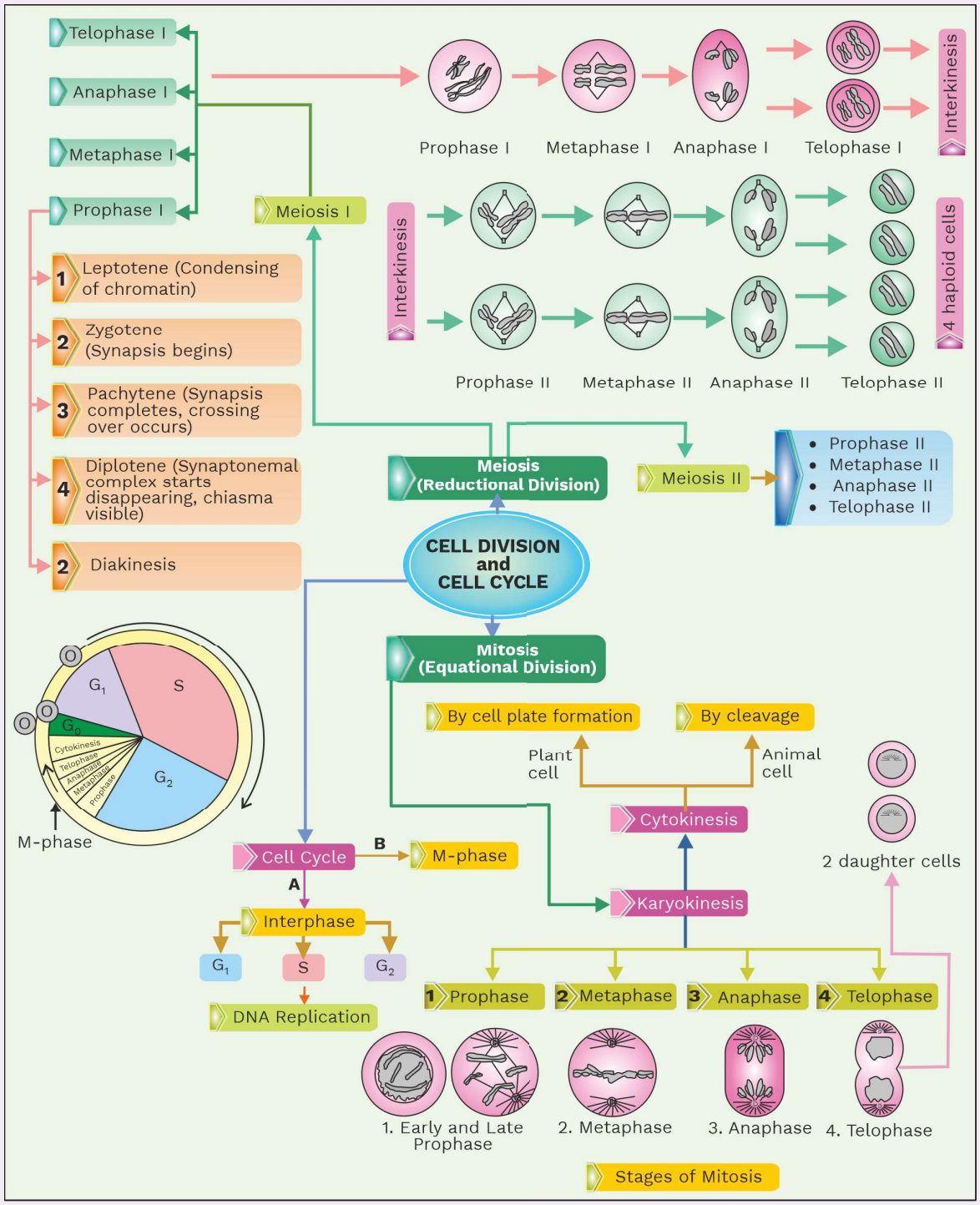
FIG. AMITOSIS IN AMOEBA

Types of Meiosis

Meiosis is almost similar in all plants and animals. Depending upon the stage, when meiosis occurs, it can be of three types— gametic, zygotic and sporic.

- Gametic or terminal meiosis. In most of animals and some lower plants meiosis takes place during the formation of gametes. Such a meiosis is called gametic meiosis. When two gametes fuse in fertilization, the diploid zygote is formed. Gametic meiosis results in diplontic life cycle.
- Zygotic or initial meiosis. In some lower plants (such as fungi, certain protists, and some algae) meiosis takes place in the zygote and the resulting organisms are haploid. It is called zygotic meiosis. Organisms having zygotic meiosis have haplontic life cycle.
- Sporic or intermediate meiosis. In most of the plants (such as pteridophytes, gymnosperms and angiosperms) meiosis occurs at the time of sporogenesis (formation of spores, or microspores and megaspores). It is called sporic meiosis.

Summary


Telophase I
Anaphase I
Metaphase I
Prophase I
Meiosis I
Prophase I
Metaphase I
Anaphase I
Telophase I
Interkinesis
Interkinesis
4 haploid cells
Prophase II
Metaphase II
Anaphase II
Telophase II
1 Leptotene (Condensing of chromatin)
2 Zygotene (Synapsis begins)
3 Pachytene (Synapsis completes, crossing over occurs)
4 Diplotene (Synaptonemal complex starts disappearing, chiasma visible)
2 Diakinesis
Meiosis (Reductional Division)
Meiosis II
Prophase II
Metaphase II
Anaphase II
Telophase II
CELL DIVISION and CELL CYCLE
Mitosis (Equational Division)
G1
S
G2
M-phase
Cytokinesis
Telophase
Anaphase
Metaphase
Prophase
By cell plate formation
By cleavage
Plant cell
Animal cell
Cytokinesis
2 daughter cells
Cell Cycle
B
M-phase
A
Interphase
G1
S
G2
DNA Replication
Karyokinesis
1 Prophase
2 Metaphase
3 Anaphase
4 Telophase
1. Early and Late Prophase
2. Metaphase
3. Anaphase
4. Telophase
Stages of Mitosis

Summary

Mitosis	Meiosis
• Mitosis takes place in the vegetative or somatic cells.	• Meiosis occurs in the reproductive cells at the time of formation of gametes (in spores or at the time of zygote germination in lower organisms).
• It may occur both in haploid and diploid cells.	• It occurs only in diploid cells.
• Mitosis is a single division which produces two identical cells.	• Meiosis is a double division, which gives rise to four cells with recombinant chromosomes.
• The number of chromosomes remains the same after mitosis.	• The number of chromosomes is reduced to half after meiosis.
• Subsequent mitosis divisions are like the earlier ones.	• The two divisions of meiosis are not similar. The first one is heterotypic or reductional.
• Each mitosis division is preceded by an interphase.	• The second meiotic division is preceded by an interkinesis.
• The chromosomes replicate in the interphase before every division.	• The chromosomes replicate only once, prior to meiosis I.
• Prophase is relatively short and without substages.	• Prophase I is of long duration and is divisible into five substages, Prophase II is relatively short.
• Pairing of chromosomes does not occur in mitosis.	• Pairing or synapsis of homologous chromosomes takes place during zygote of prophase I.
• A synaptonemal complex is absent.	• Synapsed homologous chromosomes develop a synaptonemal complex.
• Crossing over does not occur hence chiasmata are absent.	• Crossing over usually takes place during pachytene and chiasmata are observed during diplotene and diakinesis of prophase I.
• Single metaphase plate is formed by all the chromosomes.	• A double metaphase plate is formed by the chromosomes in metaphase I but only one in metaphase II.
• Anaphase involves separation of chromatids of each chromosome.	• Anaphase I involve separation of homologous chromosomes, the chromatids are separated in anaphase II.
• Cytokinesis follows every mitosis.	• Cytokinesis may occur at the end of each division or simultaneously after meiosis II.
• No variations occur after mitosis.	• Variations are common after meiosis.

Solved Exercise

Q1 **The cells having two complete sets of chromosomes are called**
(1) Haploid
(2) Diploid
(3) Polyploid
(4) Polyhybrid

A1 **(2)**
Diploid means two sets of chromosomes where each chromosome has its homologous copy.

Q2 **DNA replication occurs during**
(1) G-1 phase
(2) G-2 phase
(3) Prophase
(4) S-phase

A2 **(4)**
During G-1 of the cell cycle, a cell is metabolically active and in its S-phase (synthetic phase) the chromosomes replicate.

Q3 **Which one is present on a chromosome?**
(1) Centrosome
(2) Centromere
(3) Nucleus
(4) Mitochondria

A3 **(2)**

Each chromosome has a region of constriction called centromere which holds its chromatids in a replicated chromosome.

Q4 **During which stage the chromosomes appear as thin long threads?**

(1) Zygotene
(2) Leptotene
(3) Prophase
(4) Metaphase

A4 **(2)**

Leptotene is the first phase of Prophase-I of the Meiosis-I. In this stage, chromosomes appear as thin long threads.

Q5 **Meiosis is**

(1) Equational division
(2) Multiplication division
(3) Disjunction division
(4) Reduction division

A5 **(4)**

During meiosis, the chromosome number in the newly formed cells, i.e., gametes, is half of the parent cell. Hence, it is called reduction division.

Q6 **Chromosome counting is best done during**

(1) Late anaphase
(2) Late prophase
(3) Telophase
(4) Metaphase

A6 **(4)**

During metaphase, the centriole lies at opposite poles of the cell. By this stage, condensation of chromosomes is completed and become arranged on a plane called metaphase plate. At this stage, the metaphase chromosome is made up of two sister chromatids, which are held together by the centromere. Therefore, they can be observed clearly under the microscope.

Q7 **Haploid complement of chromosome of an organism is called**
(1) Phenotype
(2) Genotype
(3) Genome
(4) Genetic system

A7 **(3)**
A genome is an organisms complete haploid set of genetic instructions. Each genome contains all the information needed by an organism for its development.

Q8 **Terminalisation occurs during**
(1) Mitosis
(2) Meiosis II
(3) Diakinesis
(4) Diplotene

A8 **(3)**
During Diakinesis, the chromosomes are fully condensed and the meiotic spindle is assembled to prepare the homologous chromosomes for separation. This separation of chromosomes leads to the terminalisation of chiasmata.

Q9 **Significance of mitosis is**
(1) Quick divisions
(2) Increasing cellular mass
(3) Occurrence in every tissue
(4) Production of cells, genetically similar to the parent cell

A9 (4)
The main purpose of mitosis is to give rise to cells that are identical to the parent in all aspects.

Q10 **Chromosome number in the petals of a flower in a particular plant is 24. What will be the chromosome number in the pollen grains of this plant?**

(1) 24
(2) 48
(3) 12
(4) 36

A10 **(3)**

The pollen grains are gametophyte that contains haploid male nucleus. Therefore, the chromosome number in pollen grain is 12 (n=12).