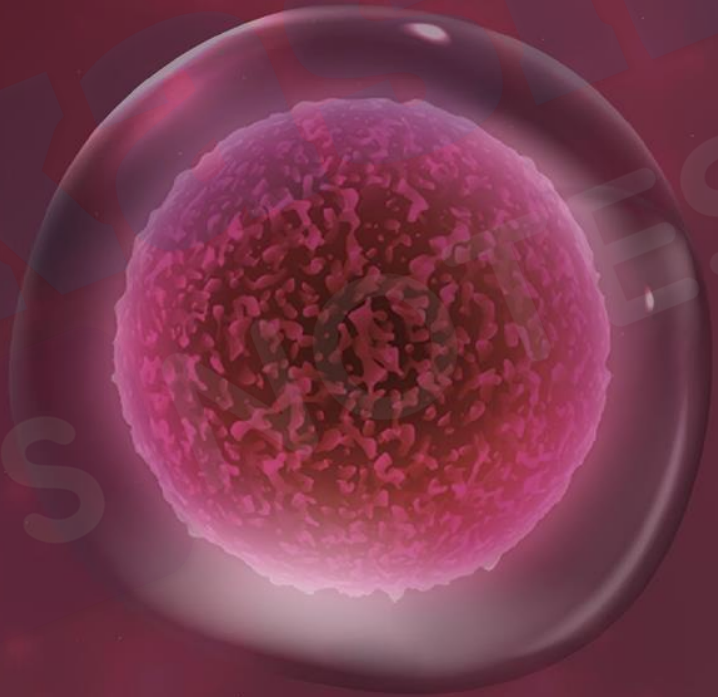
Aakash + BYJU'S NOTES

Cell Cycle and Cell Division



Key takeaways

1. Cell and cell division
2. Cell cycle
3. Phases of cell cycle
4. Interphase
   - G_1 phase
   - S phase
   - G_2 phase
   - G_0 phase
5. Cell cycle checkpoints: Interphase
   - G1/S Checkpoint
   - G2/M Checkpoint

Key takeaways

6. Mitosis phase
7. Stages of karyokinesis
   - Prophase
   - Metaphase
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8. Cytokinesis
   - Cell furrow formation
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9. Significance of mitosis
10. Regulation of cell cycle

Key takeaways

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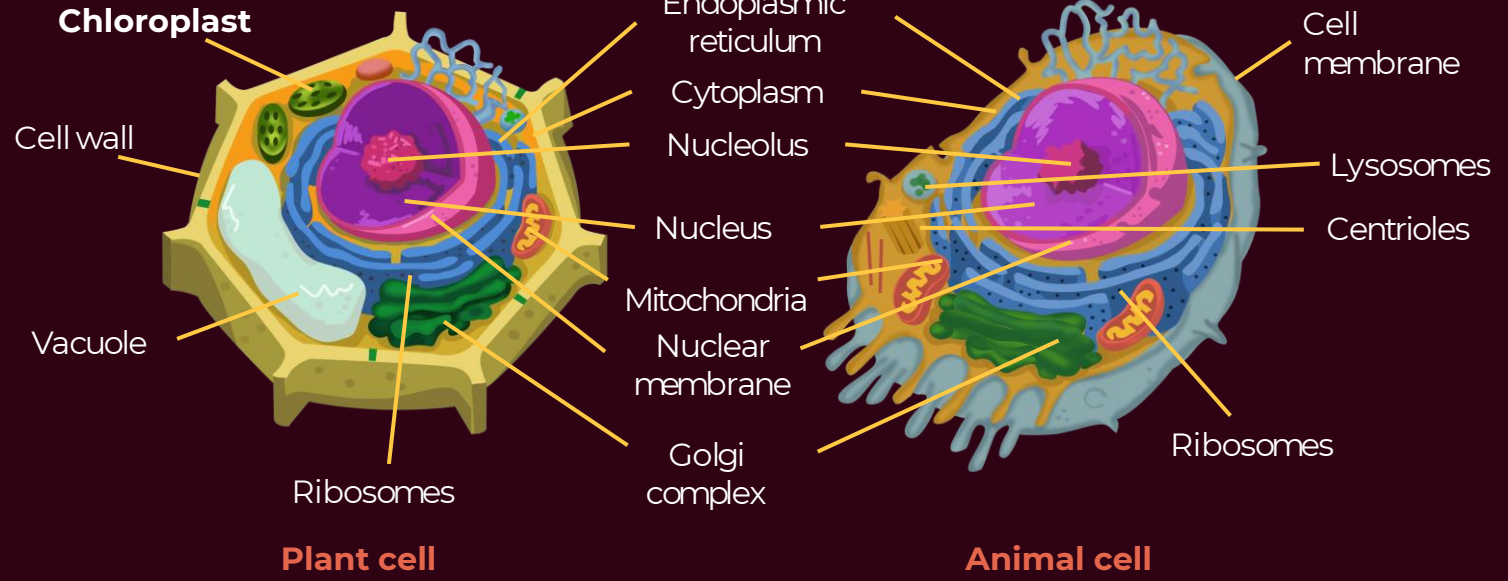
Summary

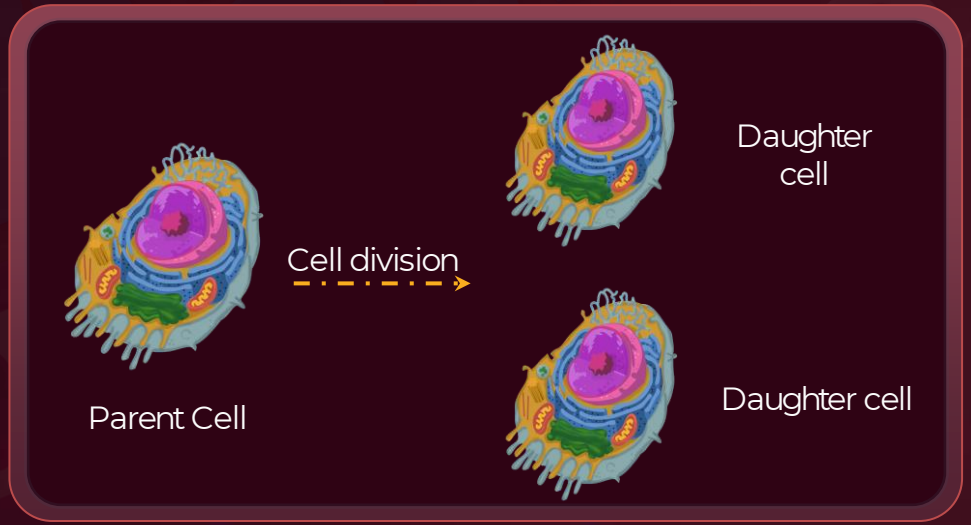
Cell

- **Cell** is the basic structural and functional unit of life.
- All living organisms are made of cells.



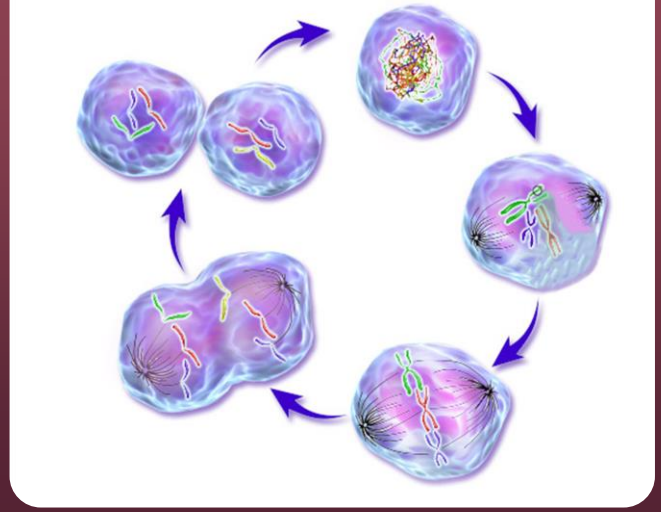
Cell Division

- **Cell division** is a process by which a parent cell divides into two daughter cells.
- Cell division is responsible for the following:
  - Wound healing
  - Regeneration
  - Growth and development



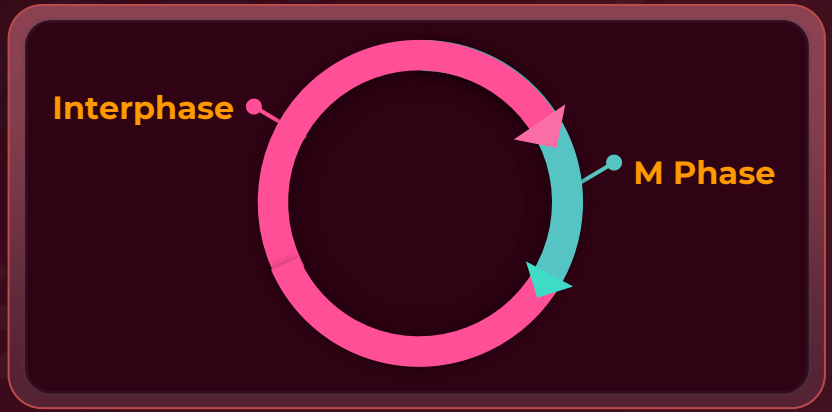
Cell Cycle

- 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.**
- During the growth of a cell, **the cell organelles duplicate,** and **DNA replication** takes place.
- Cell growth results in disturbing the ratio between the nucleus and the cytoplasm.
- Therefore, it becomes essential for the cell to divide and restore the **nucleo-cytoplasmic ratio.**



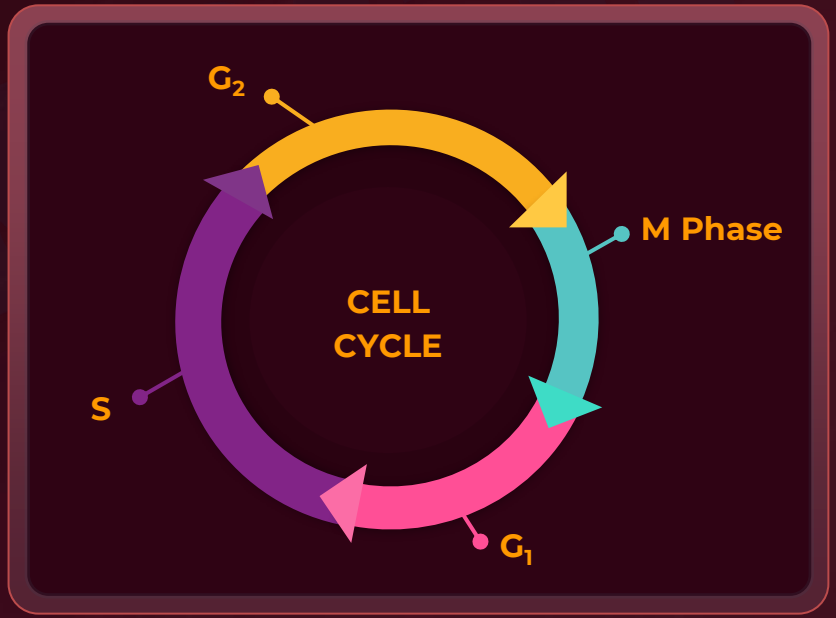
Phases of Cell Cycle

- Cell cycle consists of two basic phases
  - **Interphase**
  - **M Phase (Mitosis phase)**
- **Interphase** is the phase between two successive M phases, where the cell prepares itself for cell division.
- **M phase** is the phase where actual cell division occurs.
- Period of cell cycle varies from organism to organism.
- A **human cell** divides approximately every **24 hours.**
- A **yeast cell** divides every **90 minutes.**



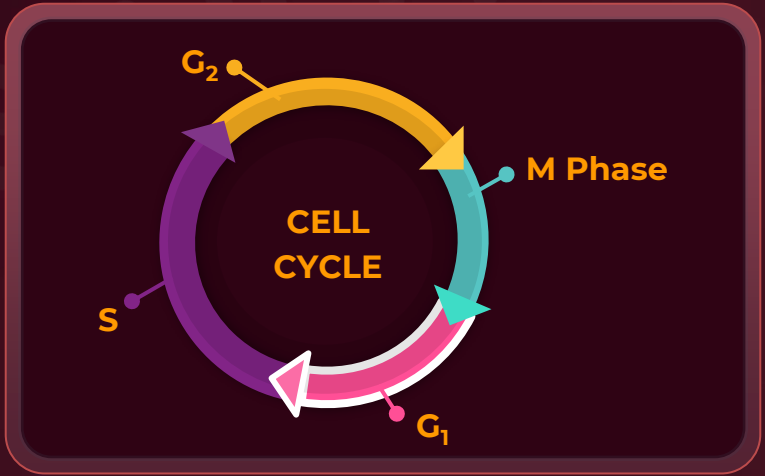
Interphase

- Interphase is the **most active phase** of the cell cycle.
- During this phase, **cell growth** and **DNA replication** takes place.
- It lasts for more than 95% of the duration of the cell cycle.
- It is also called as the **resting phase** as there is no apparent activity related to cell division.
- Interphase is further divided into 3 stages:
  - G_1 phase
  - S phase
  - G_2 phase



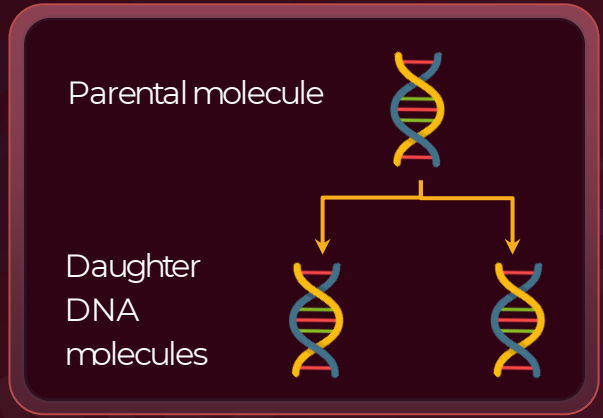
G_1 Phase

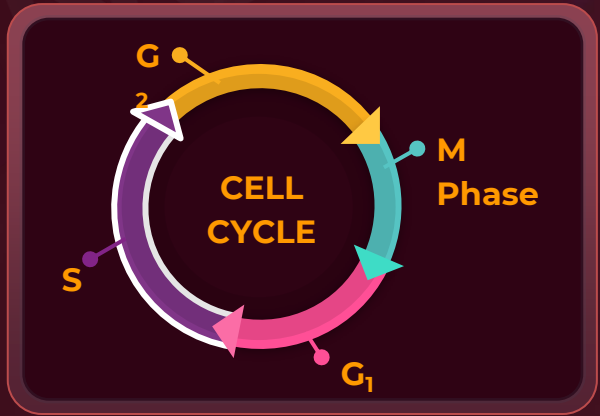
- G_1 phase or Gap 1 phase is the **longest phase** of interphase.
- It is present between mitosis and initiation of DNA replication.
- In this phase, the cell grows in size.
- Also, **active synthesis of RNA** and proteins takes place in this phase.
- The **cell organelles duplicate** during this phase.



S Phase

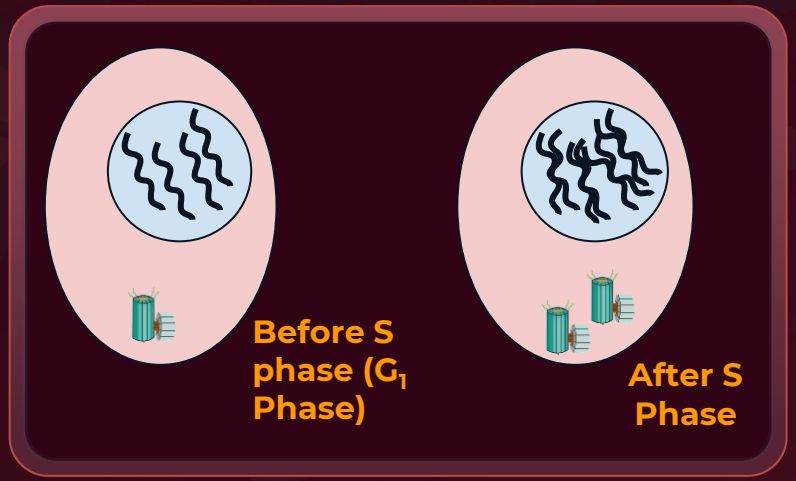
- The genetic material, in most of the organisms, is present as DNA in the nucleus.
- The DNA contains all the instructions required to build and run a cell down to the very minute detail.
- In S phase the DNA molecules are duplicated. This occurs through the process of **DNA replication**.
- **DNA replication** is the process of copying a DNA molecule to produce two identical DNA molecules.

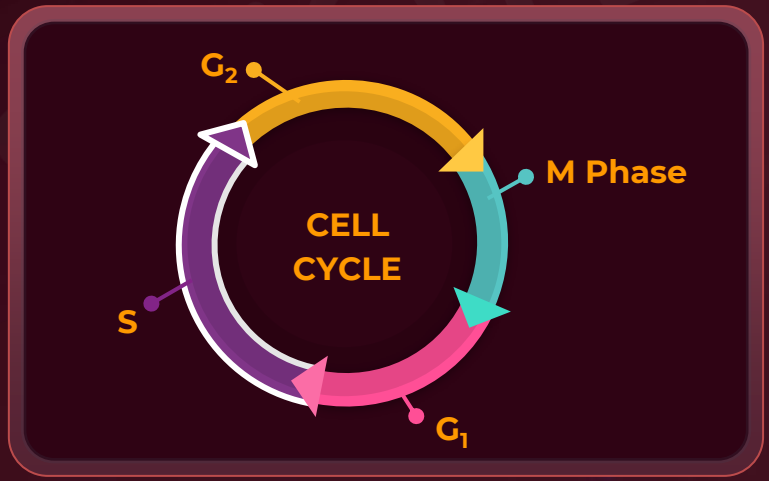




S Phase

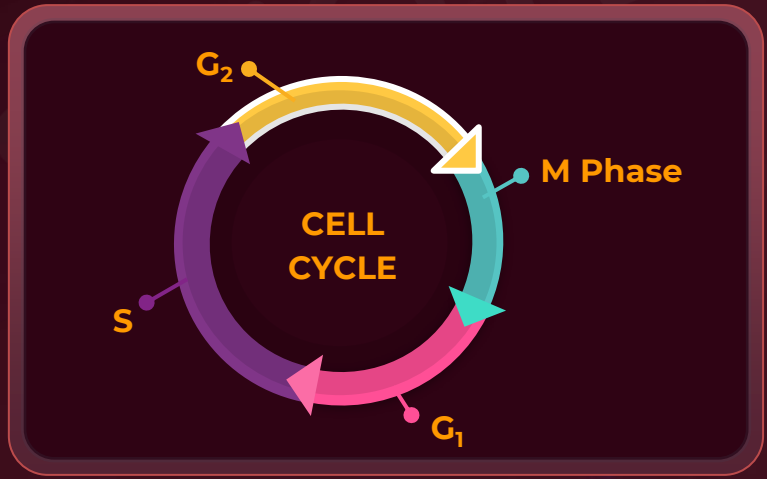
- Even though the DNA content gets doubled during the S phase, the **chromosome number remains the same** since the 2 copies of the DNA strand are still attached to each other.
- In animal cells, centrioles also duplicate in this phase.
- The centrioles help in distributing the duplicated genetic material equally.





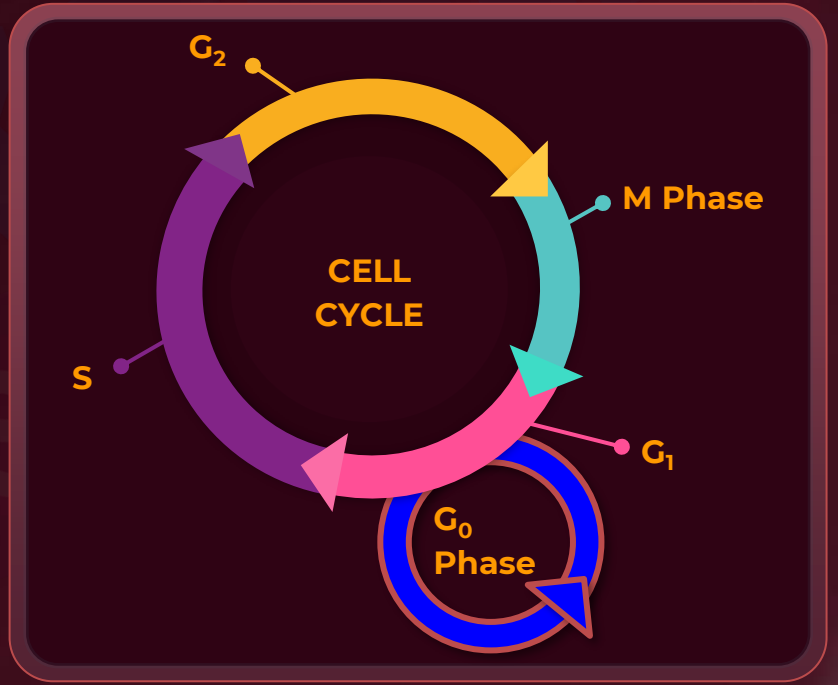
G_2 Phase

- G_2 phase or gap_2 phase is present in between S phase and M phase.
- **Mitochondria, chloroplast** and **Golgi bodies duplicate** in this phase.
- DNA synthesis stops at this phase.
- There is production of proteins required for the actual dividing phase.
- By the end of the G_2 phase, the cell is now ready for cell division.
- In animal cells, the mitotic division takes place only in the diploid somatic cells.
- In plant cells, mitotic division is seen both in diploid and haploid cells.

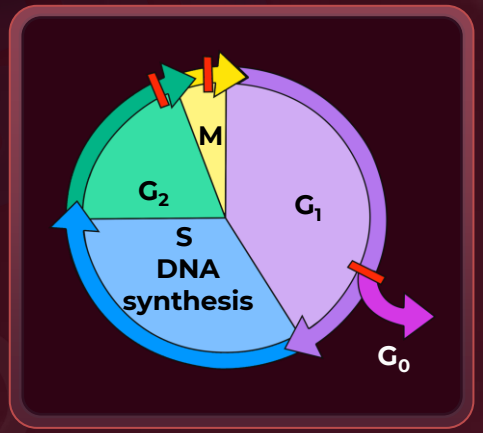


G_0 Phase

- G_0 phase is also called as **quiescent stage.**
- Cells that do not divide, exit from cell cycle in G_1 phase and enter into inactive G_0 phase.
- Some cells enter G_0 phase permanently and never divide again.
  - Examples: **Heart cells, nerve cells.**
- Cells that temporarily enter G_0 phase can enter G_1 phase and undergo division.
  - Example: **Cambial cells** that undergo division and help in **secondary growth** in plants.



Cell Cycle Checkpoints: Interphase



G_1/S checkpoint

- It is the **main checkpoint** for a cell to progress or halt cell cycle.
- It checks for nutrients, growth factors, DNA damage
- If conditions are not favourable, the cell exits G_1 phase and enters G_0 phase.

G_2/M checkpoint

- Cell checks for DNA damage and ensures that DNA replication is done without errors.
- **G_2 checkpoint**, before M phase, **ensures that cell division proceeds** and **healthy daughter cells are formed.**
- If errors have occurred during DNA replication, then cell pauses allowing the cell to undergo repair.
- If errors are not rectified, then cell undergoes programmed cell death, where the cell's lysosomes release their hydrolytic enzymes to destroy itself.

Mitotic Phase

- The mitosis phase of the cell division phase includes two steps:

Mitosis phase

Karyokinesis

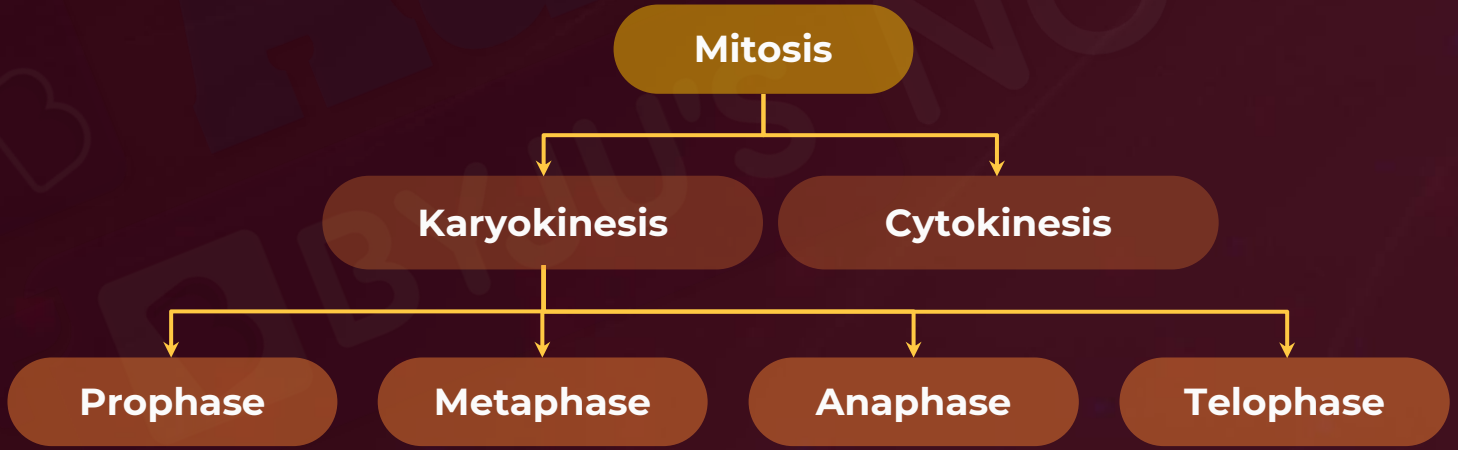
The replicated chromosomes separate and two nuclei are formed.
Following karyokinesis, the cytoplasm divides and this results in the formation of two daughter cells.
(**Karyon**- Nucleus, **Kinesis** - Movement)

Cytokinesis

Following the karyokinesis, the cytoplasm divides and this results in the formation of two daughter cells.
(**Cytos**- Cell/ Hollow, **Kinesis** - Movement)

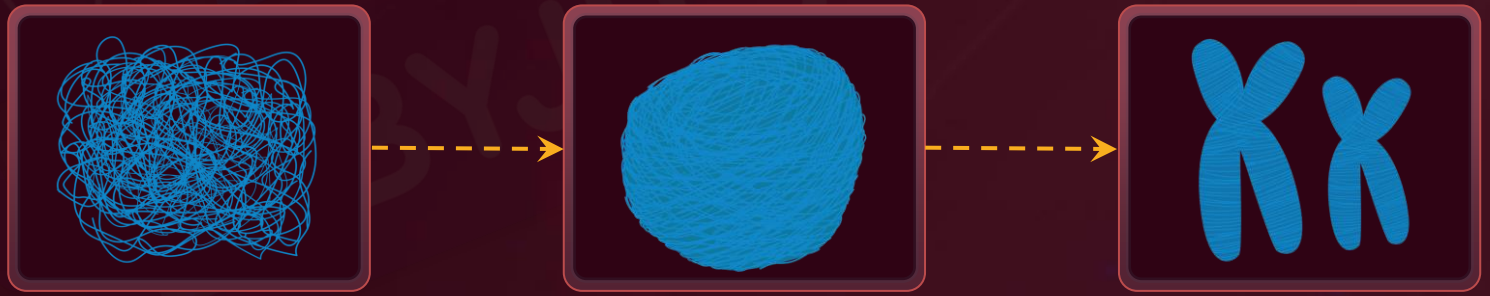
Mitosis Phase

- Mitosis was **first observed by Strasburger** in **plant cell** and by **Walter Flemming** in **animal cell.**
- The term **mitosis** was given by **Walter Flemming**.
- A type of cell division that produces:
  - Two similar daughter cells
  - Having the same number of chromosomes as parent cell.



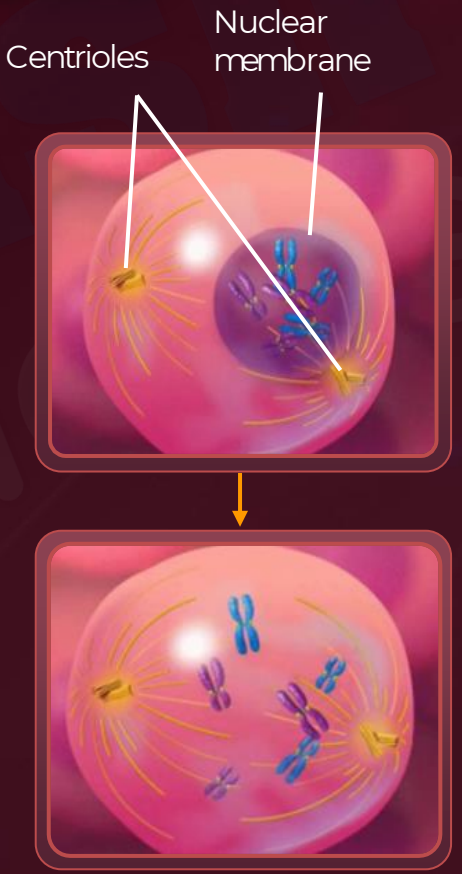
Stages of Karyokinesis: Prophase

- Prophase is the **first phase** of karyokinesis.
- It is the longest phase in terms of the time taken for completion.
- The chromatin fibres start condensing during the early prophase and form a condensed mass.
- Since, it resembles a condensed ball of wool, early prophase is also known as the **spireme stage** (tangle or coil of filament).
- By the late prophase, they further condense to form the chromosomes.



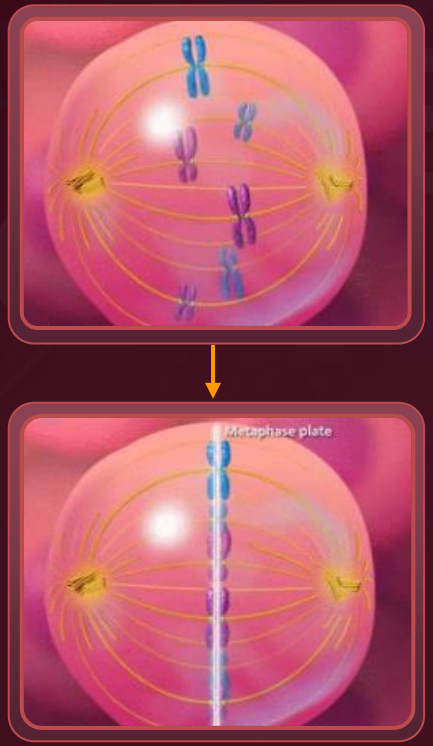
Stages of Karyokinesis: Prophase

- During prophase the **nuclear membrane degenerates** and the **nucleolus disappears**.
- If nuclear membrane disappears during the mitosis, it is called **eumitosis** and if the nuclear membrane remains intact it is called **premitosis**.
- **Disintegration** of **endoplasmic reticulum** and **Golgi apparatus** also takes place.
- The centrosomes with replicated centrioles start moving towards the opposite poles.
- Each centrosome radiates microtubules known as **asters**. Aster rays help the centrioles to hold their place in the cytoplasm.
- In animal cells, mitosis is called **amphiastral**. In plant cells, it is called **anastral**.
- The centrioles form spindle fibres.



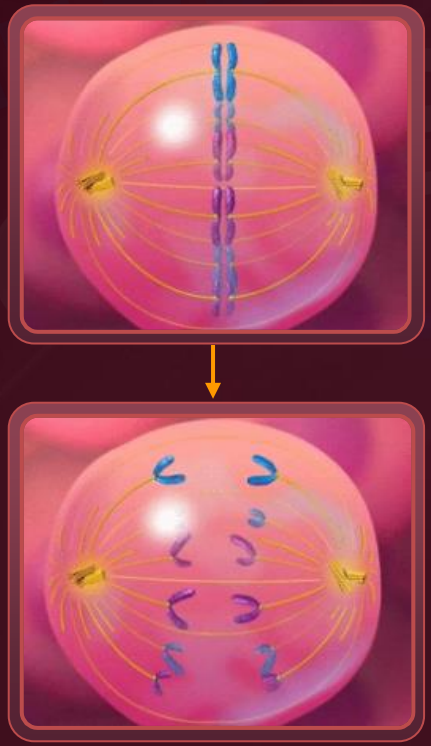
Stages of Karyokinesis: Metaphase

- The complete degradation of the nuclear membrane marks the start of metaphase.
- The chromosomes come to lie at the **equatorial plate** (equidistant from the two poles). This process is known as **congression**.
- Congression occurs with the assembly of the mitotic spindle that mediates the microtubule-chromosome interactions required for the movement of chromosomes.
- The centromere is surrounded by a small disc shaped structure called **kinetochore**. The kinetochore form the **site of attachment** of **microtubules**.
- Chromosomes are observed to be the **thickest** and the **shortest** at this stage.



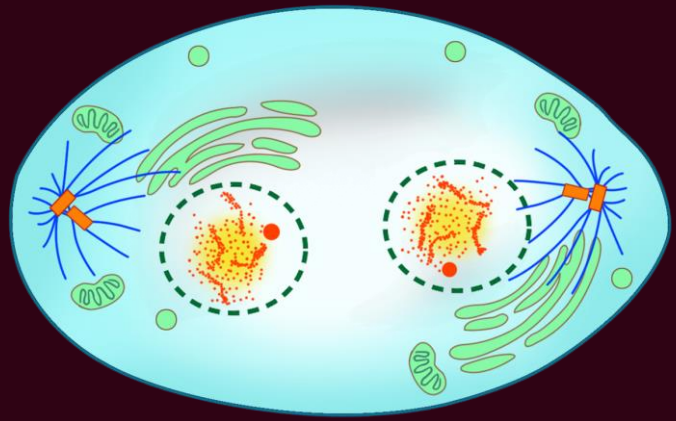
Stages of Karyokinesis: Anaphase

- The **centromere splits**.
- The **sister chromatids separate** into two identical and independent chromosomes.
- Each chromatid now has its own centromere.
- The spindle fibres pull the chromatids along with the centromere towards their respective poles.
- The **chromatids move to opposite poles**.
- Half of them reach one pole and the other half reach the other.
- During migration, **the centromere of chromosomes face towards the poles**. The chromatids or **arms of chromosomes trail behind**.



Stages of Karyokinesis: Telophase

- Chromosomes cluster at opposite poles.
- They start **decondensing into chromatin fibres** and their individuality is lost as discrete elements.
- The **nucleolus, ER, and Golgi apparatus reappear**.
- The nuclear envelope develops around the chromatin at each pole, forming two daughter nuclei.



Formation of two daughter nuclei during telophase

Cytokinesis

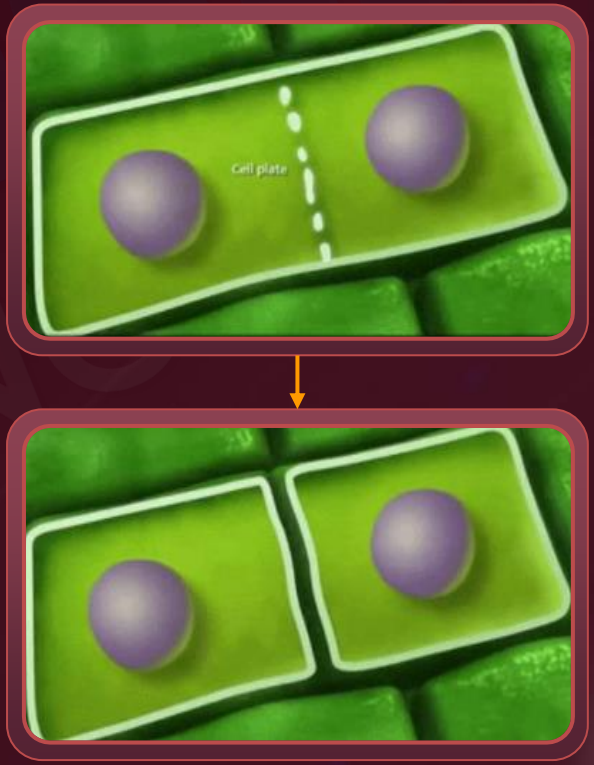
Cell furrow formation

- In **animal cells**, cytokinesis is achieved by the formation of a furrow.
- **Furrow appears** in the plasma membrane and deepens towards the centre in a **centripetal fashion**.
- Furrows from both the sides join at the centre, dividing the cytoplasm into two.
- The formation of cell furrow is aided by microfilaments and microtubules.

Cytokinesis

Cell plate formation

- In **plant cells**, wall formation starts at the centre of the cell and grows outwards.
- The formation of the new cell wall begins with the formation of a **cell plate**.
- **Fragments from the Golgi complex (phragmoplast),** which are known as **vesicles**, fuse together to form cell plates.
- The cell plate is laid in a **centrifugal manner**.
- The cell plate represents the middle lamella between the walls of two adjacent cells.
- Mitochondria and plastids get distributed between the two daughter cells.



Significance of Mitosis

- **Growth:** Mitosis causes growth and development in multicellular organisms.
- Plants can grow from a tiny zygote to huge organisms due to mitosis.
- Helps in maintenance of proper **surface area to volume ratio of a cell**
- **Repair:** The old and worn-out cells are replaced by new cells.
- **Reproduction:** Unicellular organisms reproduce (multiply) through mitosis.
- In unicellular organisms, replication of cells is synonymous with growth.
- **Regeneration:** Mitosis causes cell growth that causes the revival of the lost body parts in animals such as starfish, planaria, the tail of a lizard, etc.

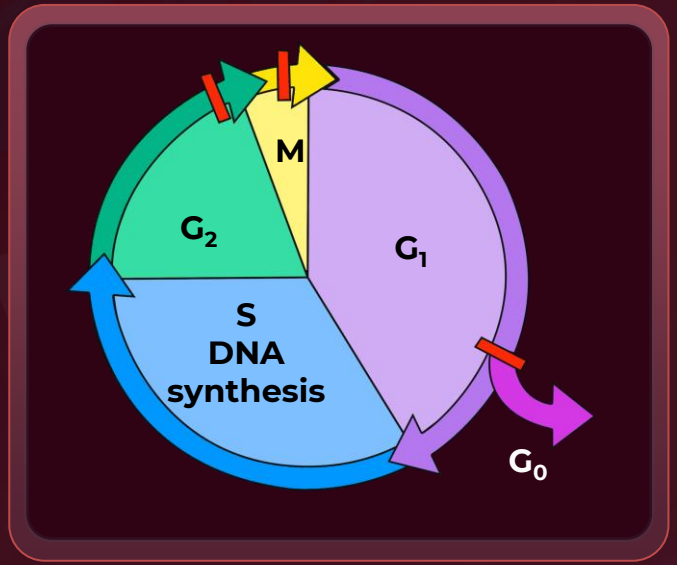
Regulation of Cell Cycle

Metaphase checkpoint

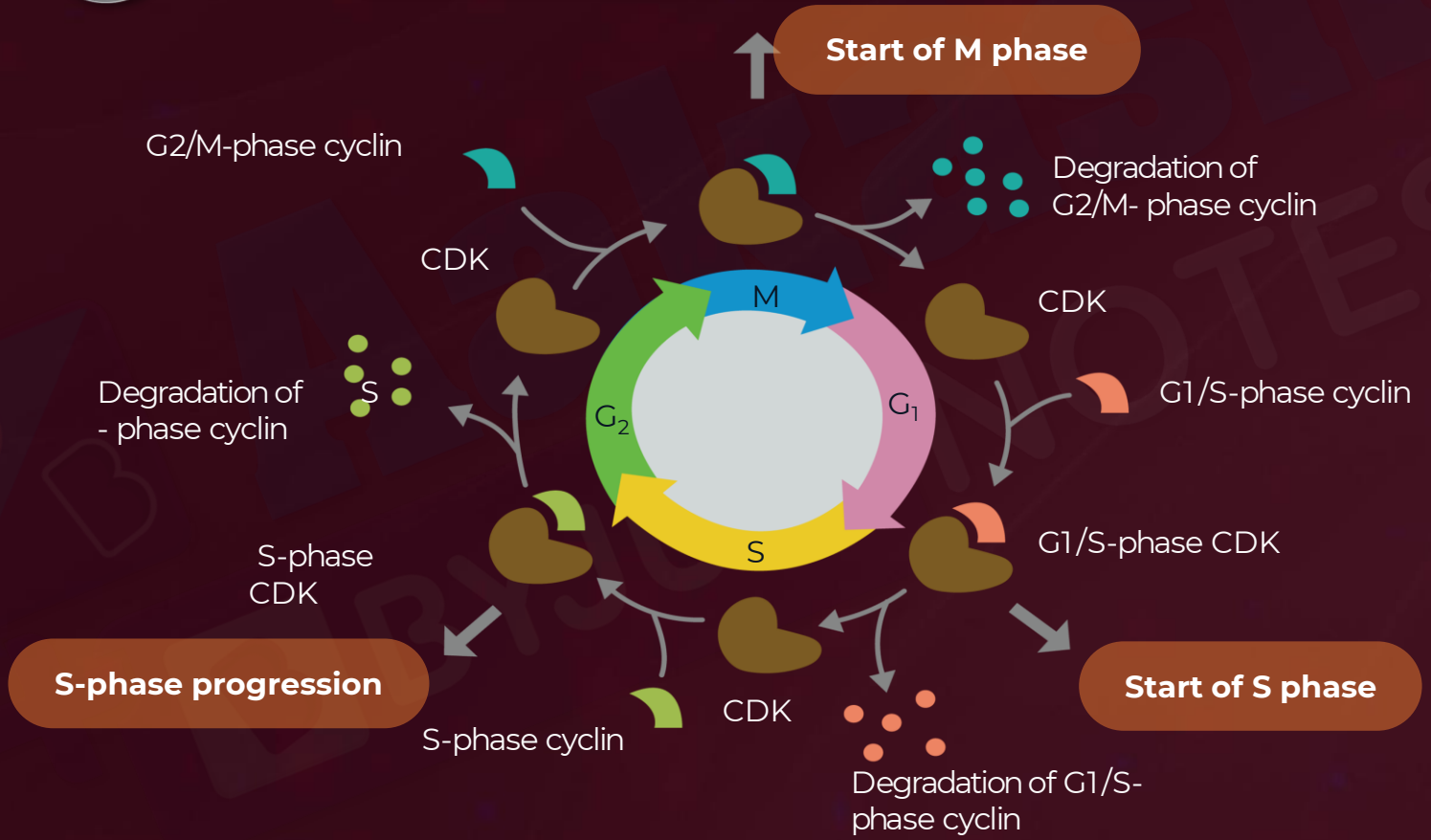
- Checks for **chromosome spindle attachment.**

Regulation of cell cycle

- **Cyclins** are proteins that bind to and activate the **cyclin-dependent kinases** (CDK's).
- Cyclin-CDK complexes control the progression of a cell from one phase to the next phase of the cell cycle.
- A stage-specific cyclin binds to a CDK and takes the cell through a checkpoint.
- To move to the next phase, the previous cyclin is degraded and a new cyclin specific for the next stage binds to CDK, and the cell progresses into the next phase.

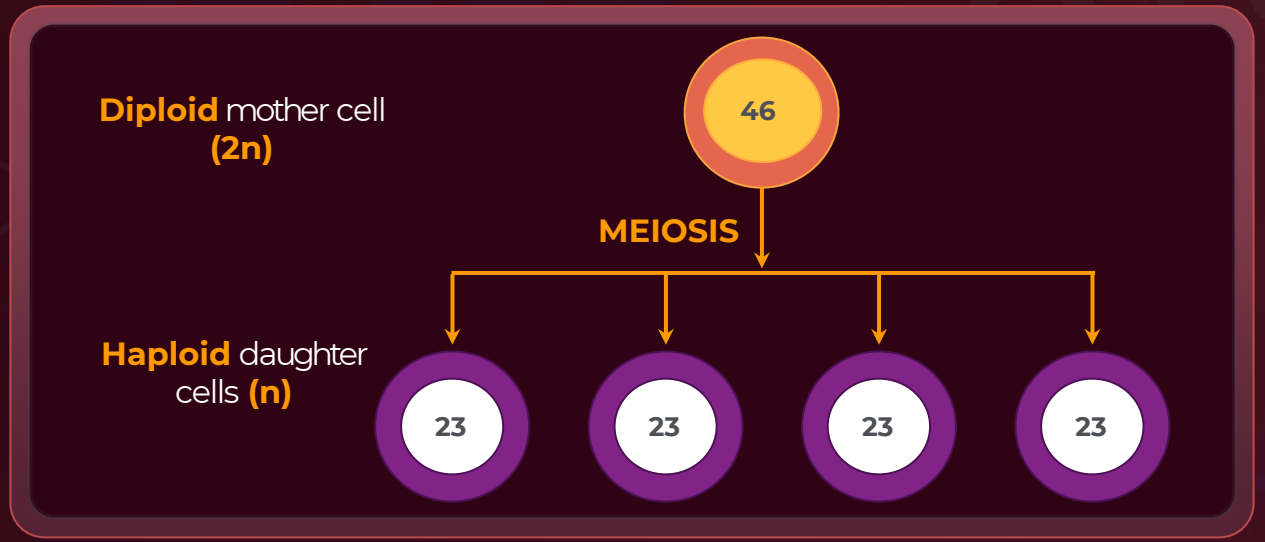


Regulation of Cell Cycle



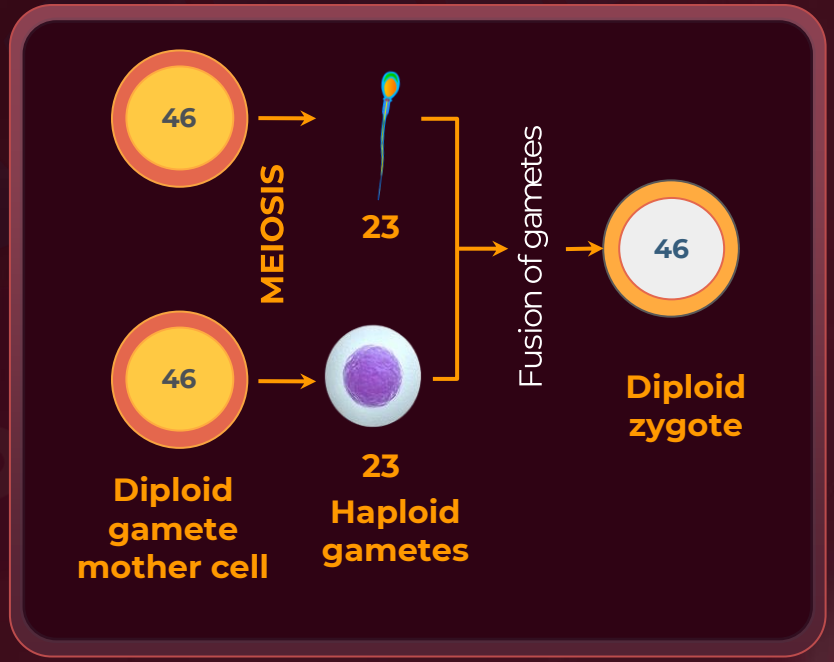
Meiosis

- The term meiosis was coined by **Farmer** and **Moore in 1905**.
- Meiosis is the kind of cell division where the chromosome number is reduced to half in the daughter cells.
- It involves **two sequential cycles** of nuclear division but only **one cycle** of DNA replication.
- It is **reductional division** that occurs in diploid germ cells. The single cells divide twice to produce four cells. Each daughter cell contains half the amount of genetic information.



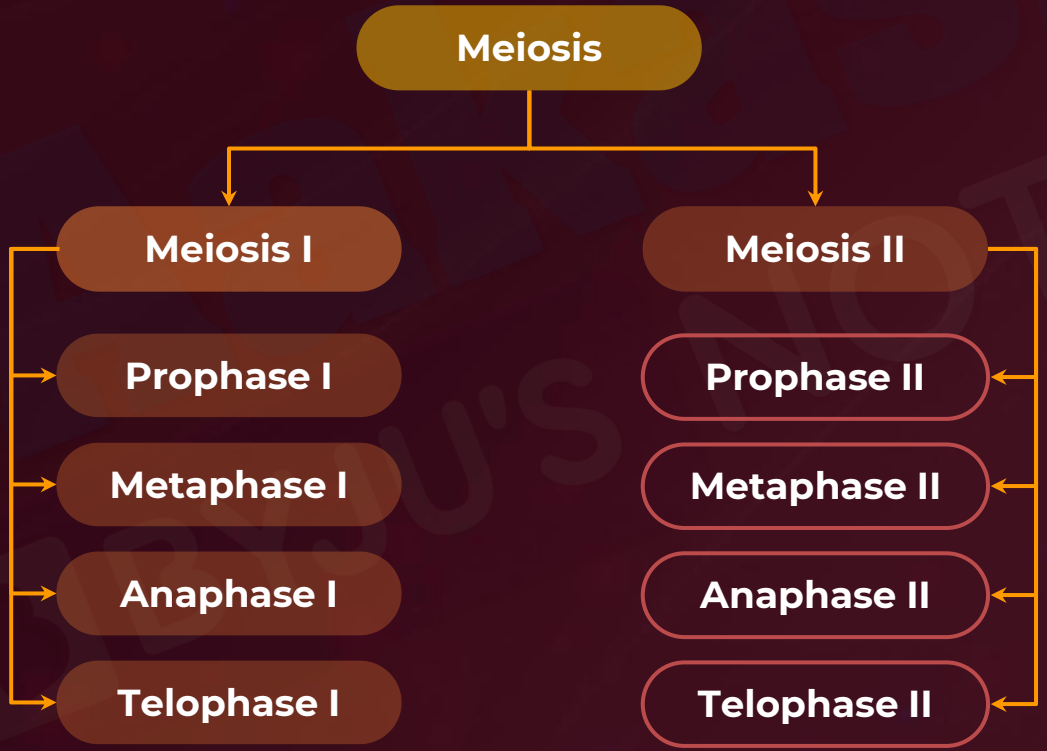
Meiosis

- **Germ cells** undergo meiosis to give rise to haploid gametes.
- **Gamete formation** happens by **meiosis** instead of mitosis.
- It ensures that gametes are haploid.
  - Parent cells in humans have two pairs of chromosomes, i.e., 23 + 23 chromosomes. They are diploid.
  - After meiotic cell division, the four daughter cells formed have only half the number of chromosomes, i.e., 23 chromosomes.
  - Such cells with only half the set of chromosomes are known as haploid cells.
  - Haploid cells are denoted by 2n/2 = n
- After fertilisation, the diploid phase is restored.



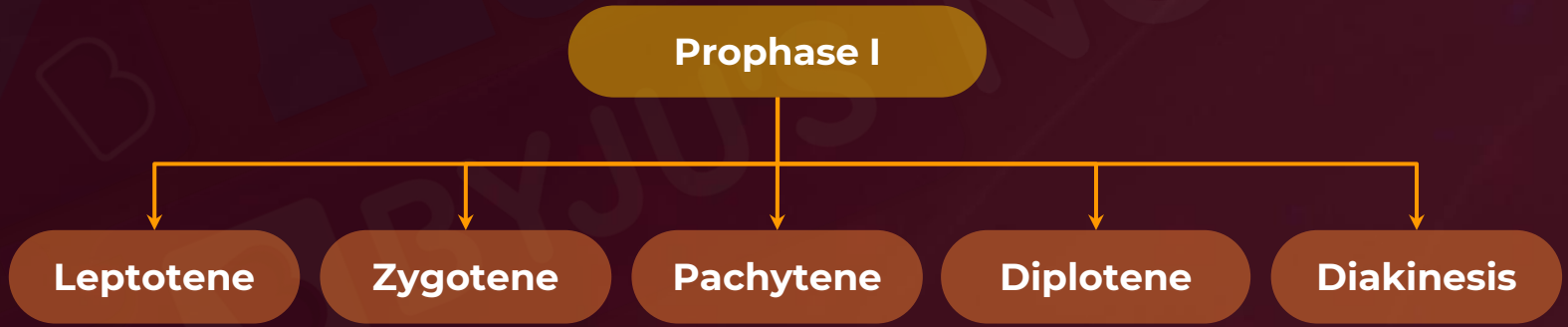
Steps of Meiosis

- Meiosis involves two sequential cycles:



Meiosis I

- Meiosis -I is initiated after the parental chromosomes have replicated to produce identical sister chromatids in the S phase.
- It is longer and more complex when compared to the prophase of mitosis.
- Unlike mitosis, meiotic prophase I has **five substages** based on the chromosomal changes in the nucleus.



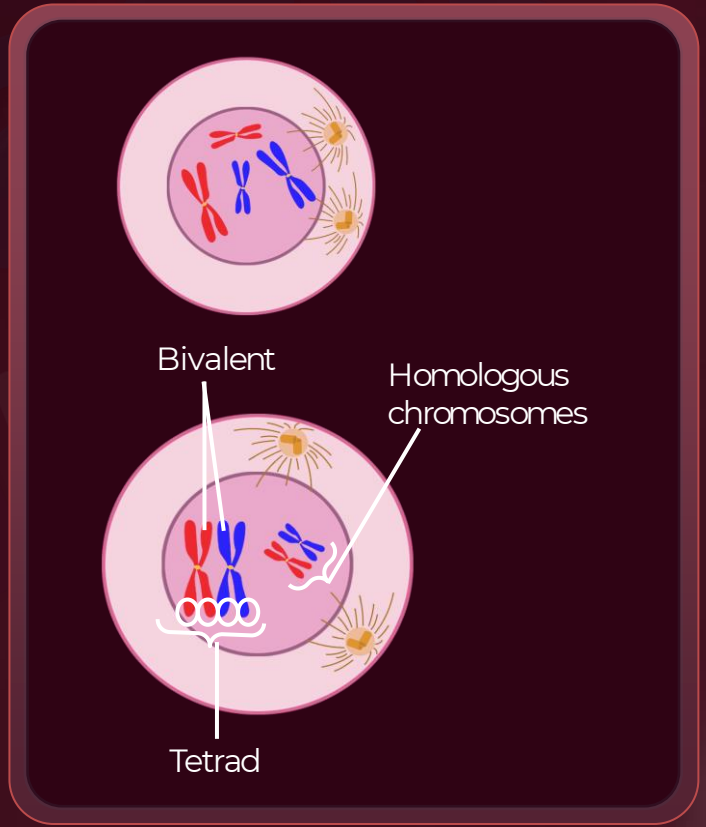
Prophase-I

Leptotene (Bouquet stage)

- Leptotene is the '**thin thread**' stage.
- Chromatin fibres start condensing.
- Chromosomes become gradually visible under light microscope.

Zygotene

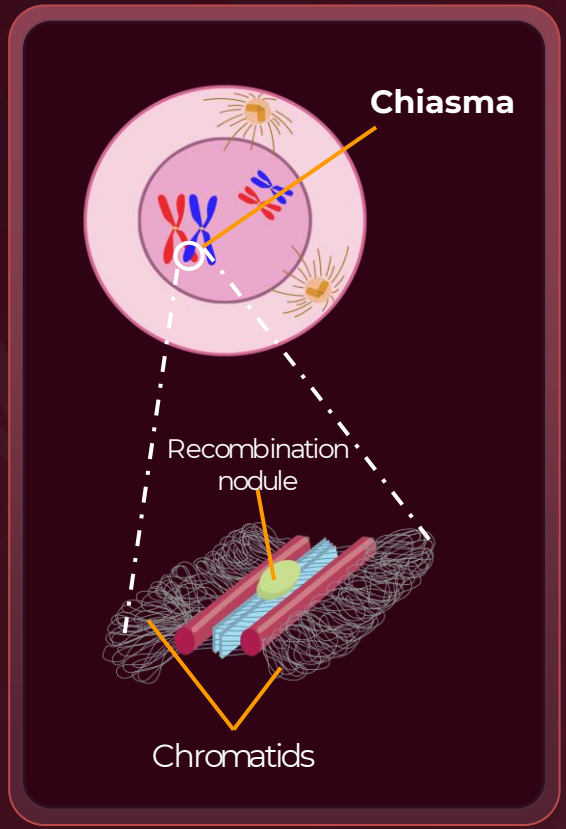
- Zygotene is the **paired thread** stage.
- The two chromosomes which are similar in form, size and structure are called **homologous chromosomes**.
- Homologous pairs come together to form a **synaptonemal complex**.
- The homologous chromosomes come to lie side by side in pairs and this pairing is known as **synapsis**.
- The pair of synapsed chromosomes is known as the **bivalent** or **tetrad**.



Prophase-I

Pachytene

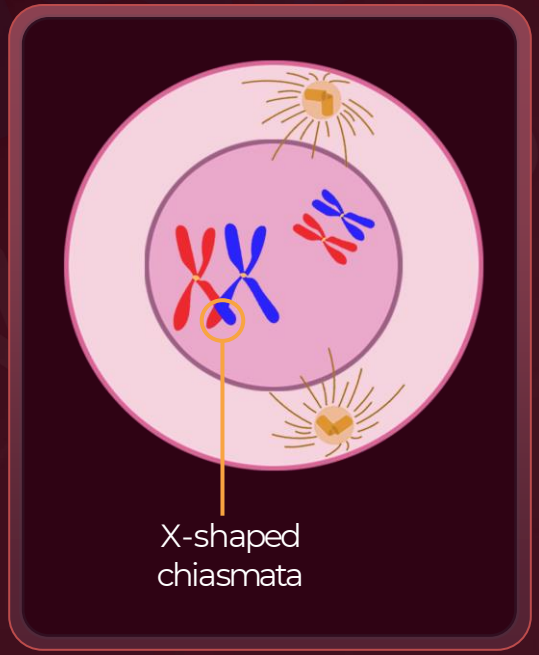
- Pachytene is the '**thick thread**' stage, as the synapse chromosomes appear thick.
- **Bivalent chromosomes** are clearly **visible**. They appear as tetrads.
- By the end of pachytene, the recombination between the homologous chromosomes is complete and the t**wo chromatids are linked** at the **site of crossing over.**
- **Recombination nodules** appear on the **non-sister chromatids** of **homologous chromosomes.**
- The exchange of genetic material between the non-sister chromatids of homologous chromosomes takes place, which is also known as **crossing over**.
- Recombination is catalysed by enzyme **recombinase**.



Prophase-I

Diplotene

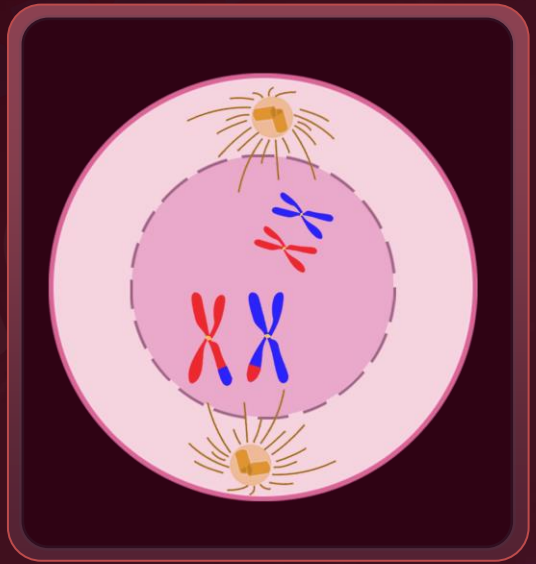
- Diplotene is the '**twin thread**' stage.
- In this stage, **dissolution of the synaptonemal complex** occurs.
- The homologous chromosomes start separating i.e. **desynapsis occurs**.
- Recombined homologous chromosomes separate from each other at all sites except at the site of crossover.
- **X-shaped chiasmata** is observed.
- In oocytes of some vertebrates, diplotene lasts for month or years. It is called **dictyotene stage**.
- Terminalisation of chiasmata starts in this stage.



Prophase-I

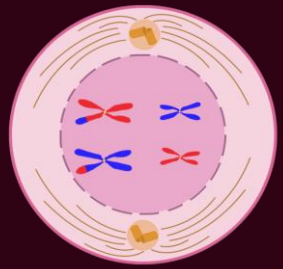
Diakinesis

- This is the last stage of prophase I.
- The chromosomes are fully condensed.
- **Termination of chiasmata** is observed.
- Spindle apparatus assembles.
- The nuclear membrane breaks down.
- Nucleolus also disappears.

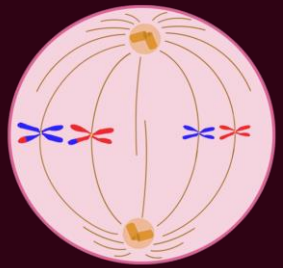


Metaphase- I

- As the early metaphase-I starts, the **microtubules** arise from the opposite spindle poles of the spindle apparatus.
- Microtubules are made up of tubulin protein.
- They provide both mechanical support and cell movement.
- As it enters late metaphase-I, bivalent chromosomes align on the **equatorial plate**.
- Microtubules from opposite poles attach to the homologous chromosomes.
- These microtubules attach to the **kinetochores** of the pair of homologous chromosomes.



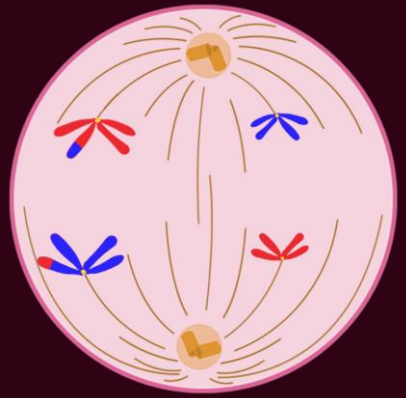
Early metaphase I



Late metaphase I

Anaphase- I

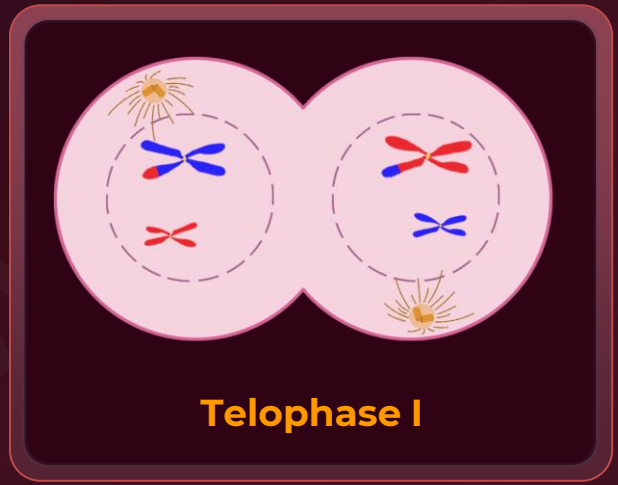
- In this phase, the **homologous chromosomes are separated**.
- The spindle microtubules pull the homologous chromosomes towards the opposite poles, respectively.
- The sister chromatids of the homologous chromosomes are associated with each other at the centromere.
- **Reduction in the number of chromosomes** occurs during anaphase- I



Anaphase I

Telophase- I

- Telophase- I is the final step of meiosis -I.
- The **chromosomes reach the poles**.
- The **spindle fibres completely disappear**.
- At this stage, the **nuclear membrane and the nucleolus reappear** after the homologous chromosomes have separated.
- It produces two daughter nuclei each containing half the number of chromosomes but double the amount of nuclear DNA.



Telophase I

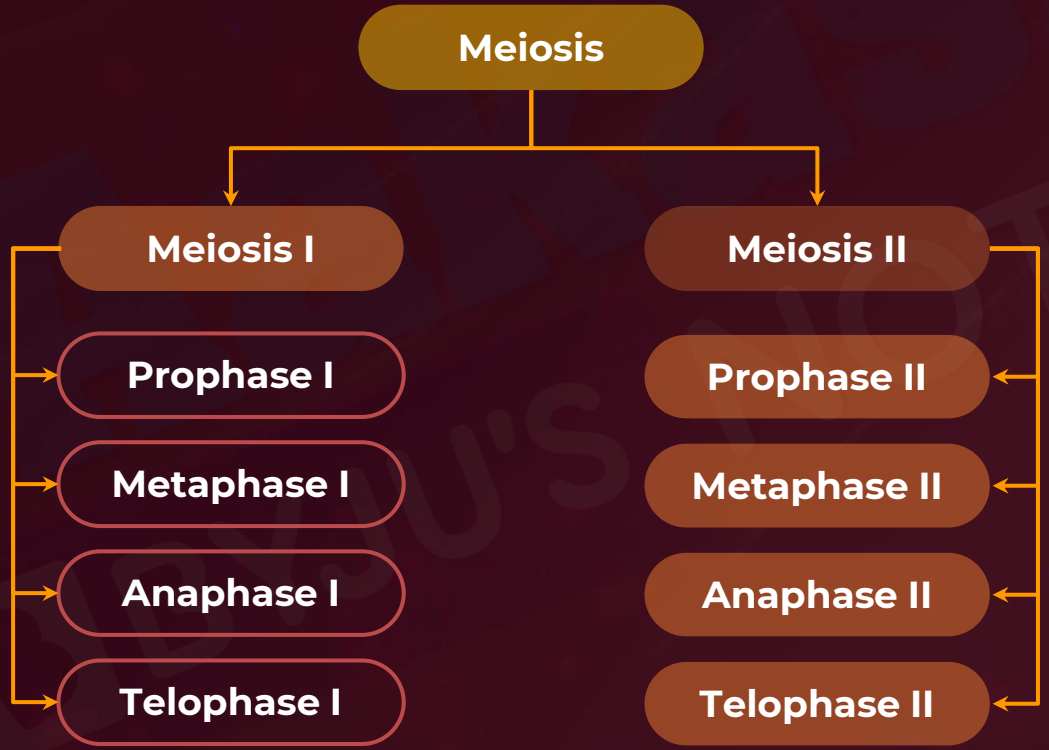
Cytokinesis

- Telophase I is followed by cytokinesis.
- Cytokinesis is the process where the cytoplasm is divided equally into daughter cells.
- The daughter cells formed at the end of meiosis have bivalent chromosomes, and this chromosome is also known as a **dyad** (one pair of chromosomes from the tetrad).

Interkinesis

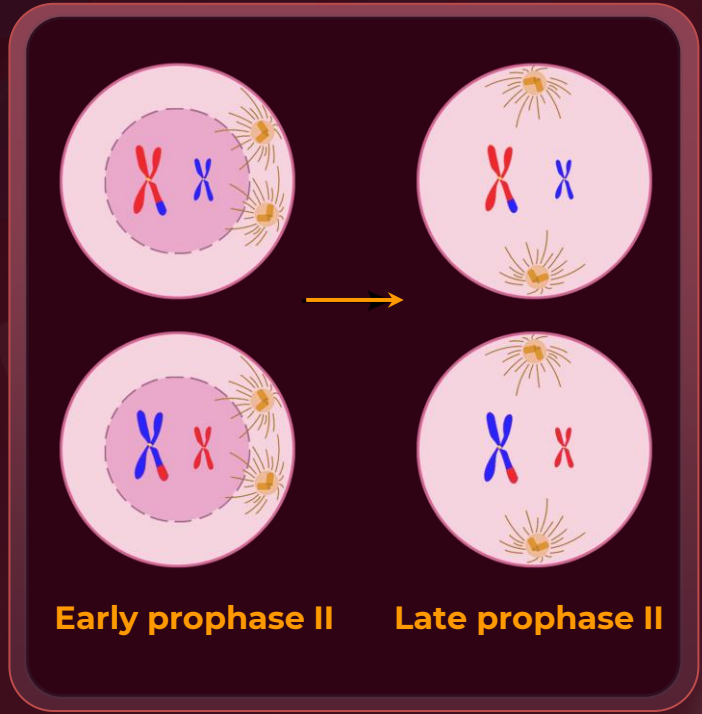
- It is a short-lived stage between meiosis I and meiosis II.
- During this phase, the chromosomes are elongated but do not form chromatin fibres.
- This stage has **no DNA replication**.
- The RNA and protein required during meiosis -II are synthesized during this phase.

Meiosis- II



Prophase II

- This phase is initiated after cytokinesis I and is simpler than prophase I of meiosis I.
- In early prophase II, the **nuclear membrane starts to disintegrate**.
- **Chromatin fibres begin to condense** to form chromosomes.
- As the cell enters late prophase II, the nuclear membrane disintegrates, and chromosomes become compact.
- The **centrioles also move towards the opposite ends**.



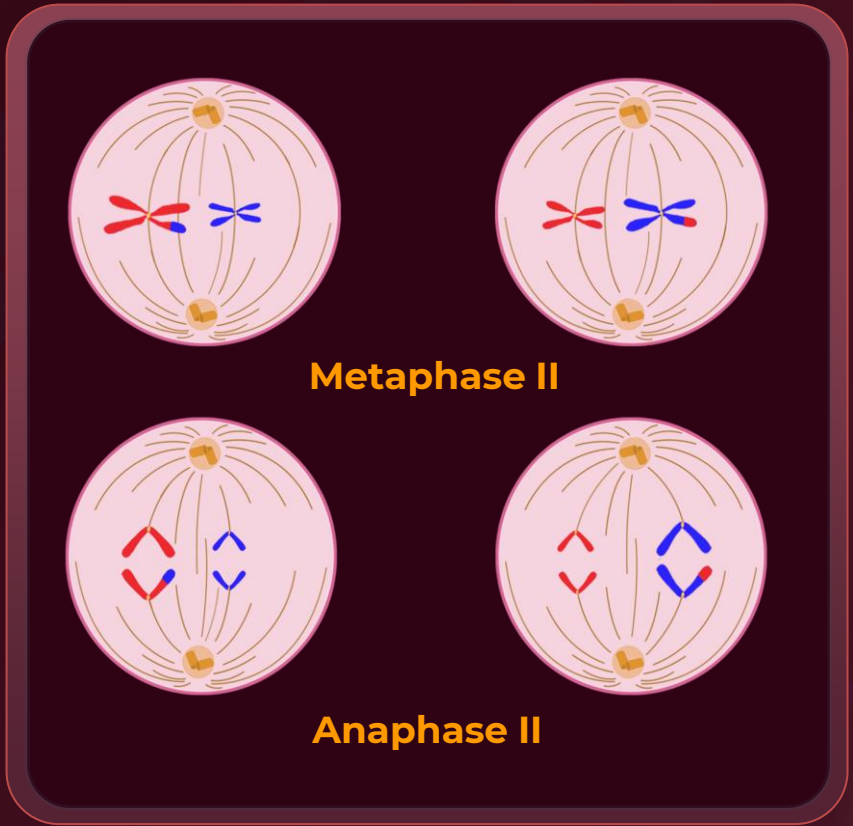
Metaphase II, Anaphase II

Metaphase -II

- Condensed chromosomes **align at the equatorial plate**.
- The microtubules of the spindle apparatus get attached to the sister chromatids at kinetochore.

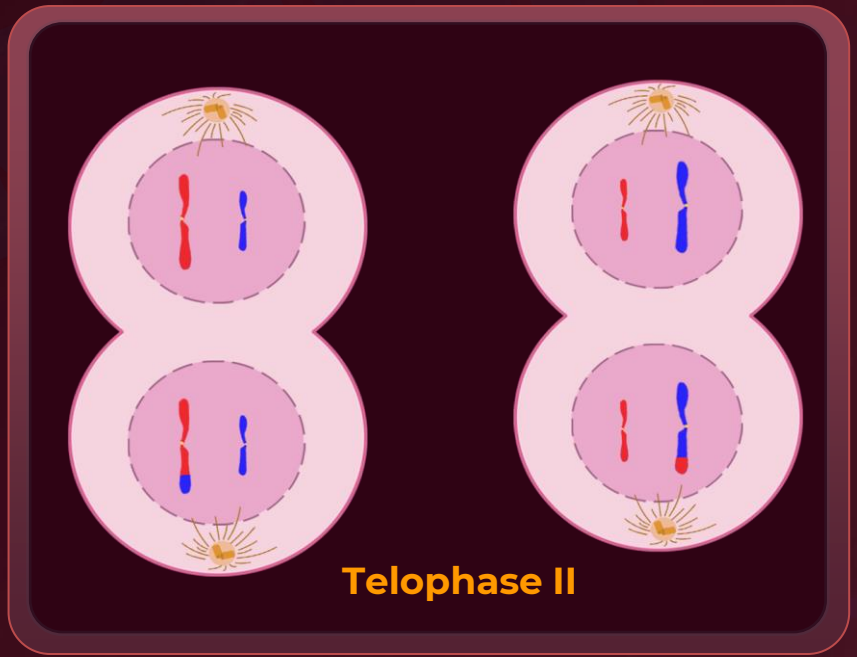
Anaphase-II

- The microtubules of the spindle pull the sister chromatids to the opposite poles.
- The **centromere of the sister chromatids splits**.



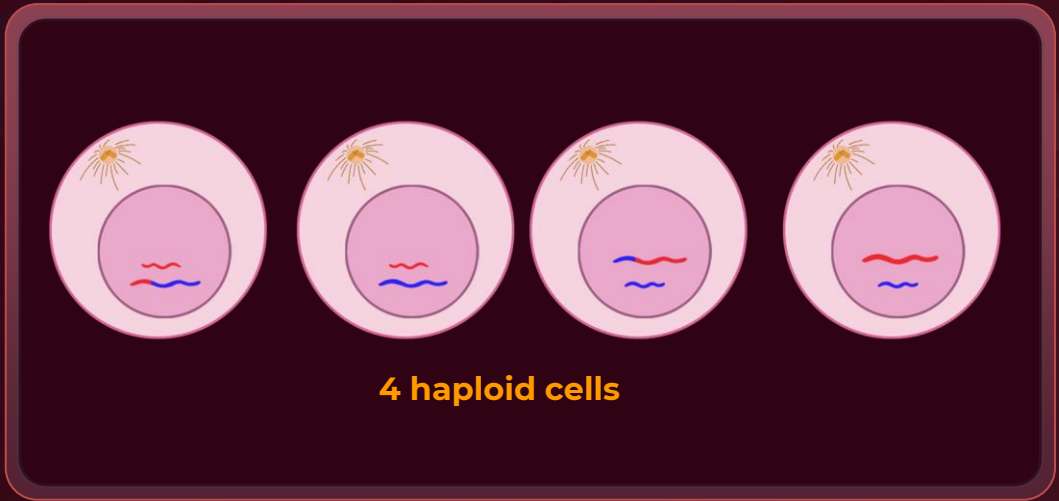
Telophase II

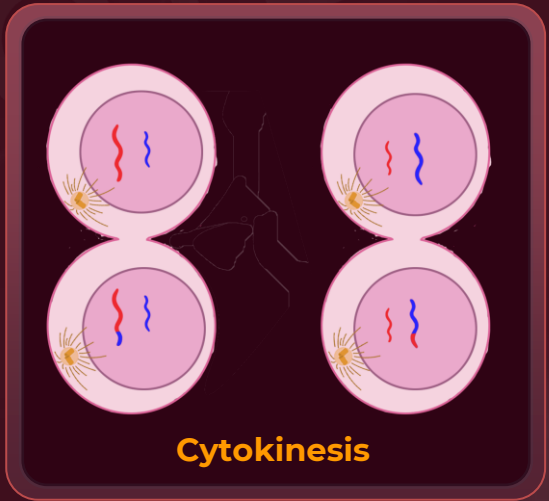
- It marks the end of meiosis II.
- The **nuclear membrane** and the **nucleolus reappear**.
- The chromosomes decondense into chromatin.
- The spindle fibers degenerate.



Cytokinesis

- Telophase II is followed by cytokinesis.
- The cytoplasm is divided into daughter cells.
- The end of cytokinesis is marked by the tetrad of the haploid cells.
- The two cells give rise to **four cells** or a tetrad of cells.





Significance of Meiosis

- Meiosis produces gametes for sexual reproduction.
- It **conserves the specific chromosome number** of each species in the category of sexually reproducing organisms.
- It increases the **genetic variability** from one generation to the next.
- Genetic variations contribute to **evolution**.

Meiosis- II vs Mitosis

Similarities:

- Both are **equatorial divisions**.
- The sister chromatids are separated during the anaphase to become the chromosomes of the daughter cells.
- Microtubules attach from the opposite directions to the centromere of each sister chromatid pair.
- **Chromosomes decondense** during telophase.

Differences:

Mitosis	Meiosis -II
Mitosis occurs in diploid somatic cells.	Meiosis -II always occurs in haploid germ cells.
Mitosis is always followed by DNA replication.	Meiosis-II is not followed by DNA replication.
After mitosis, the daughter cells are exactly similar to one another and the parent cell.	The daughter cells formed are neither similar to each other nor similar to the parent cell.

Summary

Cell cycle

Cell division

Interphase

G1 phase:
- Cell grow in size
- Protein production
- Nutrients synthesis

S phase:
- DNA replication
- Centriole duplication

G2 phase:
- Cell growth
- Protein production

M phase

Karyokinesis:
- Chromosomes separate
- Two nuclei are formed

Cytokinesis:
- Cytoplasm divides
- Two daughter cells formed

Checkpoints in cell division

G1/S checkpoint:
i) Check for nutrients
ii) Growth factors
iii) DNA damage

Metaphase checkpoint:
i) Checks for chromosome spindle attachment

G_2/M checkpoint:
i) Check for cell size
ii) DNA replication

Summary

Mitosis

Karyokinesis

Karyon = Nucleus; Kinesis = Movement
It is the division of the nucleus.

Prophase
- Condensation of chromatin fibres
- Nuclear membrane degenerates

Metaphase
- Chromosomes are attached to spindle fibres.
- Chromosomes are arranged in the equatorial plane.

Anaphase
- Centromere splits and chromatids separate.
- Chromatids move to opposite poles.

Telophase
- Chromosome reach the poles
- Disappearance of spindle fibres
- Decondensation of chromosomes

Cytokinesis

Cytos = Cell, Kinesis = Movement
It is the division of the cytoplasm.

Cell furrow formation
Observed in animals

Cell plate formation
Observed in plants

Summary

Meiosis