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CELL CYCLE AND CELL DIVISION

CHAPTER 10

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Introduction: - The cell cycle and cell division are fundamental processes in biology, governing the growth, development, and reproduction of all living organisms. From the simplest single-celled organisms to the most complex multicellular entities, the ability to reproduce and generate new cells is vital for the continuation of life.

The cell cycle is a well-coordinated series of events that lead to the division of a single cell into two daughter cells. It ensures that DNA is accurately replicated and then equally partitioned between the new cells. The stages of the cell cycle include preparatory phases, where the cell grows in size and duplicates its DNA, and the mitotic phase, where division takes place.

Cell division, on the other hand, can be of two major types: mitosis and meiosis. While mitosis results in two genetically identical daughter cells and is responsible for growth, repair, and general asexual reproduction, meiosis is a specialized process that leads to the formation of gametes (like sperm and egg) with half the original number of chromosomes. This reduction is crucial for sexual reproduction, ensuring that when two gametes fuse during fertilization, the resulting offspring has the correct number of chromosomes.

Given the central role that these processes play, it's not surprising that they are tightly regulated by a multitude of mechanisms. Any disruption or malfunction in the process can lead to diseases, including cancer, where cells may divide uncontrollably.

In essence, the cell cycle and cell division are the means by which life perpetuates itself, maintaining the intricate balance between genetic continuity and variability, which is at the heart of evolution and the survival of species.

I. CELL CYCLE

a. **Definition**: The cell cycle is the sequence of events by which a cell duplicates its genome, synthesizes cell components, and divides into two daughter cells.

b. **Importance**:

- Ensures correct division and formation of progeny cells.
- Ensures progeny cells contain intact genomes.

c. Main Processes:

1. **Cell Division**: Process by which one cell divides into two.
2. **DNA Replication**: DNA of the cell is duplicated to ensure each new cell has a complete set.
3. **Cell Growth**: Involves the synthesis of cell components and increase in cytoplasm. This is continuous.

d. Coordination:

- All processes (division, replication, growth) must occur in a coordinated manner.
- Ensures integrity and functionality of progeny cells.

e. DNA Synthesis:

- Occurs only during a specific stage in the cell cycle.
- This ensures that DNA replication doesn't happen arbitrarily.

f. Chromosome Distribution:

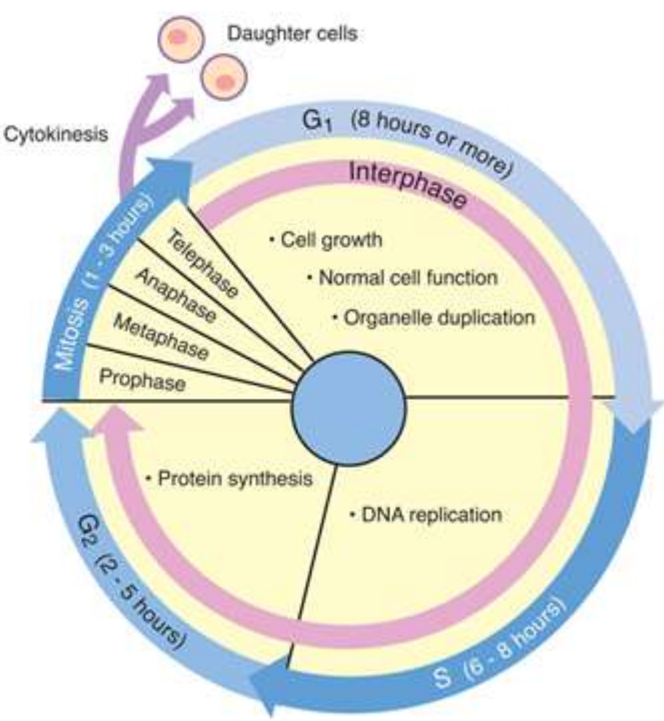
- After replication, chromosomes (containing DNA) are distributed to daughter nuclei.
- This distribution happens through a complex series of events during cell division.

g. Regulation:

- The events of the cell cycle are under genetic control.
- Ensures processes occur in the correct order and at the right times.

• PHASES OF CELL CYCLE

- **Duration & Variability**:
  - Human cells in culture: Divide roughly every 24 hours.
  - Duration varies depending on the organism and cell type.
    - **Example:** Yeast completes the cell cycle in about 90 minutes.



- **Main Phases:**
  - **Interphase**: The period between two successive M phases.

    - **M Phase (Mitosis phase)**: The phase when actual cell division occurs.

- **Details of Each Phase**:
    - **Interphase**:
        - Lasts for over 95% of the cell cycle's duration.
        - Although termed "resting phase", it's when the cell prepares for division.
        - Subdivided into:
    1. **G_1 Phase (Gap 1)**:
        - Period between mitosis and DNA replication initiation.
        - Cell grows and is metabolically active, but doesn't replicate DNA.
    2. **S Phase (Synthesis)**:
        - DNA synthesis/replication occurs.
        - DNA amount doubles (from 2C to 4C), but chromosome number remains the same (e.g., 2n).
        - DNA replication starts in the nucleus in animal cells, and centriole duplicates in the cytoplasm.
    3. **G_2 Phase (Gap 2)**:
        - Protein synthesis in preparation for mitosis.
        - Continuation of cell growth.

  - **M Phase (Mitosis)**:
      - Lasts about an hour in a 24-hour cell cycle.
      - Begins with nuclear division (karyokinesis) and typically ends with division of the cytoplasm (cytokinesis).

- **G_0 Phase (Quiescent Stage)**:
    - Some cells exit G1 and enter this inactive phase.
    - Cells remain metabolically active but don't divide.
    - They can be stimulated to divide depending on organismal needs.

- **Animal vs. Plant Cells**:
    - In animals:
        - Mitotic division typically seen in diploid somatic cells.
        - Exceptions exist, like male honey bees where haploid cells divide mitotically.
    - In plants:
        - Both haploid and diploid cells can undergo mitotic division.

- **Example to recall:** Alternation of generations in plants, where mitosis can occur in haploid stages.

II. M PHASE

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 (karyokinesis), it is very essential to understand that cell division is a progressive process and very clear-cut lines cannot be drawn between various stages. Karyokinesis involves following four stages:

- Prophase
- Metaphase
- Anaphase
- Telophase

a. PROPHASE

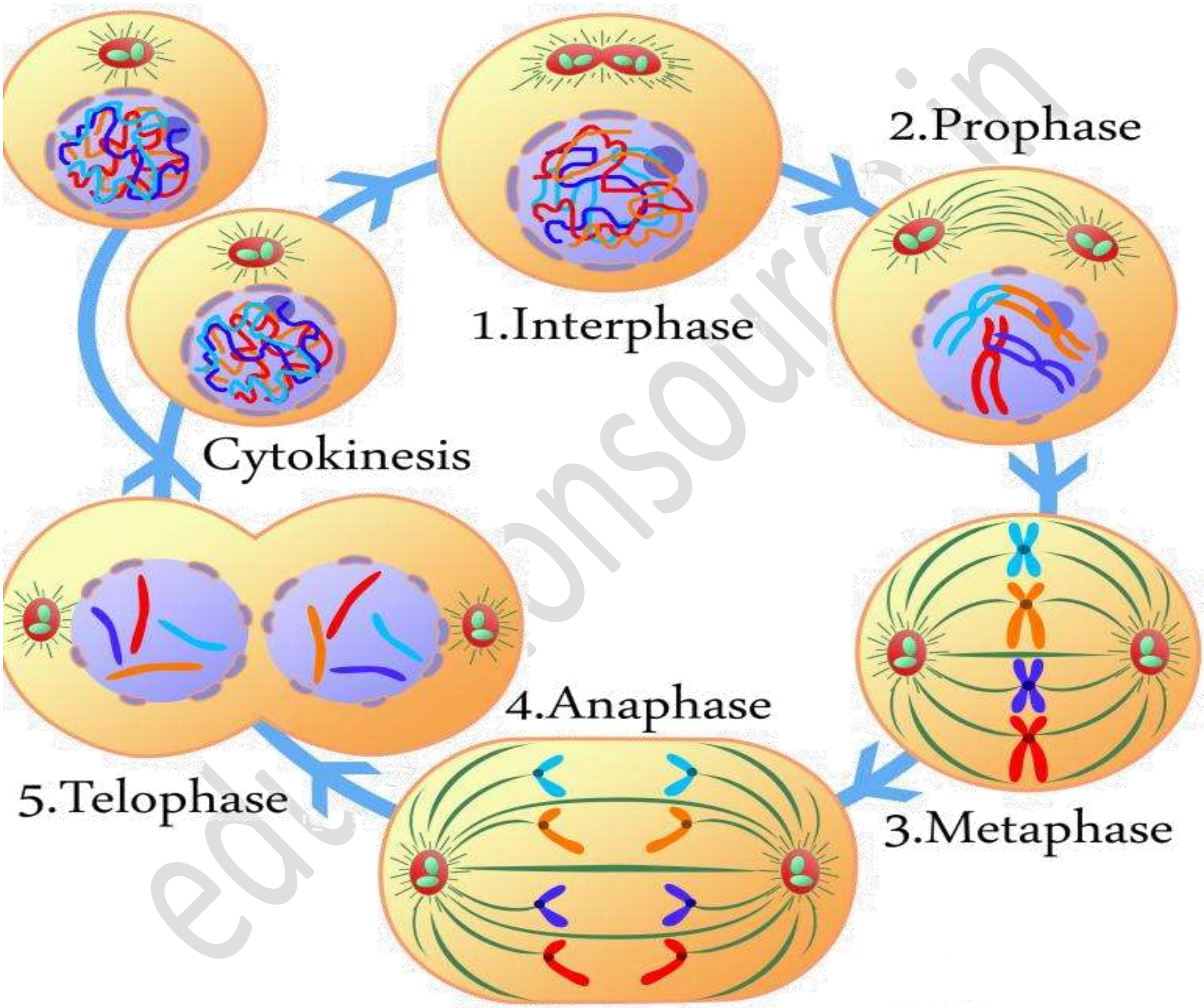
- **Position in Cell Cycle**:
  - First stage of karyokinesis during mitosis.
  - Follows the S and G2 phases of interphase.
- **Events during S and G2 Phases**:
  - New DNA molecules formed remain intertwined.

- **Main Characteristics of Prophase**:
  - **Chromosomal Material Condensation**:
    - Chromosomal material starts to condense.
    - Results in the formation of compact mitotic chromosomes.
    - Each chromosome consists of two chromatids attached at the centromere.

  - **Centrosome Movement and Duplication**:
    - The centrosome had duplicated during the S phase.
    - Now, these centrosomes begin to migrate towards opposite poles of the cell.
    - Each centrosome produces microtubules known as asters.

  - **Formation of Mitotic Apparatus**:
    - The asters, along with spindle fibers, collectively form the mitotic apparatus.

- **Disappearance of Cellular Structures**:
    - Upon examination under a microscope, by the end of prophase, certain cellular structures are no longer visible:
        - Golgi complexes
        - Endoplasmic reticulum
        - Nucleolus
        - Nuclear envelope



b. METAPHASE

- **Beginning**:
    - Marked by the complete disintegration of the nuclear envelope.
    - Chromosomes are distributed throughout the cell's cytoplasm.

- **Chromosome Visibility**:

- Chromosome condensation is complete, making them clearly observable under a microscope.
- Ideal stage for studying chromosome morphology.

- **Chromosome Structure**:
    - Each metaphase chromosome consists of two sister chromatids connected at the centromere.
    - At the centromere surface are disc-shaped structures called **kinetochores**.

- **Role of Kinetochores**:
    - Serve as attachment sites for spindle fibers.
    - These attachments facilitate the movement and positioning of chromosomes.

- **Characteristics of Metaphase**:
    - Each chromosome aligns at the cell's equator, the **metaphase plate**.
    - One chromatid of each chromosome is connected by its kinetochore to spindle fibers from one pole, and its sister chromatid is connected to spindle fibers from the opposite pole.
    - As a result, all chromosomes are aligned with spindle fibers connecting them to both poles.

- **Key Features:**
    - Spindle fibers attach to the kinetochores of the chromosomes.
    - Chromosomes are aligned at the spindle equator, specifically on the metaphase plate, due to the pull from spindle fibers attached to both poles.

c. ANAPHASE

- **Onset**:
    - Starts immediately after the chromosomes are aligned at the metaphase plate.

- **Chromosome Movement**:
    - Each chromosome at the metaphase plate splits simultaneously.
    - Resulting two daughter chromatids, now called daughter chromosomes, start moving toward opposite poles.
    - As they move, the centromere of each chromosome points and leads toward the respective pole, with the chromosome arms trailing behind.

- **Key Features of Anaphase**:
  - **Centromere Splitting**: The centromeres of each chromosome split, allowing the sister chromatids to separate.
  - **Chromatid Separation**: Once separated, the chromatids (now referred to as daughter chromosomes) move towards opposite poles of the cell.

d. TELOPHASE

- **Initiation**:
  - Marks the final stage of karyokinesis.
  - Starts as the separated chromosomes reach their respective poles.

- **Chromosomal Changes**:
  - Chromosomes decondense, becoming less compact.
  - They lose their distinct identities, merging into an undifferentiated mass of chromatin at each pole.

- **Key Features of Telophase**:
- **Chromosome Clustering**: The chromosomes gather at opposite ends of the spindle poles, blending together and losing their individuality.
- **Nuclear Envelope Formation**: A new nuclear envelope starts forming around each chromatin cluster, creating two distinct daughter nuclei.
- **Reformation of Cellular Structures**: Cellular structures like the nucleolus, Golgi complex, and endoplasmic reticulum (ER) begin to reform within the new nuclei.

This summary gives a clear and succinct overview of the Telophase stage and its main characteristics. For a comprehensive understanding, always refer to detailed sources or textbooks.

e. Cytokinesis

1. **Mitosis:**
   - Purpose: Ensures segregation of duplicated chromosomes into daughter nuclei.
   - Comprised of two main processes: karyokinesis (division of the nucleus) and cytokinesis (division of the cytoplasm).

2. **Cytokinesis:**
   - Final stage where the cell's cytoplasm divides, completing cell division.
   - Method differs between animal and plant cells.

3. **Cytokinesis in Animal Cells:**
    - Initiated by a furrow appearing in the plasma membrane.
    - The furrow deepens and meets in the center, dividing the cytoplasm into two.

4. **Cytokinesis in Plant Cells:**
    - Due to the rigid cell wall, plant cells employ a different mechanism for cytokinesis.
    - Wall formation begins centrally and extends outwards.
    - New cell wall begins with a cell-plate, representing the middle lamella between adjacent cell walls.

5. **Organelle Distribution:**
    - During cytokinesis, organelles like mitochondria and plastids are divided between the two daughter cells.

6. **Exceptions:**
    - In some organisms, karyokinesis may not be followed by cytokinesis.
    - This can result in a multinucleate condition, forming a syncytium.
    - Example: Liquid endosperm in coconut.

Remember, the major difference between cytokinesis in animal and plant cells is the process; while animal cells utilize a furrow to divide, plant cells form a new cell wall due to their rigid external structure.

III. Significance of Mitosis: -

1. **Nature of Division:**
    - Also known as the equational division.
    - Typically occurs in diploid cells, but in certain lower plants and social insects, haploid cells also undergo mitosis.

2. **Genetic Consistency:**
    - Produces diploid daughter cells with identical genetic information.
    - Ensures genetic stability across cells, maintaining the same DNA sequence in all somatic cells.

3. **Growth:**
    - Fundamental to the growth of multicellular organisms.
    - As cells grow, there's a disruption in the balance between the nucleus and the cytoplasm (nucleo-cytoplasmic ratio).

- Mitosis helps restore this ratio by dividing the cell, ensuring proper cell function and growth.

4. **Cell Repair and Replacement:**
    - A crucial role in replenishing cells that have a short lifespan or are damaged.
    - Examples include:
        - Cells of the epidermis's upper layer.
        - Lining cells of the gut.
        - Blood cells.

5. **Continuous Growth in Plants:**
    - Mitosis in meristematic tissues like the apical meristem and the lateral cambium allows plants to grow continuously.
    - This is a primary reason why plants can keep growing throughout their life, unlike most animals.

6. **Implication in Development:**
    - As organisms develop from a single cell (zygote), mitosis ensures that every resultant cell has the required genetic information for proper function and differentiation.

7. **Examples of Haploid and Diploid Insects:**
    - The reference hints at understanding haploid and diploid insects. Typically, in many insects like bees, haploid males arise from unfertilized eggs and are drone bees, whereas diploid females arise from fertilized eggs.

In essence, mitosis is pivotal for growth, repair, and maintenance of an organism. It maintains genetic consistency, supports cellular growth, and repairs damaged tissues.

IV. MEIOSIS

1. **Purpose of Meiosis**:
    - To produce gametes with a haploid set of chromosomes for sexual reproduction.
    - Ensures variation due to recombination and independent assortment of chromosomes.
2. **Gamete Formation**:
    - Gametes (like sperm and egg) are formed from specialized diploid cells through meiosis.

- Results in the formation of haploid daughter cells.

3. **Role in Life Cycle**:
    - Provides the haploid phase in the life cycle of sexually reproducing organisms.
    - Fusion of two haploid gametes during fertilization restores the diploid phase.
4. **Occurrence**:
    - Takes place during gametogenesis in both plants and animals.

5. **Key Features**:

   (a) Cycles of Division:
    - Consists of two sequential nuclear and cell divisions: meiosis I and meiosis II.
    - Notably, there's only one cycle of DNA replication.

   (b) Initiation:
    - Meiosis I start post the DNA replication phase (S phase), resulting in identical sister chromatids.

   (c) Chromosome Dynamics:
    - Meiosis is characterized by the pairing of homologous chromosomes.
    - Recombination (or crossing-over) occurs between non-sister chromatids of homologous chromosomes, leading to genetic variation.

   (d) Result:
    - At the end of meiosis II, four distinct haploid cells are produced.

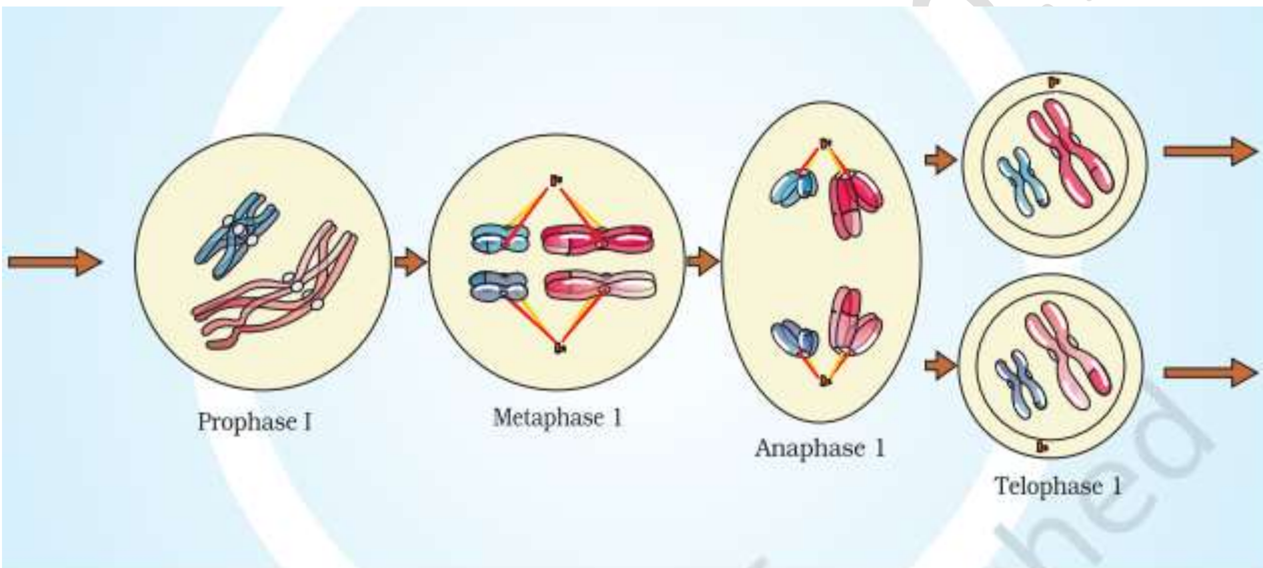
6. **Meiotic Phases**:

   Meiosis I:

1. **Leptotene**:
    - Chromosomes become visible.
    - Compaction of chromosomes begins.
2. **Zygotene**:
    - Chromosomes start pairing (synapsis).
    - Formation of synaptonemal complex.
    - Paired chromosomes = homologous chromosomes.
    - Paired homologous chromosomes = bivalent or tetrad.
3. **Pachytene**:
    - Tetrads become distinct.
    - Appearance of recombination nodules.
    - Crossing over occurs between non-sister chromatids of homologous chromosomes.
    - Enzyme involved = recombinase.
    - Result = recombination of genetic material.
4. **Diplotene**:

- Dissolution of synaptonemal complex.
- Homologous chromosomes of bivalents tend to separate, except at crossover sites.
- X-shaped structures = chiasmata.
- In some vertebrates, this phase can last very long.

5. **Diakinesis**:
   - Terminalisation of chiasmata.
   - Chromosomes fully condensed.
   - Meiotic spindle assembles.
   - End: nucleolus and nuclear envelope disappear.
   - Transition to metaphase.



Metaphase I:

- Bivalent chromosomes align on equatorial plate.
- Microtubules from opposite spindle poles attach to the kinetochore of homologous chromosomes.

Anaphase I:

- Homologous chromosomes separate.
- Sister chromatids stay connected at centromeres.

Telophase I:

- Reappearance of nuclear membrane and nucleolus.
- Followed by cytokinesis → results in dyad of cells.
- Chromosomes don't fully de-condense.

Interkinesis:

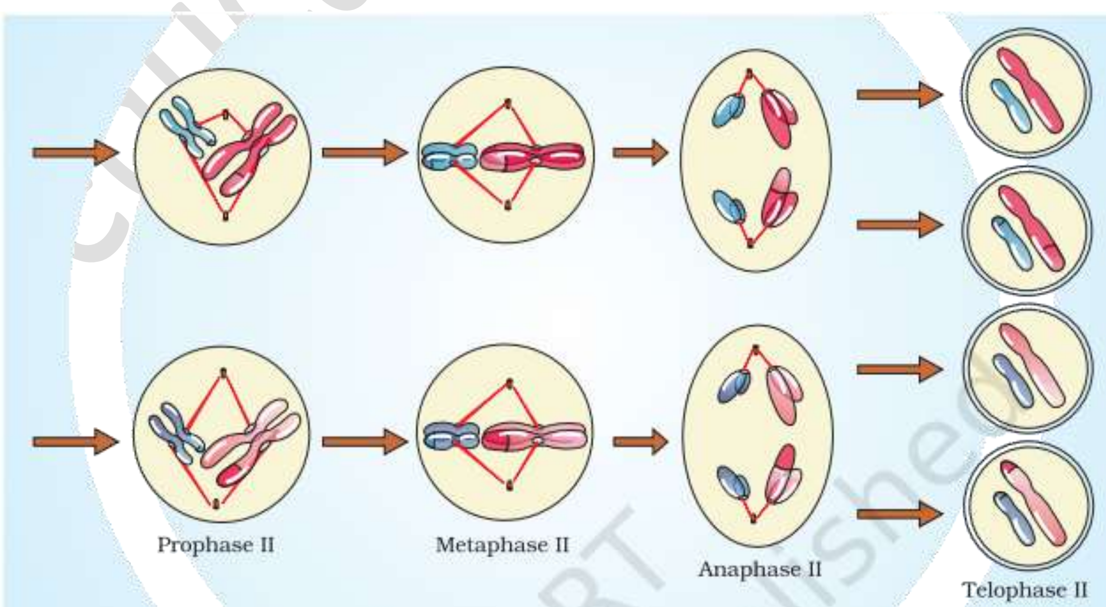
- Short phase between two meiotic divisions.
- No DNA replication.

- Leads to prophase II, which is simpler than prophase I.

(a) Meiosis II:

1. **Prophase II**:
    - Initiation: Immediately after cytokinesis, before chromosomes fully elongate.
    - Resembles a regular mitosis.
    - **Events:**
        - Nuclear membrane disappearance.
        - Chromosomes become compact again.
2. **Metaphase II**:
    - Chromosomes align at the equator.
    - Microtubules from opposite spindle poles attach to the kinetochores of sister chromatids.

3. **Anaphase II**:
    - **Initiation:** Simultaneous splitting of each chromosome's centromere (which held the sister chromatids together).
    - **Result:** Sister chromatids move towards opposite poles via the shortening of kinetochore-attached microtubules.
4. **Telophase II**:
    - End phase of meiosis.
    - **Events:**
        - Chromosome groups get enclosed by a new nuclear envelope.
        - Cytokinesis follows.
    - **Result:** Formation of four haploid daughter cells (tetrad of cells).



- **Significance of Meiosis: -**

  Meiosis is a specialized form of cell division that gives rise to gametes (sperm and egg cells in animals and pollen and ovules in plants). It is crucial for sexual reproduction and ensures the continuity of species. The significance of meiosis includes:

1. **Halving the Chromosome Number:** Unlike mitosis, which maintains the chromosome number, meiosis reduces the chromosome number by half. This is essential for sexual reproduction because when fertilization occurs, the diploid number of chromosomes (two sets, one from each parent) is restored. Without meiosis, the chromosome number would double with each generation, which would be unsustainable.

2. **Genetic Variation:** During meiosis I, homologous chromosomes (one from each parent) pair up and exchange segments in a process called crossing over or genetic recombination. This shuffles the genetic material so that each gamete carries a unique combination of genes, ensuring that offspring have a combination of traits from both parents.

3. **Independent Assortment:** The way in which chromosomes align in the middle of the cell during meiosis I is random. This means that different combinations of maternal and paternal chromosomes can end up in the resulting gametes. This independent assortment of chromosomes adds another layer of genetic variation.

4. **Elimination of Harmful Mutations:** Over time, DNA can accumulate mutations, some of which can be harmful. By recombining genetic material during meiosis, there's a chance that a gamete might not inherit certain harmful mutations. If such gametes give rise to the next generation, those harmful mutations can be purged from the population.

5. **Evolution:** The genetic variation introduced by meiosis is one of the raw materials for evolution. When combined with the process of natural selection, genetic variations can lead to the evolution of new traits that might be advantageous for survival or reproduction in changing environments.

6. **Ensures Correct Chromosome Number:** Mistakes in meiosis, such as nondisjunction (when chromosomes fail to separate properly), can lead to gametes with an incorrect number of chromosomes. When such gametes are involved in fertilization, it can lead to conditions like Down syndrome in humans. While this illustrates the importance of the accurate progression of meiosis, it also highlights how errors in meiosis can have significant consequences.