Cell Biology

Chapter (5): Cell division and cell cycle

- Binary fission
- Cell cycle
- Mitosis
- Meiosis

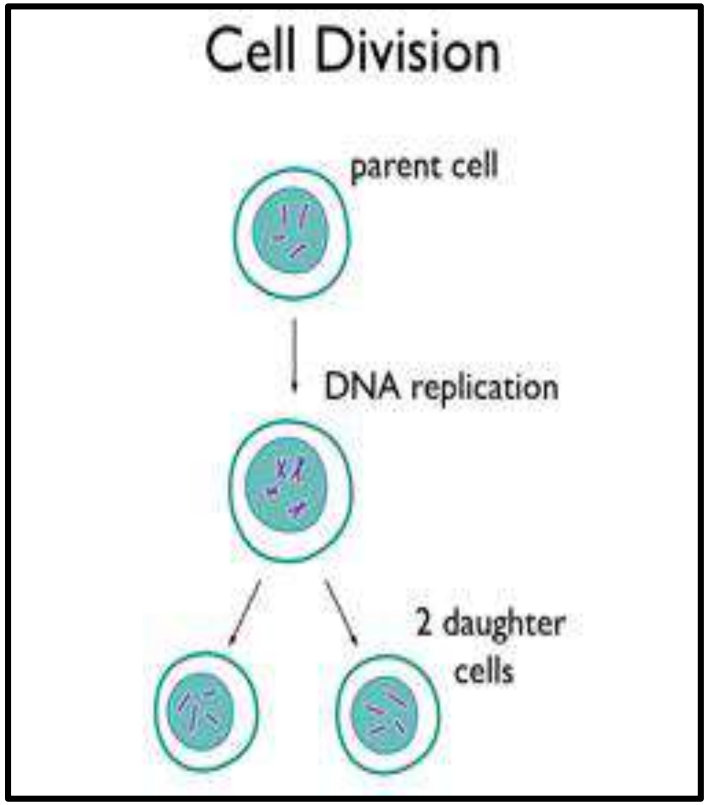
Cell division

- **Cell division is a biological process in which a parent cell divides into two or more daughter cells.**

- **The function of cell division in prokaryotes (unicellular organisms) is reproduction (binary fission).**

- **The function of cell division in multicellular organisms are:**

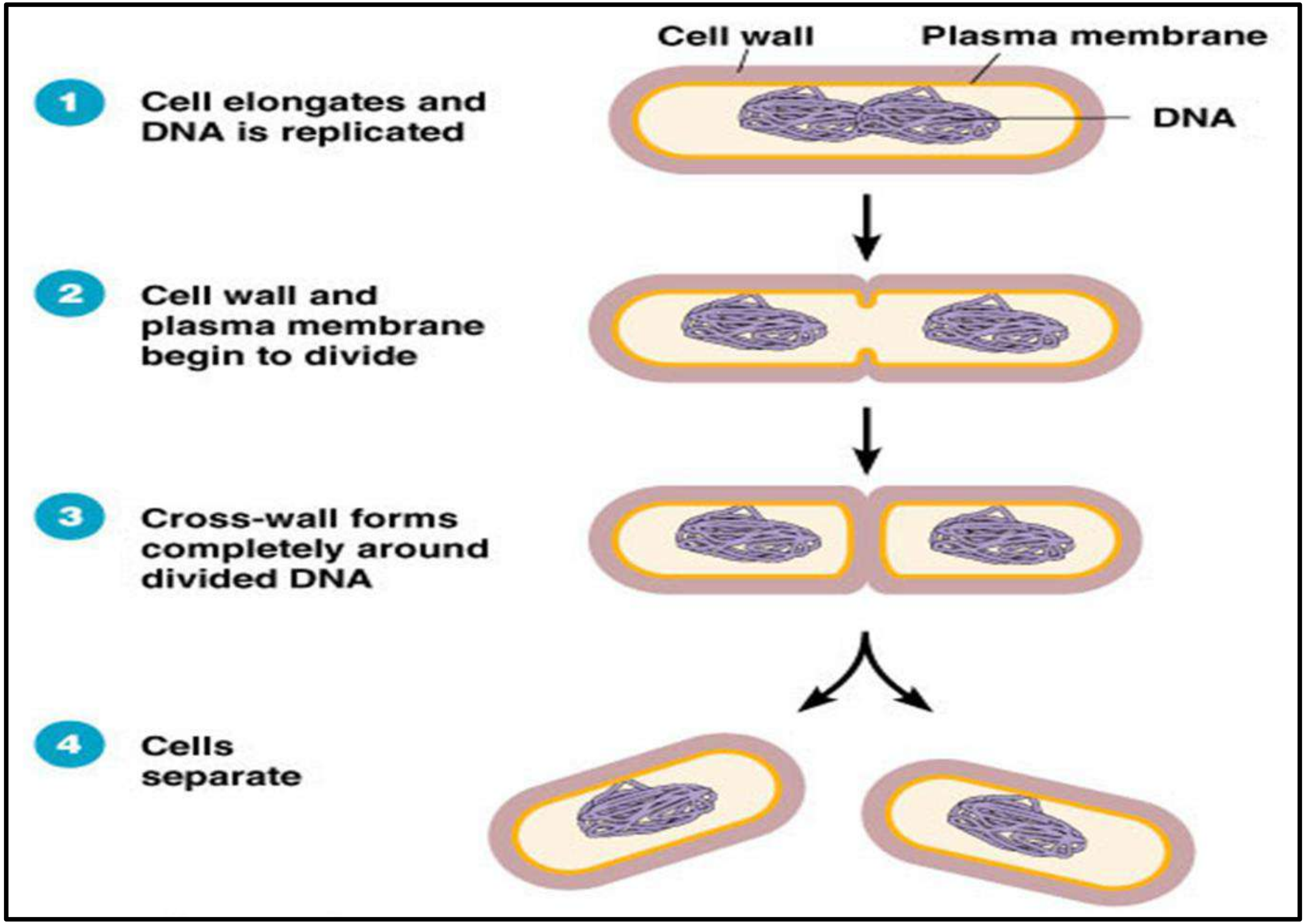
  - **Growth of living organisms**
  - **Replacement of damaged and dead cells (Tissue repair)**
  - **Reproduction**



Cell division

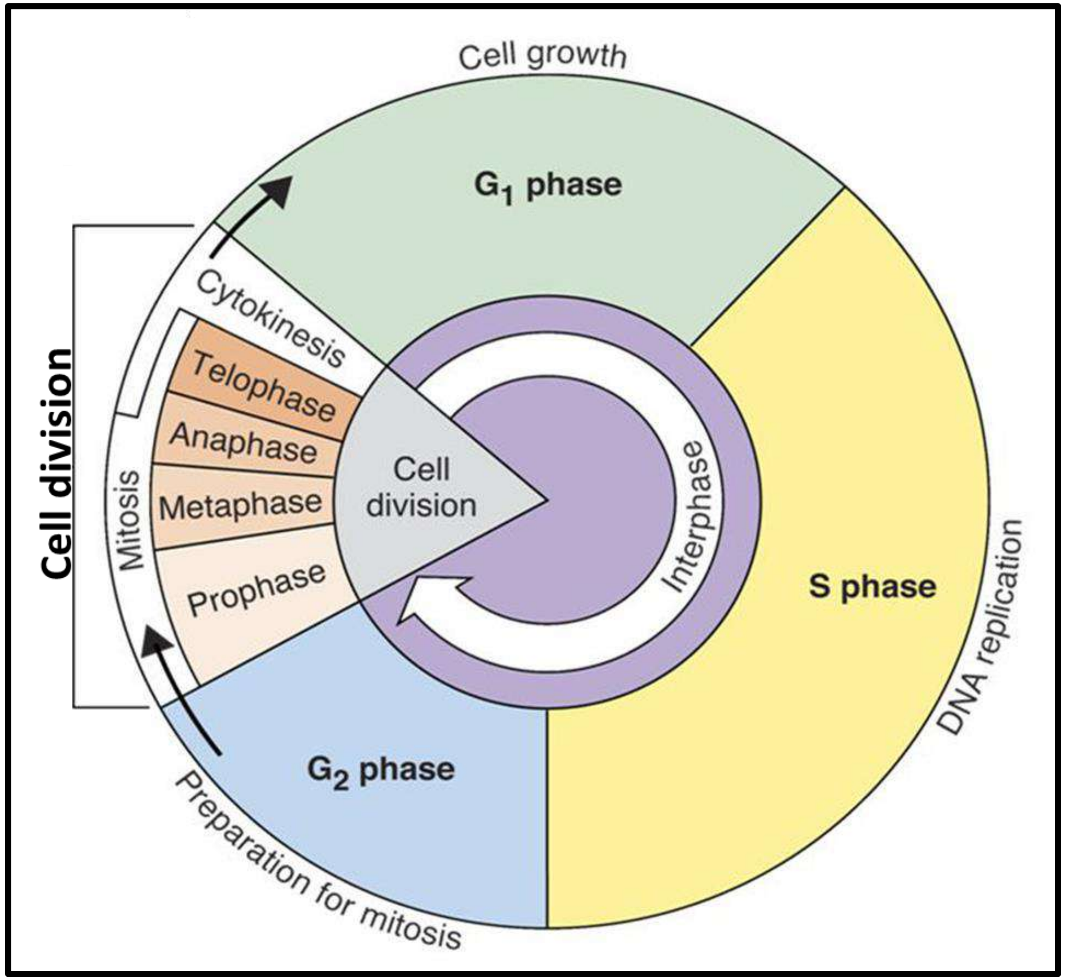
Cell division in bacteria

- **Bacteria are divided in a process called binary fission (asexual reproduction) into two identical daughter cells.**



Cell division

- Cell division usually occurs as part of a larger process called cell cycle.
- Cell cycle is sequence of events in which a cell duplicates its genome, synthesizes other cell components, then divides into two daughter cells.
- In eukaryotes, the cell cycle includes three (or five) phases: interphase, mitosis (M phase) and cytokinesis (C phase).



<u>Phases of cell cycle</u>

1. Interphase

- It is a preparation phase to perform cell division, meaning the cell does not divide during this phase.
- In this phase, the cell prepares all substances and organelles required for growth, DNA duplication and division.
- It includes three phases (G1, S, G2).

Cell division

Phases of cell cycle

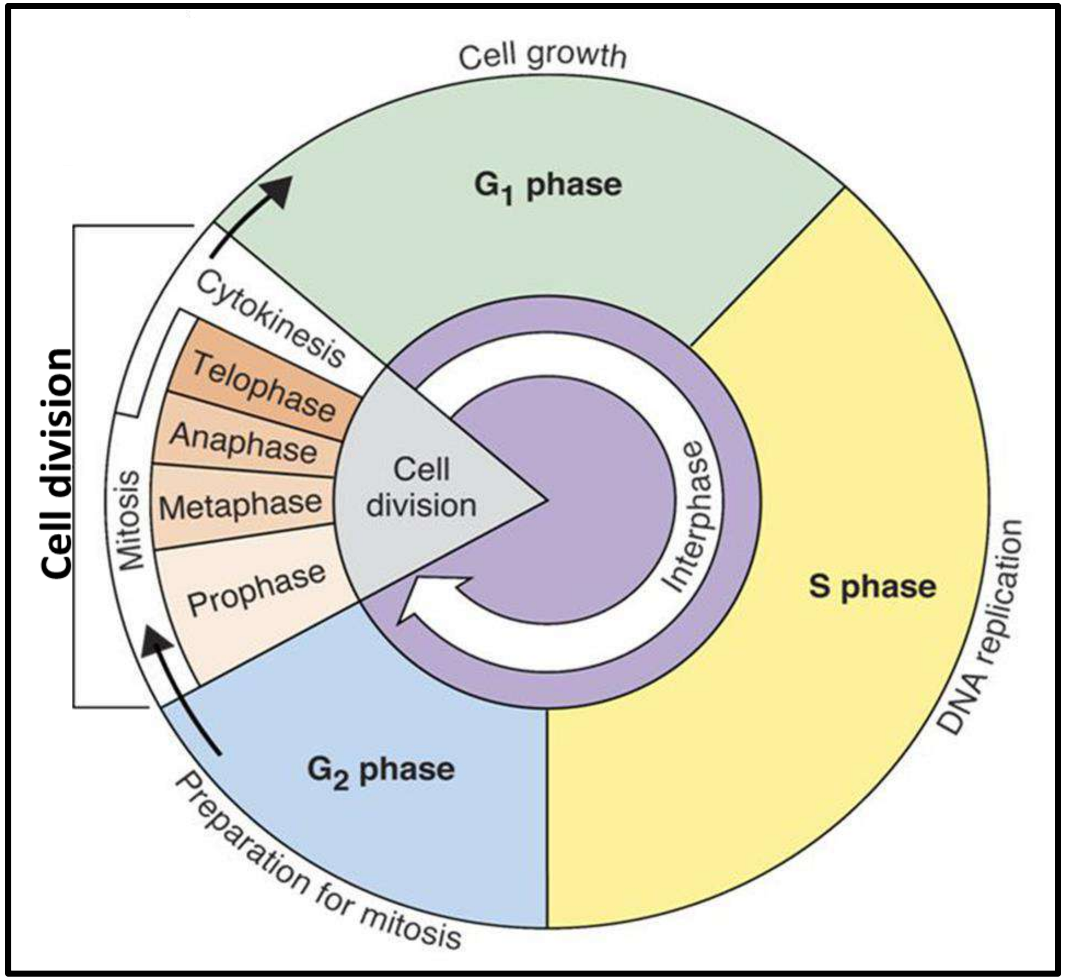
1. Interphase

a. G1 phase

- **It is the first phase in interphase where G means gap or growth (*the cell grows in size*).**

- **In this phase, the cell grows continuously and enlarges in size, the biosynthetic activities of the cell increase where many proteins and enzymes required for S phase for DNA replication are synthesized, but no DNA replication occurs during this stage.**

- **In G_1 phase, a cell has two options. (1) To continue cell cycle and enter S phase (2) Stop cell cycle and enter G_0 phase (rest phase).**



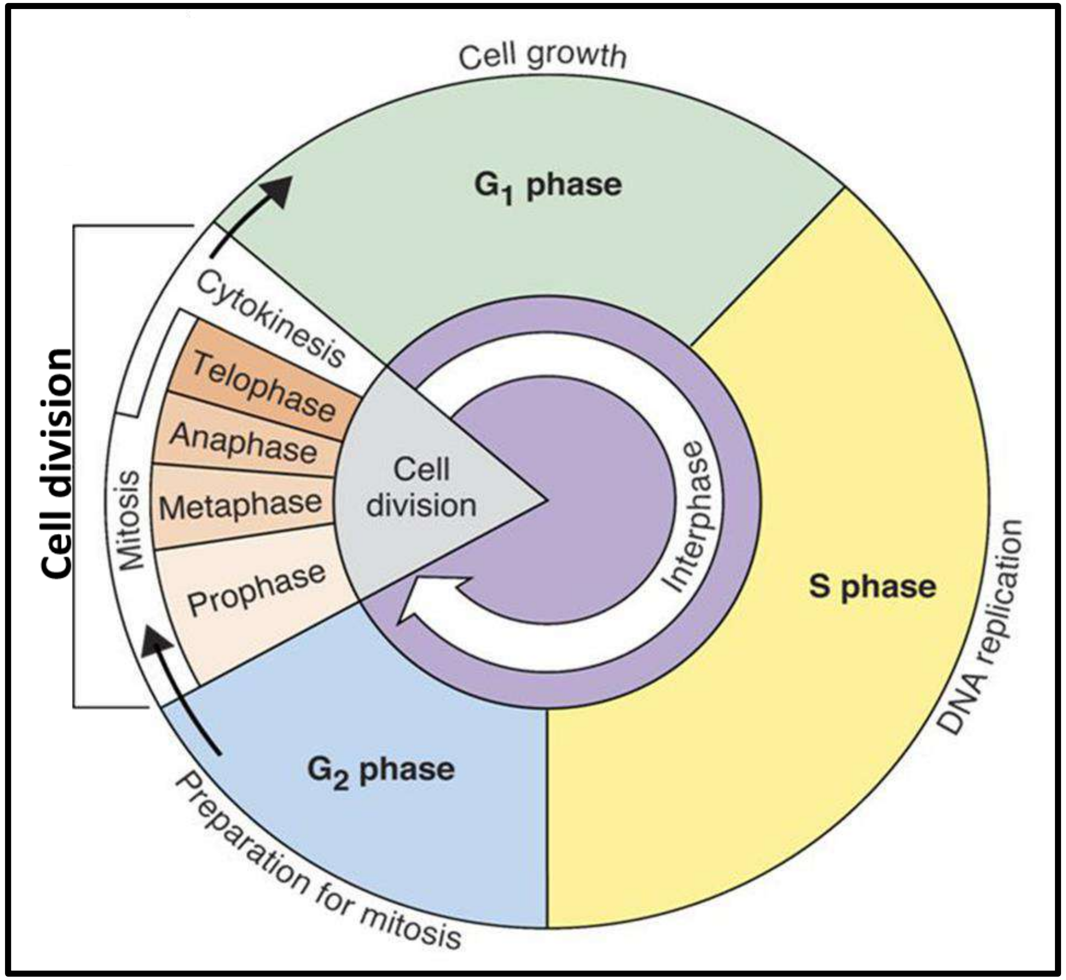
Cell division

Phases of cell cycle

1. Interphase

b. S phase

- **It is also known as the synthesis phase.**
- **During S phase, the genetic material (DNA) is replicated.**
- **Also the centrosome is replicated.**
- **The rates of RNA transcription and protein synthesis are very low during this phase. An exception to this is histone production, most of which occurs during the S phase**



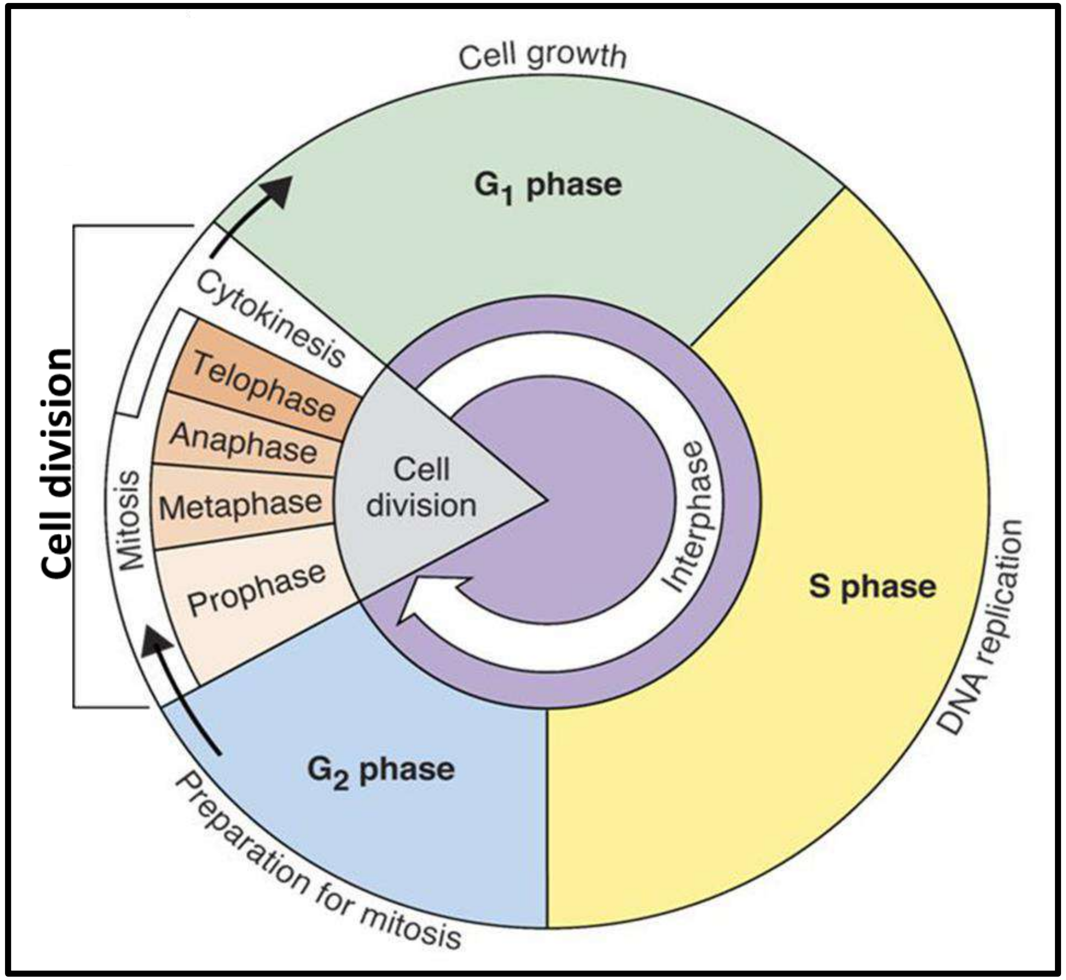
Cell division

<u>**Phases of cell cycle**</u>

1. Interphase

c. G2 phase

- **It is also known as the second growth phase in which organelles are duplicated.**
- **It occurs after DNA replication and is a period of protein synthesis (mainly tubulin) and rapid cell growth to prepare the cell for mitosis.**
- **During this phase, microtubules begin to organize the spindle fibers.**
- **Chromatins begin to condense into chromatids.**



Cell division

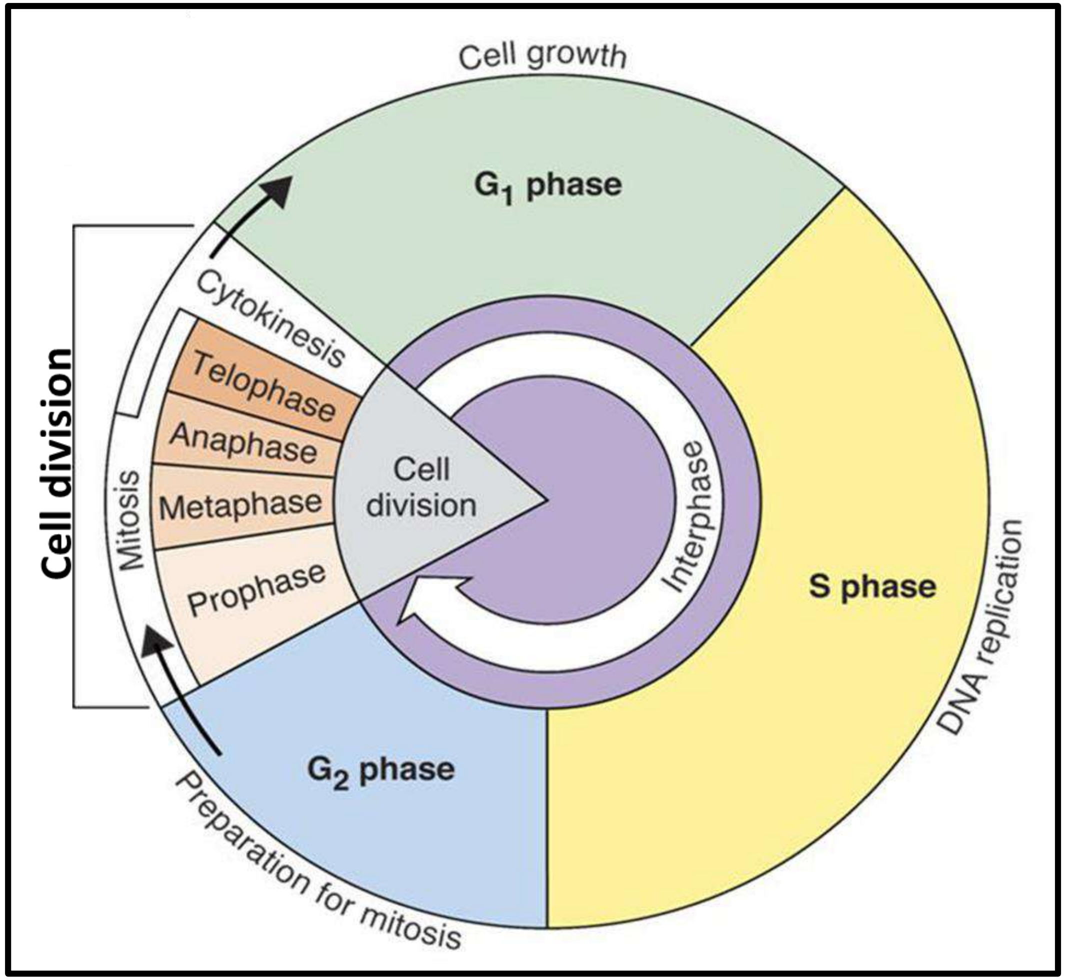
<u>**Phases of cell cycle**</u>

2. Mitosis (M phase)

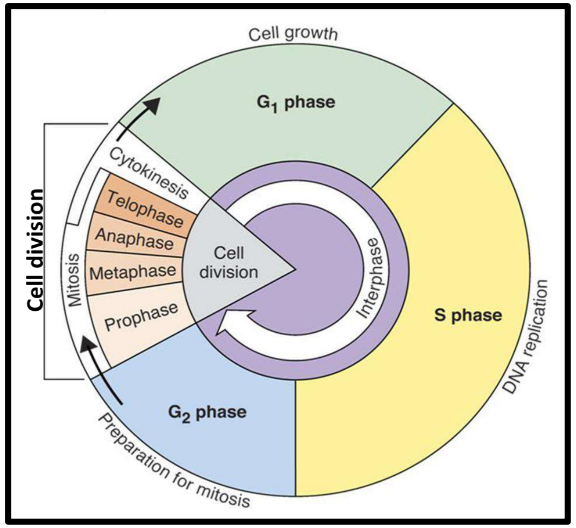
- **M phase is the actual period of cell division, in which the eukaryotic cell separates its chromatids into two identical sets in two nuclei.**

- **It includes four stages: prophase, metaphase, anaphase, and telophase.**

- **During M phase, the duplicated chromatids condense into compact structures known as chromosomes and the nuclear envelope surrounding the DNA begins to break down.**



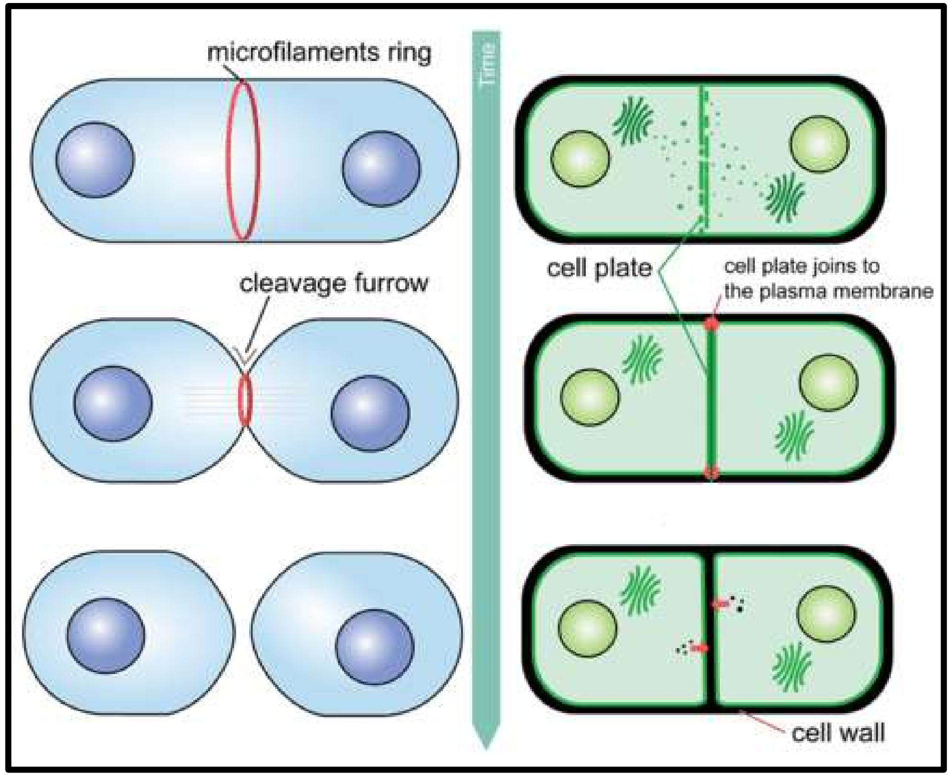
Cell division



Phases of cell cycle

3. Cytokinesis phase (C phase)

- **It is the phase where the cytoplasm is divided into two separated daughter cells containing roughly equal cellular components.**
- **In animal cells, C phase is performed by formation of cleavage furrow**
- **Plant cytokinesis differs from animal cytokinesis because of the plant cell walls. Plant cells form a cell plate in the cytoplasm, instead of the cleavage furrow, which grows into a new, doubled cell membrane and cell wall between plant daughter cells.**
- **Mitosis and cytokinesis phases together refer to the division of the mother cell into two daughter cells.**



NOTE:

- **Some cells as nerve and heart muscle cells, become quiescent and enter in G0 phase (zero or rest phase) when they reach maturity.**

Cell division

Regulation of cell cycle

- **In contrast to prokaryotes which divide very fast and their cell division depends on the availability of nutrition, the cell division in eukaryotes is highly controlled.**

- **To ensure the accuracy of cell division in eukaryotic cells, there is a cell cycle control system that confirms whether the processes at each phase of the cell cycle have been correctly completed before progression into the next phase.**

- **The cell cycle control system, which includes proteins called regulatory proteins, responds to signals from inside and outside of the cell.**

- **The cell contains checkpoints that generate inside signals controlling the cell cycle.**

- **Moreover, the individual cell divides only when it receives a signal from other cells through a group of proteins called growth factors. This means that the cell cycle is controlled from outside by signals produced from growth factors.**

Cell division

Regulation of cell cycle

<u>Inside checkpoints</u>

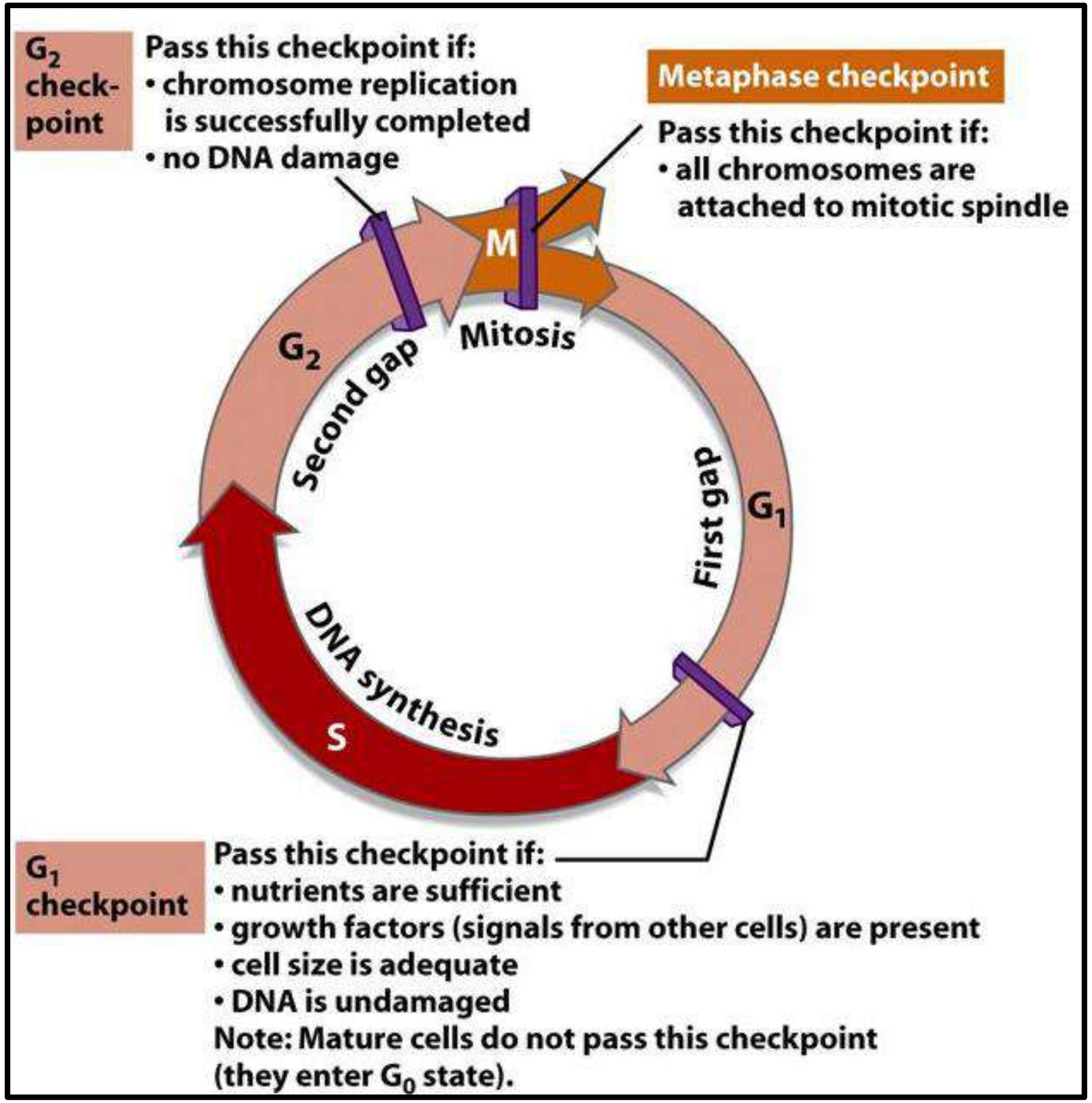
- **The main checkpoints that control the cell cycle in eukaryotes are:**

1. G_1 Checkpoint

- **It is the first checkpoint located at the end of the G_1 phase, but before entry into S phase, making decision of whether the cell should divide, delay division or enter a resting stage (G0 phase).**

2. G_2 Checkpoint

- **It is located at the end of G_2 phase, triggering the start of the M phase. If this checkpoint is passed, the cell initiates the processes that signal the beginning of mitosis.**



Cell division

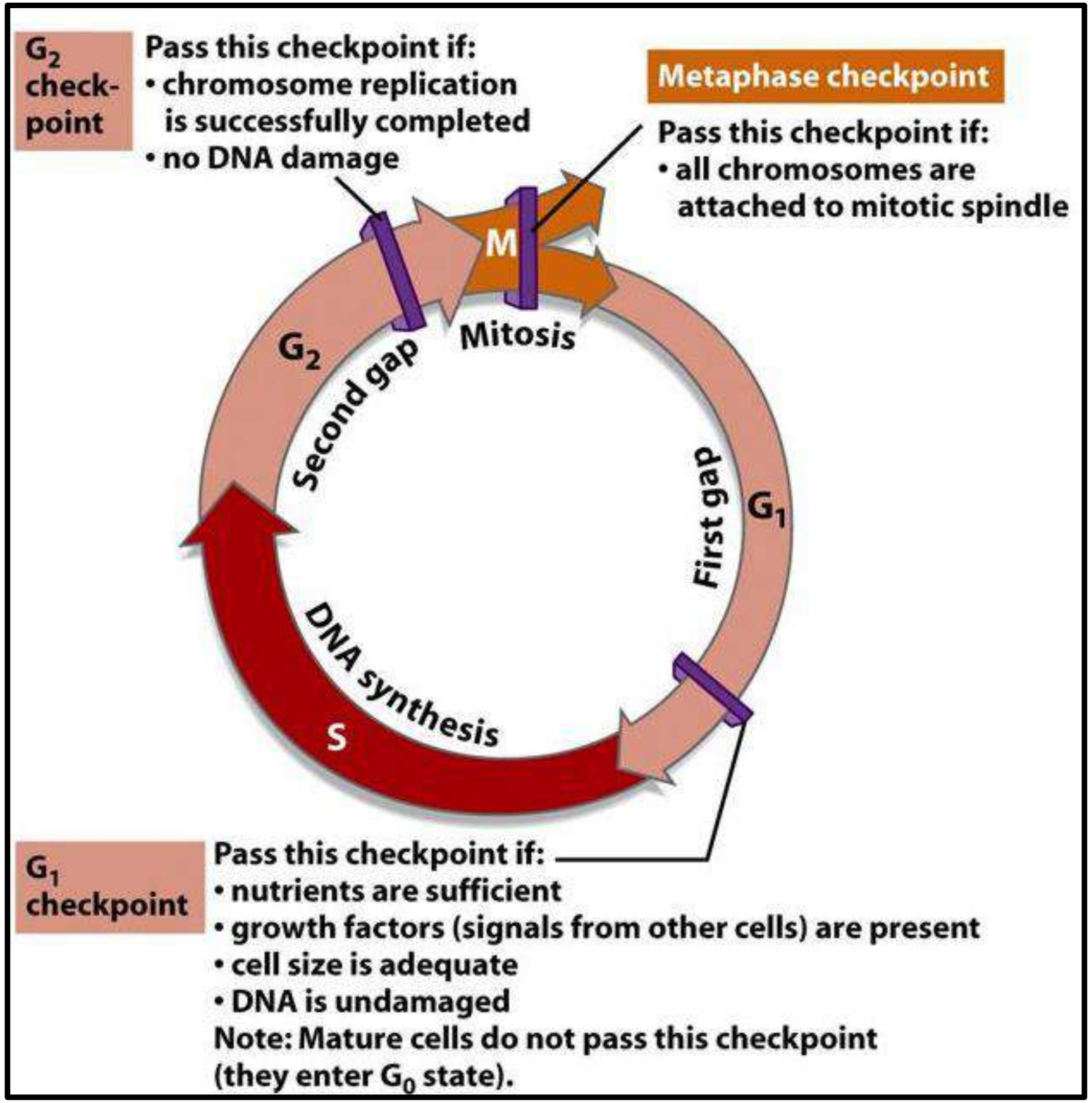
Regulation of cell cycle

Inside checkpoints

- The main checkpoints that control the cell cycle in eukaryotes are:

3. M Checkpoint

- This checkpoint occurs in metaphase to check if all chromosomes are attached to the spindle fibers and if all chromosomes are arranged in the cell center.



Cell division

Regulation of cell cycle

External signals

- **The cell cycle is controlled from outside by signals produced from growth factors.**
- **Growth factors are proteins released from certain body cells that stimulate and regulate the division in other cells.**
- **Each growth factor has a specific receptor on the target cell, and binding with its receptor triggering internal events which enhance the cell to divide.**

Examples:

1. Erythropoietin: It is a growth factor made by the kidney which stimulates the stem cells in bone marrow to divide and to produce red blood cells.

2. Platelet-derived growth factor (PDGF): It is a growth factor made by the platelets at injury. It is required for stimulation of fibroblasts division, a type of connective tissue cells needed to wound healing.

3. Cytokines: Large group of proteins synthesized and secreted from white blood cells (immune cells) to enhance the cell division of other immune cells.

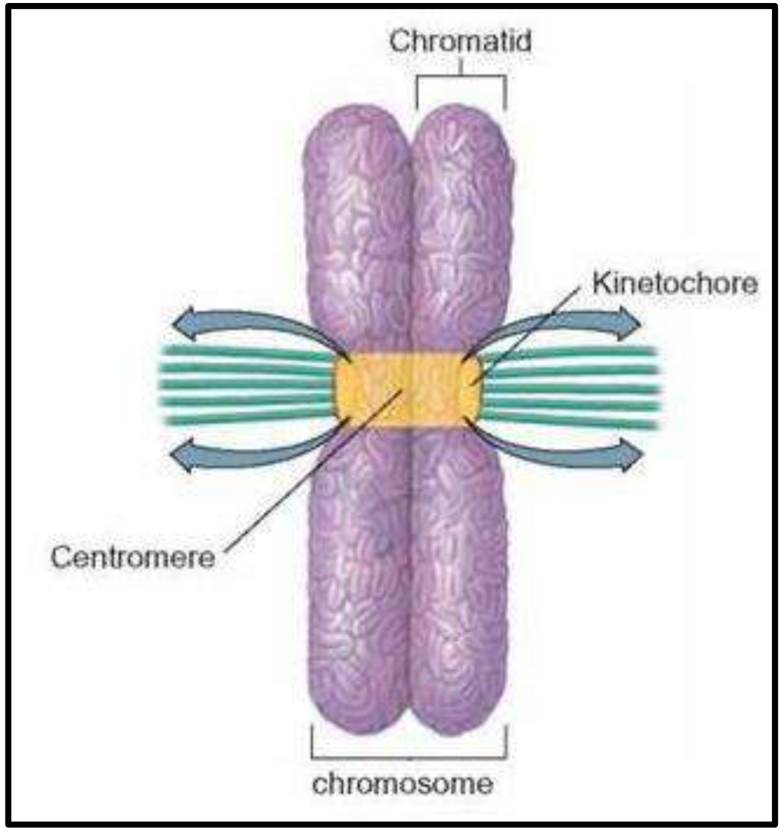
Cell division

Mitosis division

- **Mitosis division is the process in which the eukaryotic cell separates its chromatids into two identical sets to form two identical daughter cells.**

- **It includes four stages: prophase, metaphase, anaphase, and telophase.**

1. Prophase



- **It is the first stage in mitosis division and the following changes can occur:**

  a. **Chromatids condense into chromosomes and become visible where each two sister chromatids bind together by centromere.**

  b. **The nuclear envelope and nucleolus disappear.**

  c. **Each centrosome (two centrioles), which are duplicated in interphase begins to move to reach the opposite pole of the cell.**

  d. **The kinetochores and spindle fibers begin to form.**

- **A kinetochore is a disc-shaped protein structure attached with the centromere, and through which the spindle fibers bind with the chromosomes to pull sister chromatids apart during cell division.**

Cell division

Mitosis division

2. Metaphase

- **In this phase the two centrosomes start pulling the chromosomes to arrange them in the center of the cell (*equatorial plane).***

3. Anaphase

- **In this phase the spindle fibers begin to shortening to separate the centromere into two which separate the two sister chromatids from each other.**
- **Then, each sister chromatid is pulled toward the centrosome to which it is attached.**

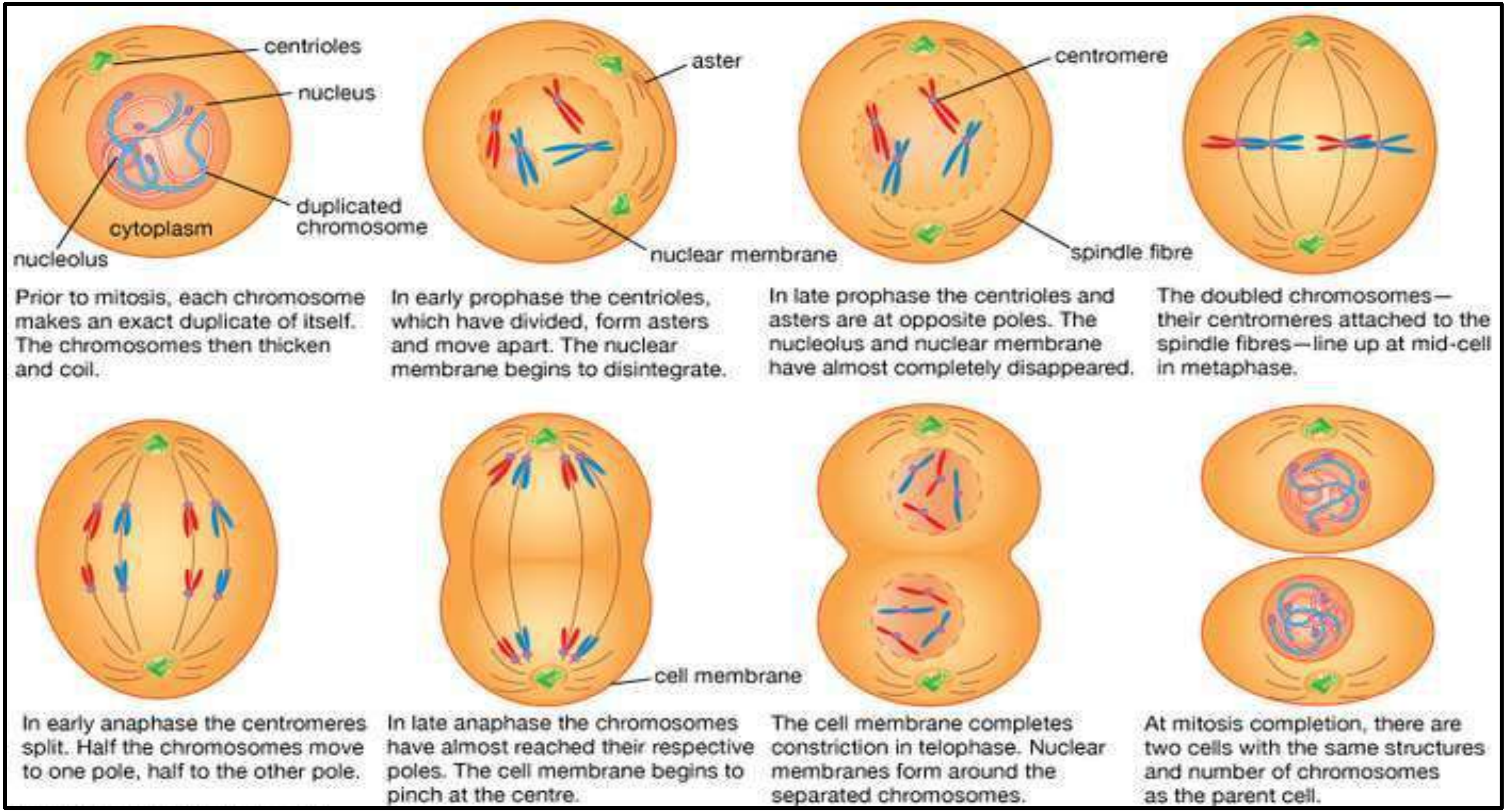
Cell division

Mitosis division

4. Telophase

- It is the reverse of prophase in which the following changes can occur:
    a. The kinetochores start to disappear.
    b. The spindle fibers start to break down into tubulin subunits that can be used to construct the cytoskeleton of the new daughter cells.
    c. The nucleolus appears and the nuclear envelope forms around each set of DNA.
    d. Chromatids uncoil into chromatins.
- After that, cytoplasm is divided into two parts during cytokinesis phase to produce two daughter cells.
- The result of mitosis process is production of two cells with exactly the same genetic information.

Cell division: Mitosis division



Prior to mitosis, each chromosome makes an exact duplicate of itself. The chromosomes then thicken and coil.

In early prophase the centrioles, which have divided, form asters and move apart. The nuclear membrane begins to disintegrate.

In late prophase the centrioles and asters are at opposite poles. The nucleolus and nuclear membrane have almost completely disappeared.

The doubled chromosomes—their centromeres attached to the spindle fibres—line up at mid-cell in metaphase.

In early anaphase the centromeres split. Half the chromosomes move to one pole, half to the other pole.

In late anaphase the chromosomes have almost reached their respective poles. The cell membrane begins to pinch at the centre.

The cell membrane completes constriction in telophase. Nuclear membranes form around the separated chromosomes.

At mitosis completion, there are two cells with the same structures and number of chromosomes as the parent cell.

Cell division

Meiosis division

- It is a special type of cell division involved in sexual reproduction in eukaryotes because it is necessary for gametes production.

- The number of sets of chromosomes in the cell undergoing meiosis is reduced to half from diploid cell (2n) to haploid cell (n).

- It occurs in two stages, meiosis I and meiosis II, where the final result of this process is the production of four genetically different haploid cells from one diploid cell.

- Diploid cell (2n) is a cell that has two copies of each chromosome (homologous chromosomes), one from the mother and one from the father. Example: Somatic cells which are all body cells except gametes.

- Haploid cell (n) is a cell that has one set of chromosomes. Example: Gametes (sperm and ovum).

Cell division

Meiosis division: <u>Meiosis I</u>

- Meiosis I is called a reduction process because it reduces the diploid (2n) cell to haploid (n) cell.
- It includes four phases: prophase I, metaphase I, anaphase I, telophase I.

1. Prophase I:

- It is the first stage of meiosis I and many changes occur during this phase.
- It includes two steps that do not occur in mitosis division: Synapsis and Homologous recombination.
- These are vital steps required to produce genetic variations in the cells. See next slide
- Also, in prophase I the following changes occur:
    - The nuclear envelope and nucleolus disappear.
    - Each two centrioles which are duplicated in interphase begins to move to reach the opposite pole of the cell.
    - The kinetochores and spindle fibers begin to form.

Cell division

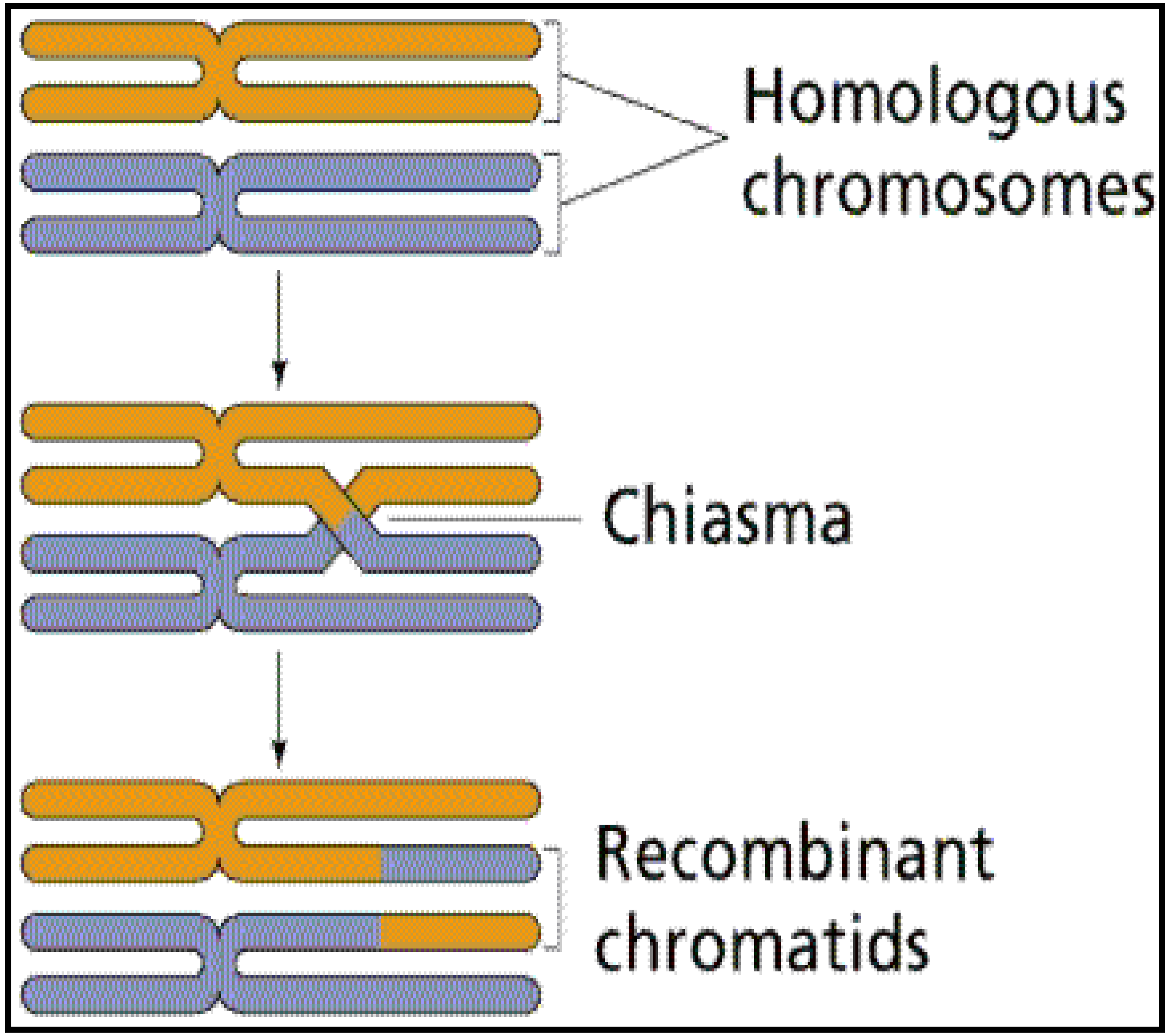
Meiosis division: Meiosis I

1. **Synapsis (pairing)**

- **Process in which two chromosomes (four chromatids) with the same length and position of centromere pair forming homologous chromosomes.**

2. **Homologous recombination**

- **It is a process in which nucleotide sequences are exchanged between two non-sister chromatids in the same homologous chromosome to produce genetic variations.**
- **The point at which the sequences are exchanged is called chiasma.**



Cell division

Meiosis division: <u>Meiosis I</u>

2. Metaphase I:

- **Spindle fibers attach to the kinetochore proteins only at the outside of each centromere in the homologous chromosome pair.**
- **Then, the homologous chromosomes arrange in the center of the cell (*equatorial plane).***

3. Anaphase I:

- **In this phase, the spindle fibers begin to shortening to separate the recombined chromosomes into whole chromosomes, where each separated chromosome still contains a pair of sister chromatids linked by a centromere.**
- **Then, the separated chromosome are pulled toward opposing poles, forming two haploid sets.**

Cell division

Meiosis division: <u>Meiosis I</u>

4. Telophase I:

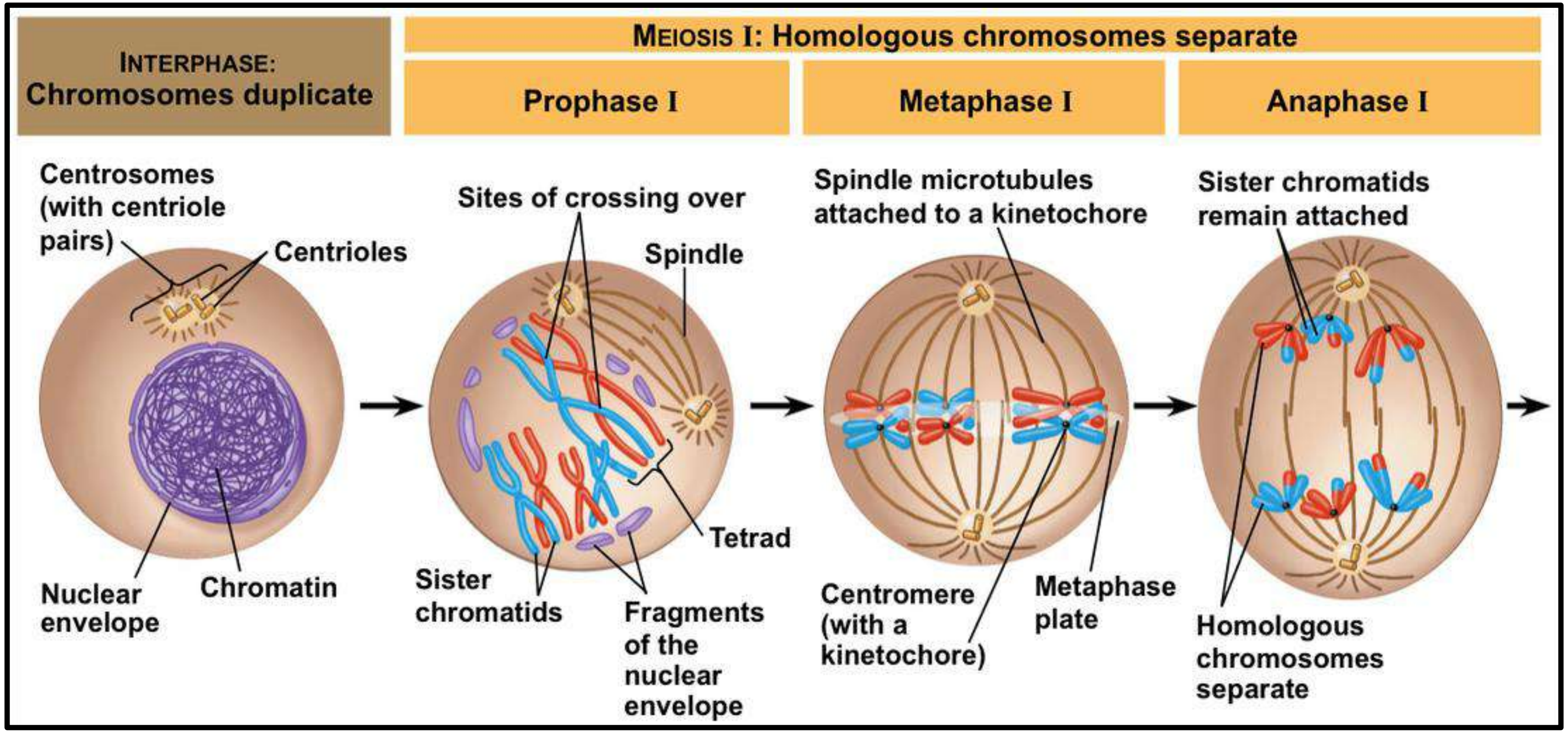
- **In this phase, the chromosomes arrive at the poles of the cell and the spindle fibers disappear.**
- **The nuclear envelope reforms and the nucleolus appears.**

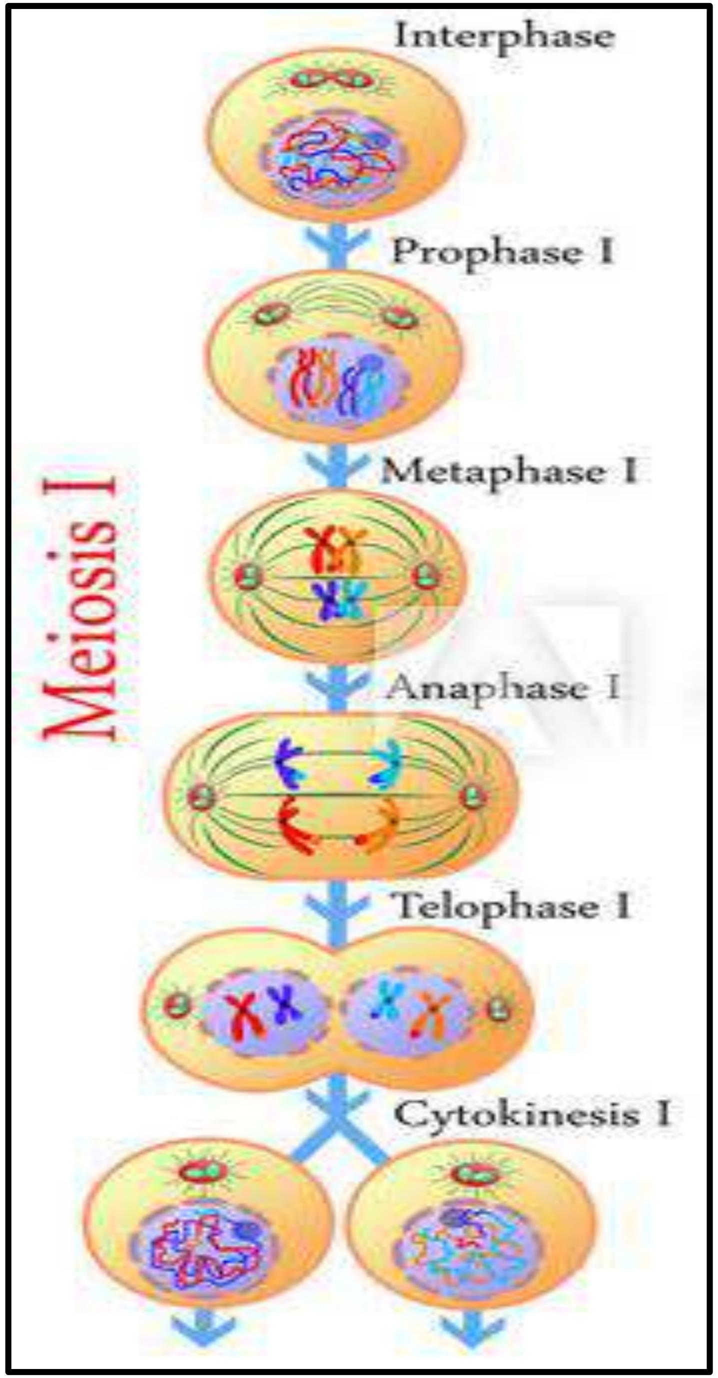
NOTES:

- **The outcome of meiosis I process is two haploid cells.**
- **Cytokinesis may or may not occur after this phase.**
- **The produced haploid cells enter to meiosis II after a preparation period.**
- **There is no DNA duplication process.**

Cell division

Meiosis division: Meiosis I





Cell division

Meiosis division: Meiosis II

- **Meiosis II is the second part of the meiosis process and it is similar to mitosis division, but its results are genetically different.**
- **The end result of this process is production of four haploid cells from the two haploid cells produced in meiosis I.**
- **It includes four steps : Prophase II, Metaphase II, Anaphase II, and Telophase II.**
- **It is similar to prophase in mitosis but the cells are haploids and there is no DNA duplication in interphase.**

1. ***Prophase II***

- **The nuclear envelope and nucleolus disappear.**
- **Each two centrioles begin to move to reach the opposite poles of the cell.**
- **The kinetochores and spindle fibers begin to form.**

Cell division

Meiosis division: <u>Meiosis II</u>

2. Metaphase II

- **In this phase, the spindle fibers attach to the kinetochores at the two sides of each centromere.**
- **Then, the two centrosomes start pulling to arrange the chromosomes in the center of the cell (*equatorial plane).***

3. Anaphase II

- **In this phase, the spindle fibers begin to shortening to separate the sister chromatids.**
- **Then, the sister chromatids are pulled toward the centrosomes to which they are attached.**

Cell division

Meiosis division: <u>Meiosis II</u>

4. Telophase II

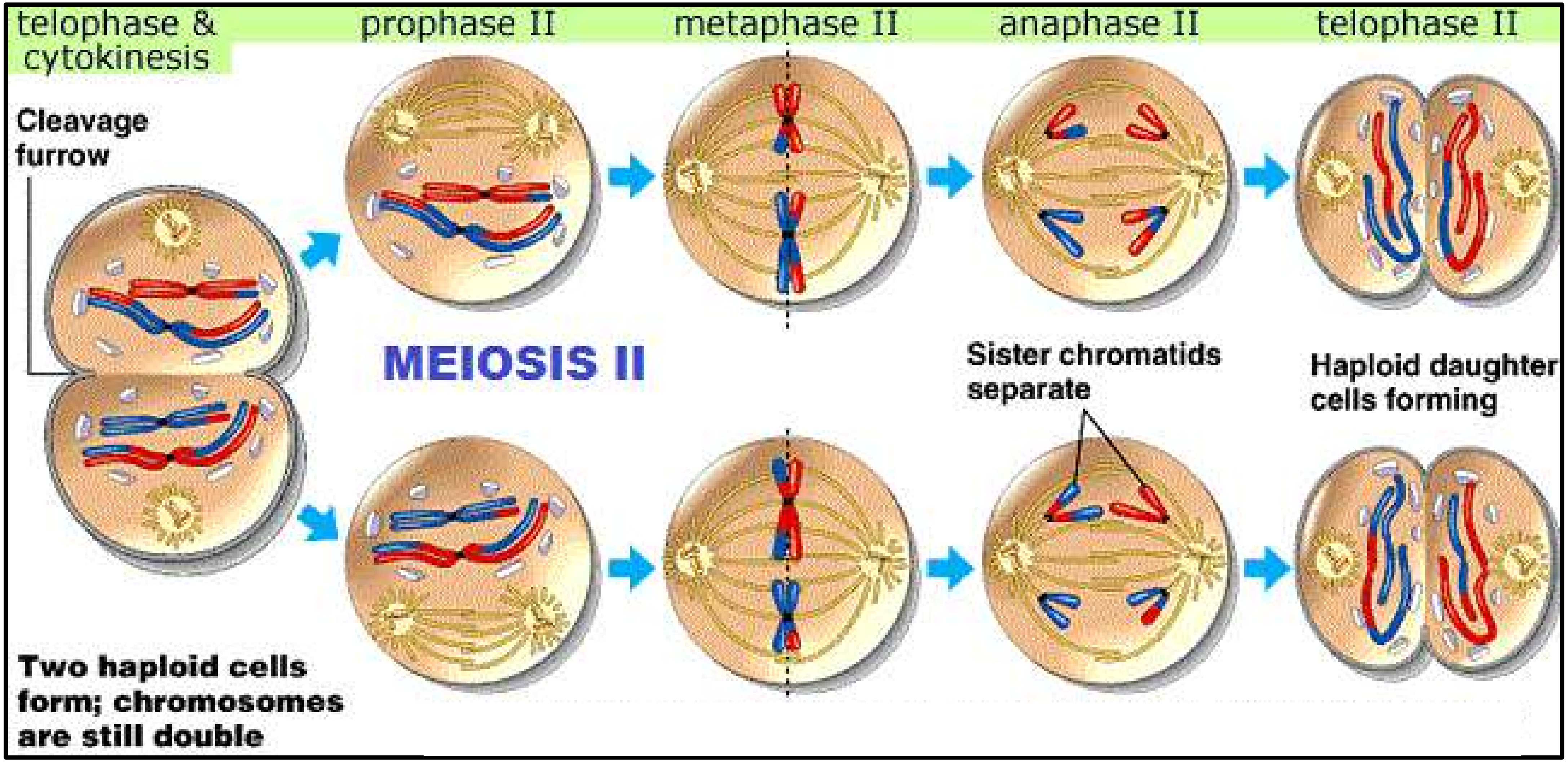
- It is the reverse of prophase II in which the spindle fibers and kinetochores disappear.
- The nuclear envelope reforms and the nucleolus appears.
- Chromatids uncoil into chromatins.
- Then, this step is followed by cytokinesis process.

NOTES:

- The final result of meiosis process is production of four haploid cells.
- The cells are genetically different due to homologous recombination.
- These haploid cells develop to gametes (sperm and ovum).

Cell division

Meiosis division: <u>Meiosis II</u>



Cell division

Sexual reproduction

- In asexual reproduction like mitosis division in eukaryotes, a single cell is considered as a parent cell which divides into two daughter cells having the exact copy of DNA.

- In sexual reproduction, two parent cells give rise to offspring that have a combination of genes from the two parent cells.

- Sexual reproduction is a process which includes both gametogenesis and fertilization to create new genetically different cells from their parents.

- Fertilization is the process by which the haploid sperm cell fuses with the haploid ovum cell to produce a zygote (diploid cell), then the zygote cell divides by mitosis process to grow up.

- Diploid cell (2n) is a cell that has two copies of each chromosome (homologous chromosomes), one from the mother and one from the father. Example: Somatic cells which are all body cells except gametes.

- Haploid cell (n) is a cell that has one set of chromosomes. Example: Gametes (sperm and ovum).

Cell division

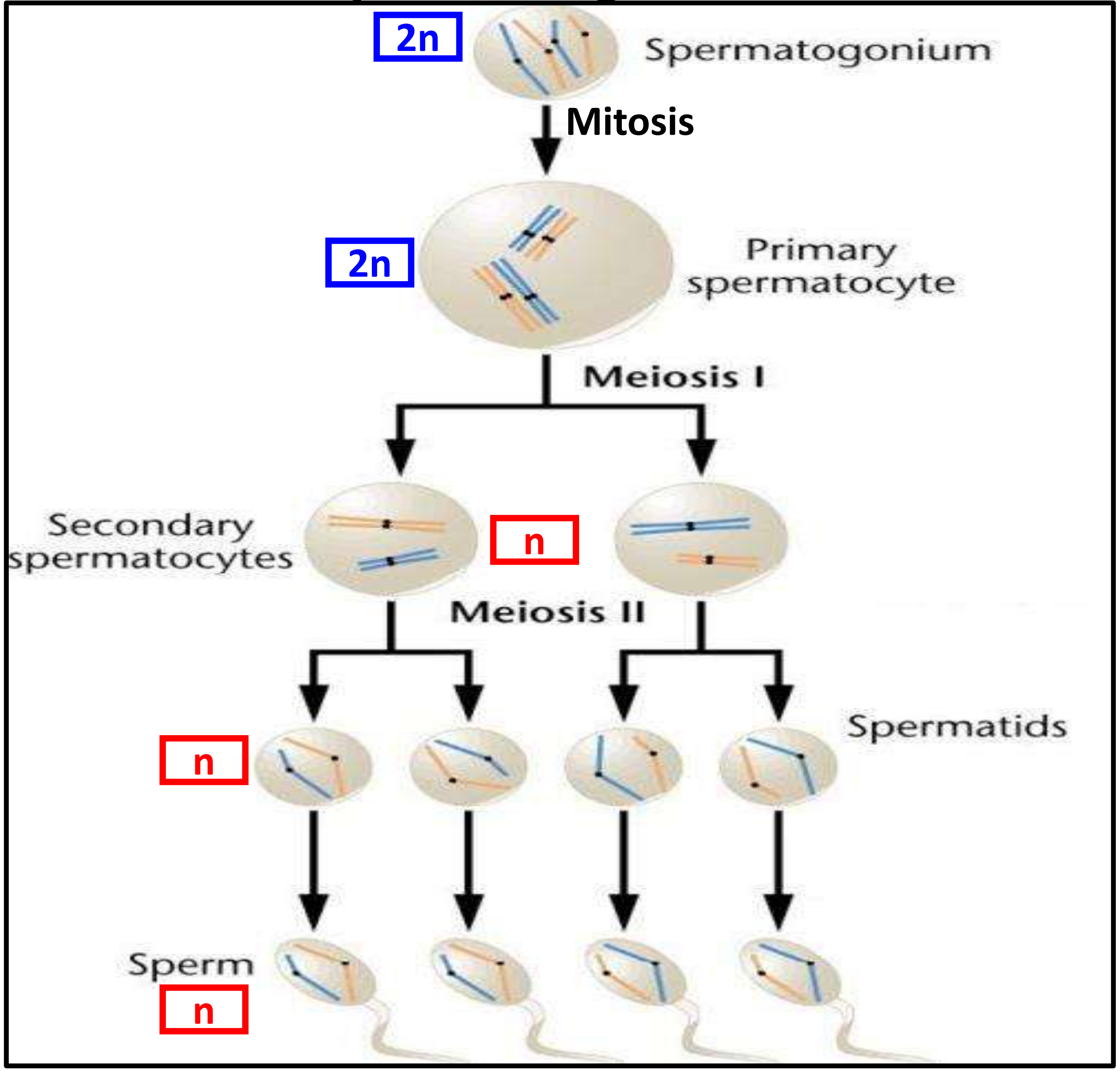
Sexual reproduction and meiosis division

- **Gametogenesis is the production of gametes from germ-line cells by meiosis division only.**
- **The only cells in human body not produced by mitosis division are gametes.**
- **Gametes are haploids as sperm, ovum, and pollen grain.**
- **Gametogenesis includes both spermatogenesis and oogenesis.**

a. Spermatogenesis

- **It is the process by which sperm cells are produced from male germ-line cells in the testes.**
- **The initial cells in this pathway are called spermatogonia, which yield primary spermatocytes by mitosis.**
- **The primary spermatocyte divides into two secondary spermatocytes by meiosis I, then each secondary spermatocyte divides into two spermatids by meiosis II. Then the spermatids develop into mature sperm cells (haploid).**
- **Finally, each one spermatogonium (2n) produces four sperms (n).**

Spermatogenesis



Cell division

b. Oogenesis

- It is the process by which ovum cells are produced from female germ cells in the ovary.
- The initial cells in this pathway are called oogonia, which lead to primary oocytes by mitosis.
- The primary oocyte divides into a secondary oocyte and the first polar body by meiosis I.
- The secondary oocyte divides into an ootid and secondary polar body by meiosis II, and then the ootid develops into mature ovum (haploid).
- Finally, each one oogonium (2n) produces one ovum (n).