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XI NEET

02 CELL

BIOLOGY

IIT-JEE
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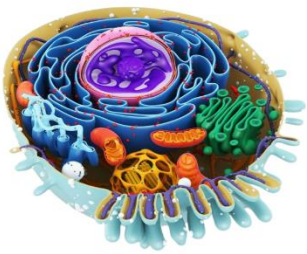
CELL
THE STRUCTURAL UNIT OF LIFE

02



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CHAPTER : 04

BIOLOGY

CELL: THE UNIT OF LIFE

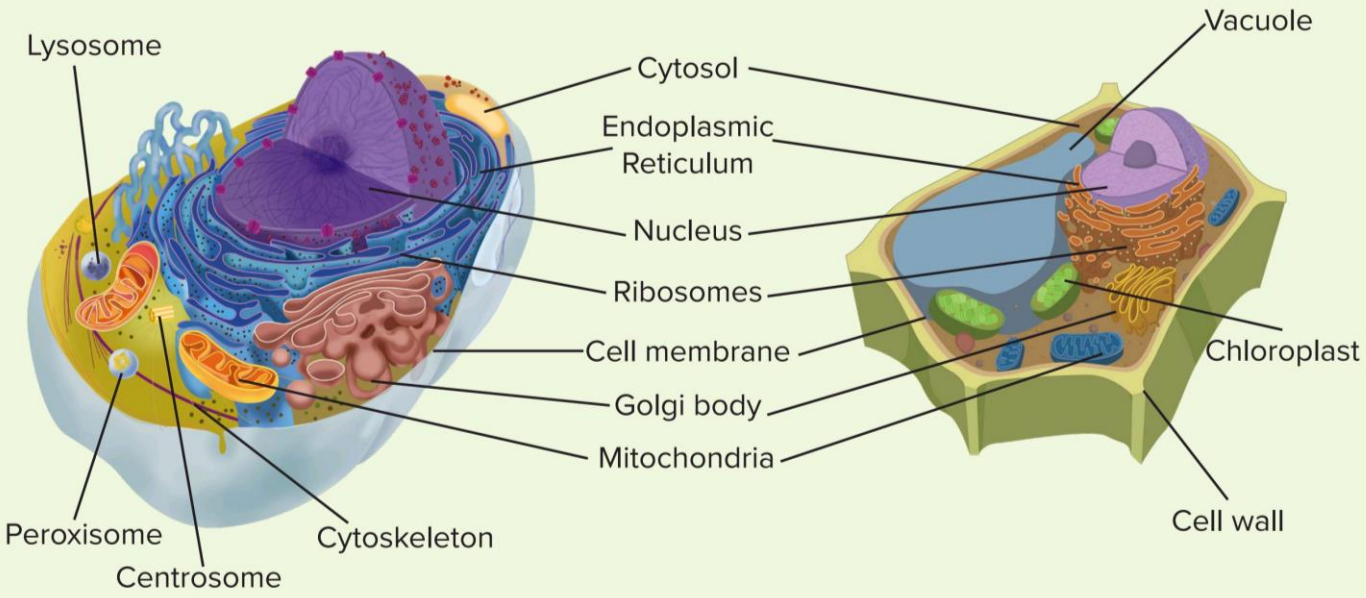
NUCLEUS, MITOCHONDRIA, CHLOROPLAST

Key Takeaways

- Nucleus
- Mitochondria
- Plastids
  - ➔ Chromoplasts
  - ➔ Leucoplasts
  - ➔ Chloroplasts

Prerequisites

- Eukaryotic cell and its organelles



Nucleus

History of the nucleus

1831 - Discovery of the nucleus

Robert Brown observed a distinct structure in the centre of the cell and termed it as **'nucleus'**.

Robert Brown

Nucleus

1879 - Discovery of chromatin

- **Walther Flemming** studied cell division in salamander cells using basic stains.
- He observed bands inside the nucleus and termed them as '**chromatin**'.

Walther Flemming

Cell division under the microscope. The **thread-like structures** seen in the cells are the **chromatin**.

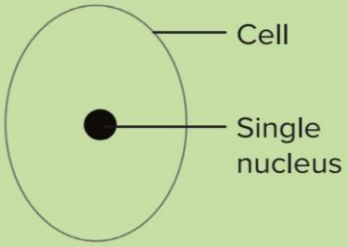
Properties of the nucleus

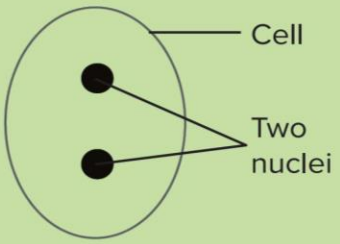
- Nucleus is a **membrane-bound organelle** found in **eukaryotic cells**.
- It takes up about 10% of the volume of the eukaryotic cells.

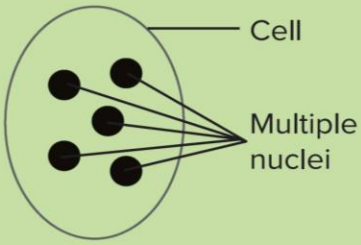
- It is known as the **'Brain of the cell'** as it contains **DNA* (genetic material)** which **controls all the important functions** of the cell.
- Usually, each cell has a single nucleus. But some types of cells may have more than one nucleus.

Types of cells (Based on the number of nuclei)

Monokaryotic/Uninucleate	Dikaryotic/Binucleate	Multinucleate/Coenocytic/ Syncytium
• Presence of **one central nucleus**	• Presence of **two nuclei**	• Presence of **multiple nuclei**





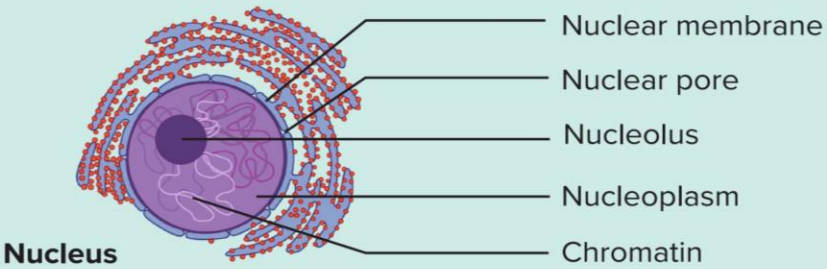


Note

DNA* (Deoxyribonucleic acid)

- It is the **genetic material** present in the cell which **provides information for important functions** of the cell.
- It also **encodes information** for the next generation of cells.
- DNA is present in the following organelles:
  - Nucleus
  - Mitochondria
  - Plastids

Structure of the nucleus

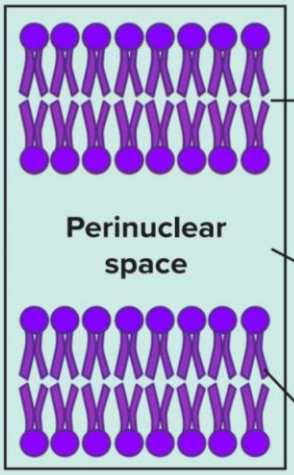


Nucleus

Nuclear membrane (Nuclear envelope)

- It **encloses** the **genetic material** in an exclusive compartment.
- It **protects** the **genetic material** from the degrading enzymes present in the cytoplasm of the cell.

Structure of nuclear membrane

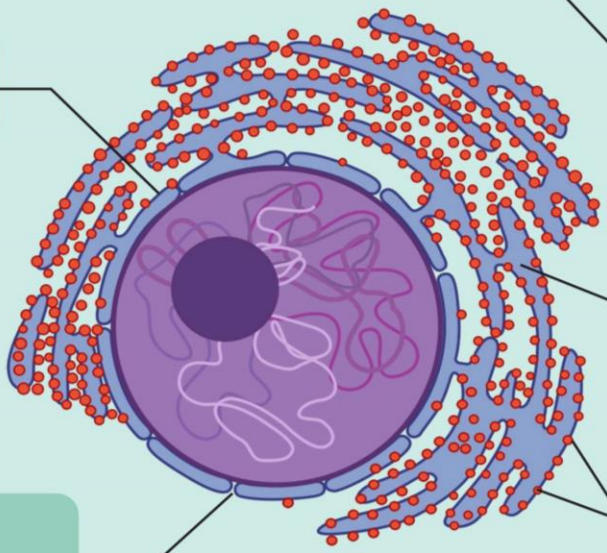


Outer membrane (Associated with ribosomes and is continuous with endoplasmic reticulum)

Perinuclear space (10-50 nm wide, fluid-filled space between the membranes)

Inner membrane

Double membrane (Phospholipid bilayer)



Endoplasmic reticulum

Ribosomes

Nuclear pore (Small gaps in the nuclear membrane through which movement of RNA and protein molecules takes place in both directions between the nucleus and the cytoplasm)

- **Nuclear lamina** - Mesh-like structure formed by **intermediate filaments** which provides **mechanical support** and **structural scaffolding** for the nucleus.

Nucleoplasm/Karyoplasm/Karyolymph

- The nuclear membrane encloses a part of the protoplasm known as the **nucleoplasm** (Hence, nucleoplasm + cytoplasm = protoplasm).
- The nucleoplasm is a **jelly-like matrix** that contains water, lipids, proteins and dissolved ions.
- The **nucleolus** and **chromatin** are suspended in the nucleoplasm.

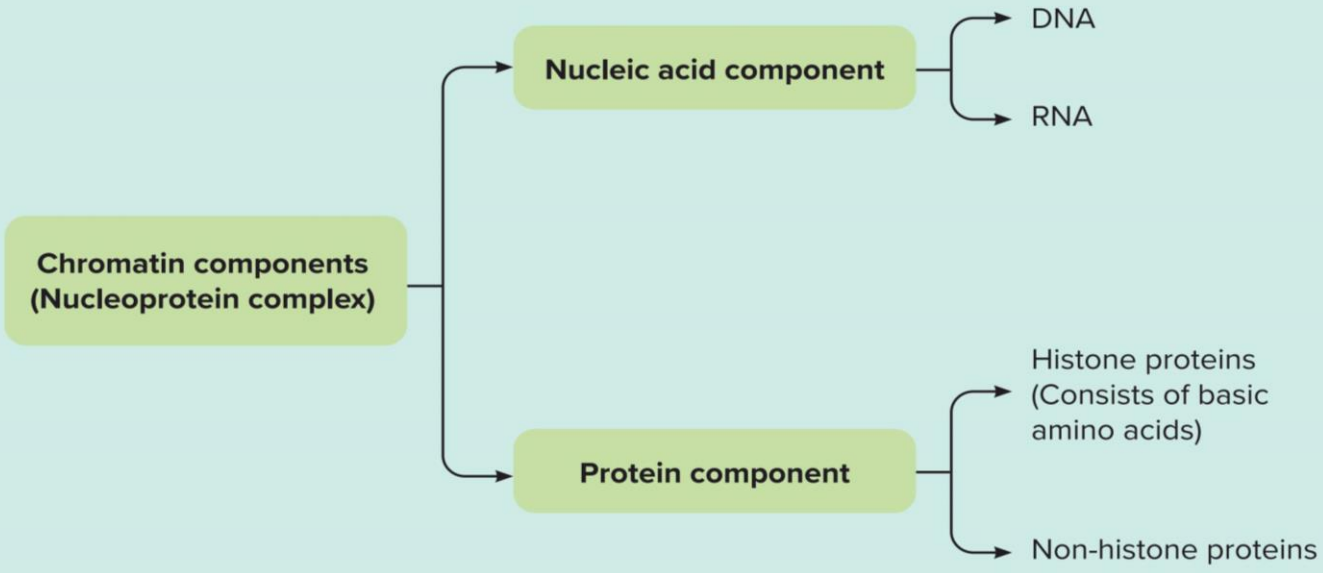
Nucleolus

- It is the **dense, spherical structure** suspended in the nucleoplasm.
- It is not bound by a membrane.
- Thin thread-like networks of **nucleo-protein fibres** are present. This includes:
  - **DNA**
  - **RNA**
  - **Histone proteins** (proteins that contain basic amino acids)
  - **Non-histone proteins**
- It is the site of **ribosomal RNA synthesis** (ribosomes are non-membrane bound organelles involved in protein synthesis).
- Cells may have one or more nucleoli.

Chromatin and chromosomes

Chromatin

- The DNA in the nucleus is arranged in the form of **thread-like structures** known as **chromatin.**
- Chromatin is present in the **interphase nucleus** as a network of **nucleoprotein fibres**.



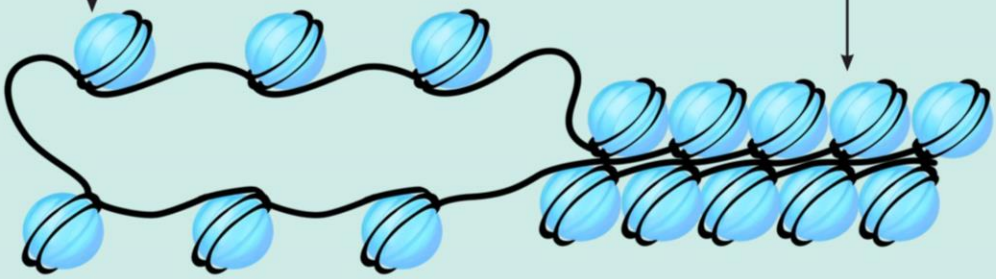
Types of chromatin

Euchromatin

- **Loosely packed** part of chromatin
- **Stains lightly** with nuclear stains

Heterochromatin

- **Tightly packed** part of chromatin
- **Stains darkly** with nuclear stains

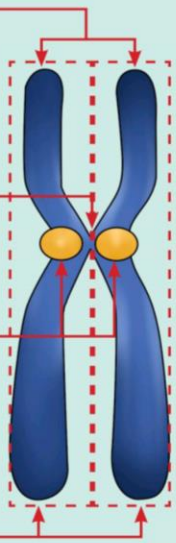


Chromosomes

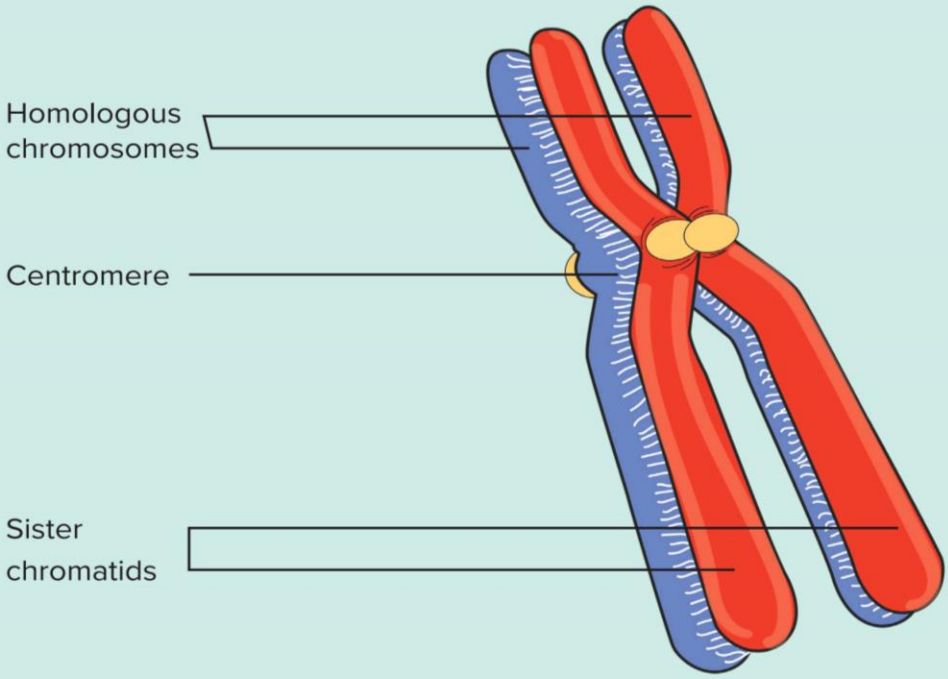
- **Chromosomes** are formed by **condensation of chromatin**.
- A single human cell has approximately **two metre** long thread of DNA distributed among its **23 x 2 = 46** chromosomes.

Structure of chromosomes

- **Chromatid** - Each chromosome has two sister chromatids
- **Centromere** - Primary constriction
- **Kinetochore** - Proteinaceous disc-shaped structures on the sides of the centromere which helps in cell division
- **Telomere** - Terminal ends of the chromatids



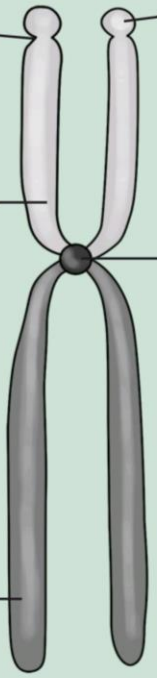
- **Homologous chromosomes** are pairs of chromosomes which are similar but not identical. They have similar centromere location and are similar in length and gene position.



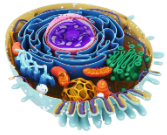
Constrictions of the chromosome

ondary cons
Found in some chromosomes at sites other than primary constriction

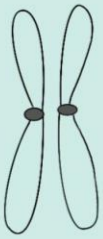
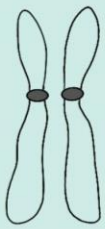
Satellite
- Part of the chromosome separated by secondary constriction
- Helps in distinguishing between organisms
- Helps in formation of nucleolus after cell division



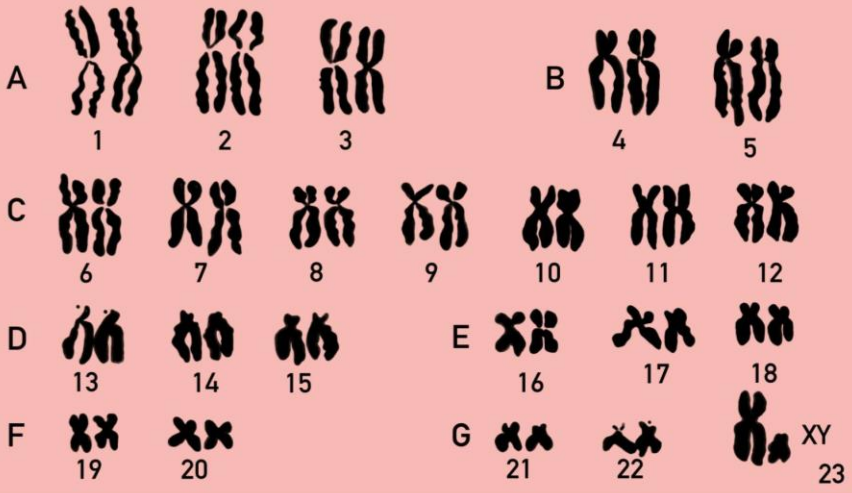
Primary constriction
- Narrowing of the chromosome due to centromere
- Divides chromosomes in **short (p) arm** and **long (q) arm**



Types of chromosomes

Metacentric	Sub-metacentric	Acrocentric	Telocentric
			
Centromere is at centre **p arm = q arm**	Centromere is almost near centre **p arm < q arm**	Centromere is farther from centre **p arm < q arm**	Centromere is at terminal position **No p arm and 1 q arm**

Did you know?



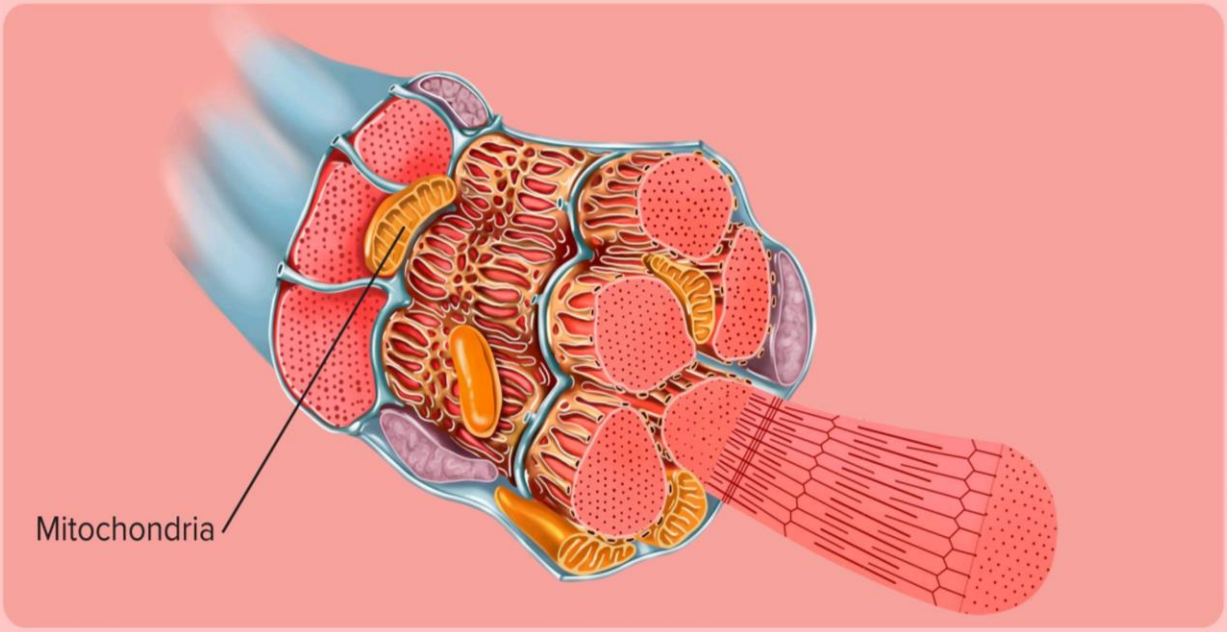
- **Human karyotype** is a representation of the chromosomes present in a human cell.
- Chromosomes 1, 3, 16, 19 and 20 and X chromosome are metacentric.
- Chromosomes 2, 4-12 are sub-metacentric.
- Chromosome 13, 14, 15, 21 and 22 and Y chromosome are acrocentric
- There are no telocentric chromosomes.

Mitochondria

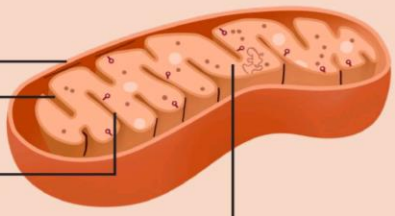
- **Mitochondria** is an organelle found in cytoplasm.
- It is known as the "**powerhouse of the cell**".
  - ➔ It is the **site for ATP synthesis** and **storage**.
- It is **semi-autonomous**.
  - ➔ Has its own genetic material - **mtDNA**
  - ➔ Can produce its **own proteins**
  - ➔ Divides itself by **fission** during cell division
  - ➔ Follows **maternal inheritance** (only mother's mtDNA is transferred to offspring)

Did you know?

- Cells that need more energy have more mitochondria.
  - ➔ Muscle cells have very high numbers of mitochondria.
  - ➔ Meristematic cells which keep on dividing are highly active.
  - ➔ The muscle cells of hummingbirds have large number of mitochondria because they beat their wings very fast and require a lot of energy.



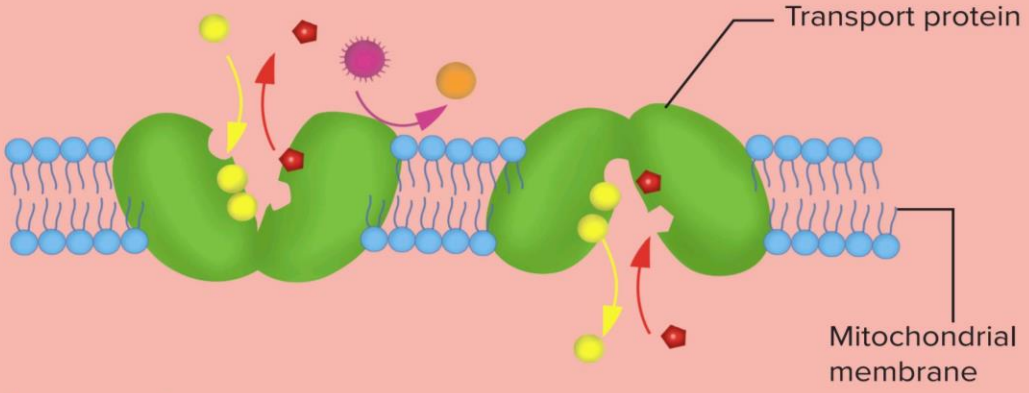
Structure of mitochondria



I → Double-membrane system

Outer membrane

- Continuous and smooth
- Contains transport proteins
- Selectively permeable

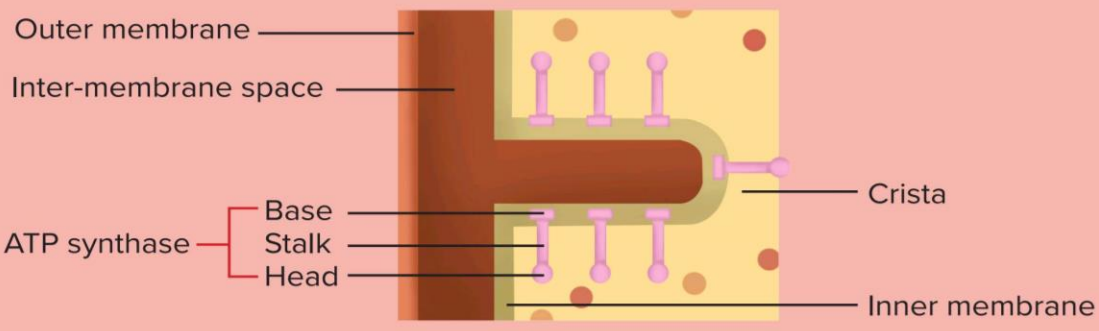


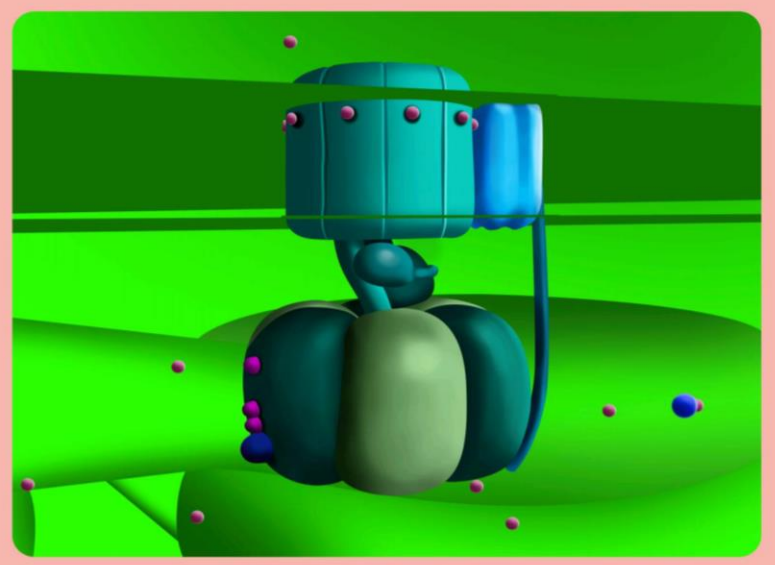
Inner membrane

- Less selectively permeable
- Folded to form cristae

II → Cristae

- Increase surface area of the inner membrane
- Contains ATP synthase/F_0 - F_1 Particle/Oxysomes
- ATP synthase is responsible for ATP synthesis





Mitochondrial ATP synthase

- Cristae creates two compartments:
  - **Outer compartment** bound by outer membrane.
  - **Inter-membrane space** or **peri-mitochondrial space**, bound by inner membrane, is filled with a fluid similar to the cytoplasm.

III → **Matrix**

- Rich in **enzymes and proteins** involved in respiration and other metabolic pathways
- Has **single, circular, double stranded DNA** called mitochondrial DNA **(mtDNA)**
- Also has **70S ribosomes** and **RNA molecules**

Plastids

- **Plastids** are present in **photosynthetic eukaryotes** like **plants** and **euglenoids**.
- They are **semi-autonomous** organelles (like mitochondria).

Types of plastids

Chromoplasts

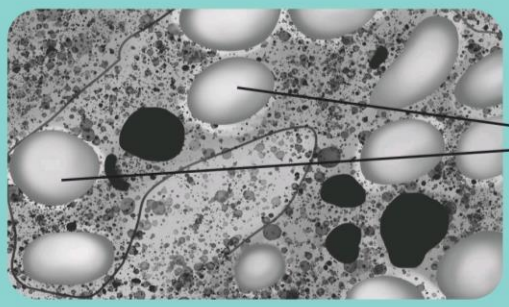
- Contain fat-soluble **carotenoid pigments** like **carotene** and **xanthophylls**.
- Impart the colours - yellow, orange, and red.

Chromoplasts impart colours to fruits of plants

- **Lack chlorophyll** (hence cannot impart green colour).
- Present in petals, flowers, fruits and other parts of the plant.
- Sometimes, chloroplasts may convert to **chromoplasts** during the ripening process.
  Example: When tomatoes ripen, it turns red from green.

Leucoplasts

- Pigments are **absent** (hence, they are colourless).
- **Store nutrients** in the cell.
- Occur in cells which are **not exposed to sunlight.**
  Example: Cells of seeds, fruits, tubers and rhizomes



Leucoplasts (Types)

- **Amyloplasts (Carbohydrates)**
  - Synthesise and store **starch**
  - Found in potato tubers, wheat and rice grains
- **Elaioplasts (Lipids)**
  - Store **lipids** and **oils** in fat droplets
  - Found in mustard and castor endosperm
- **Aleuroplasts (Proteins)**
  - Store **proteins**
  - Found in Brazil nuts, peanuts and pulses

Chloroplasts

- Green plastids present in the cells of photosynthetic organisms.
- Example: Cyanobacteria (*Spirogyra indica*), algae (*Chlamydomonas*)
- Present in green parts of the plants (such as mesophyll cells).
- Contains photosynthetic pigments **chlorophyll** and other pigments such as **carotenoids**

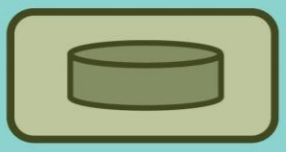
Characteristics of chloroplasts

(a) Size and number

- An average of **20-40 chloroplasts** are present in a **leaf mesophyll cell**.
- May vary depending on sunlight.
  - ➔ Plants growing in **shade** have **more chloroplasts**.
  - ➔ Plants growing in **full sun** have **fewer chloroplasts**.

(b) Shape

Cup-shaped
(*Chlamydomonas*)



Girdled/C-shaped
(*Ulothrix*)

Stellate
(*Zygnema*)

Spiral-shaped
(*Spirogyra*)

Oval-shaped
(Plants)

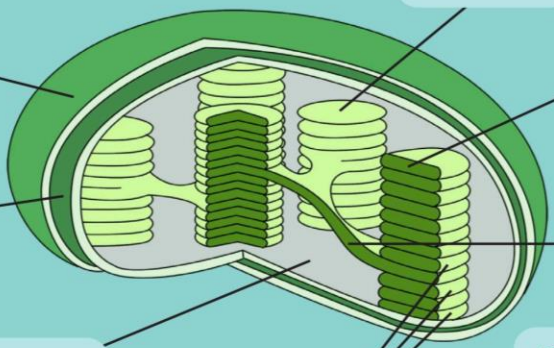
(b) Structure of chloroplast

Double membrane bound organelle

- Outer membrane
- Fluid-filled intermembrane space (periplasmic space)
- Inner membrane (relatively less permeable)

Grana/Intergranal thylakoids

- Thylakoids are stacked one over the other to form grana
- Also called intergranal thylakoids



Stroma lamellae/ Fret channels

- **Flat channels** which connect thylakoids of different grana

Stroma

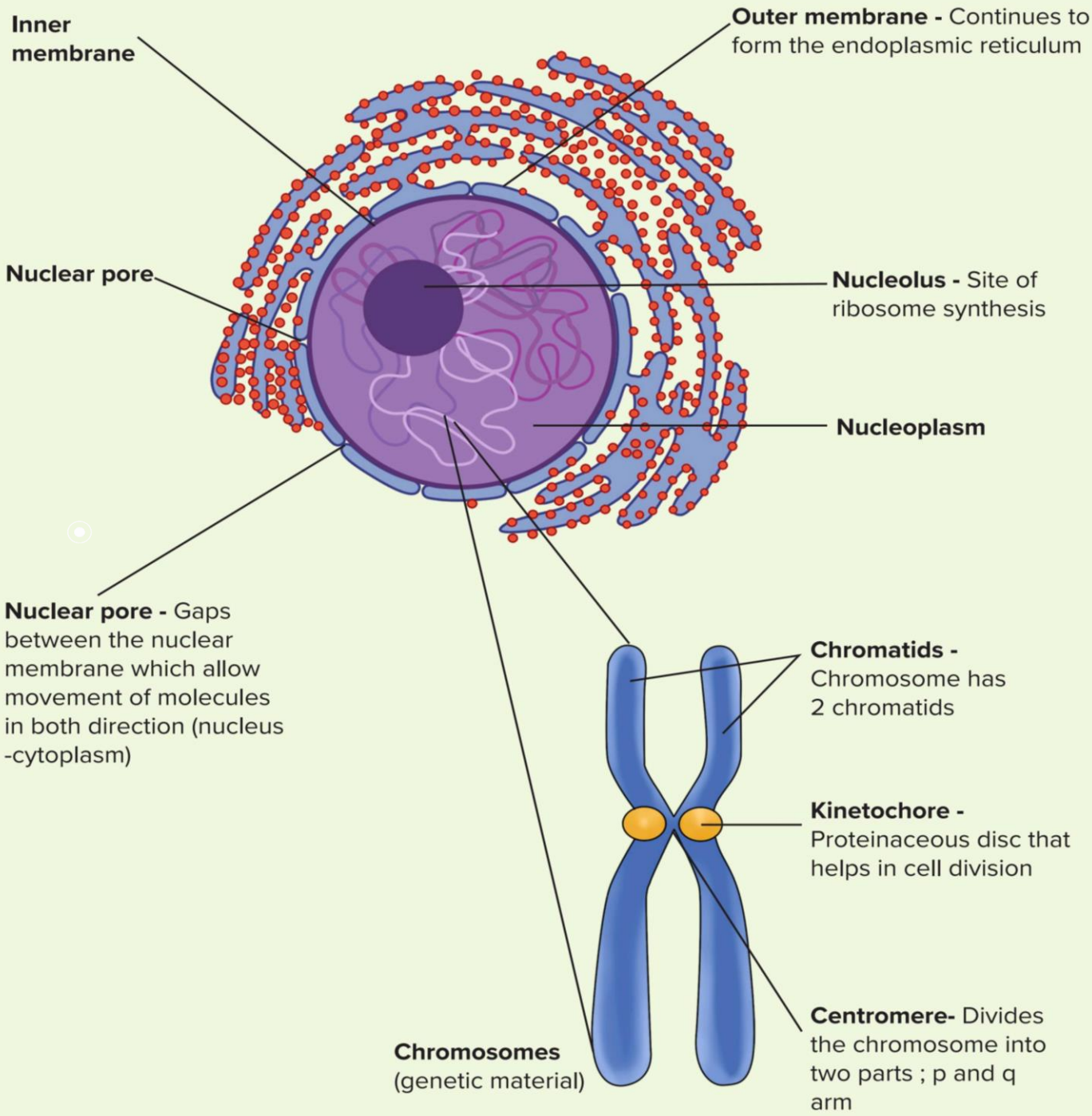
- **Transparent, fluid matrix** bound by the inner membrane
- Components of the stroma are:
  - Circular DNA (known as cpDNA)
  - Ribosomes
  - Thylakoid membrane system
  - Starch granules
  - Enzymes

Thylakoid

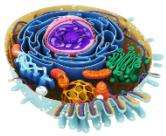
- **Membrane-bound, flattened, sac-like structures** present in the stroma.
- The thylakoid membrane encloses the **thylakoid lumen**.
- The thylakoid membrane has light capturing bodies called **quantasomes**.
- Each quantasome contains chlorophyll molecules.

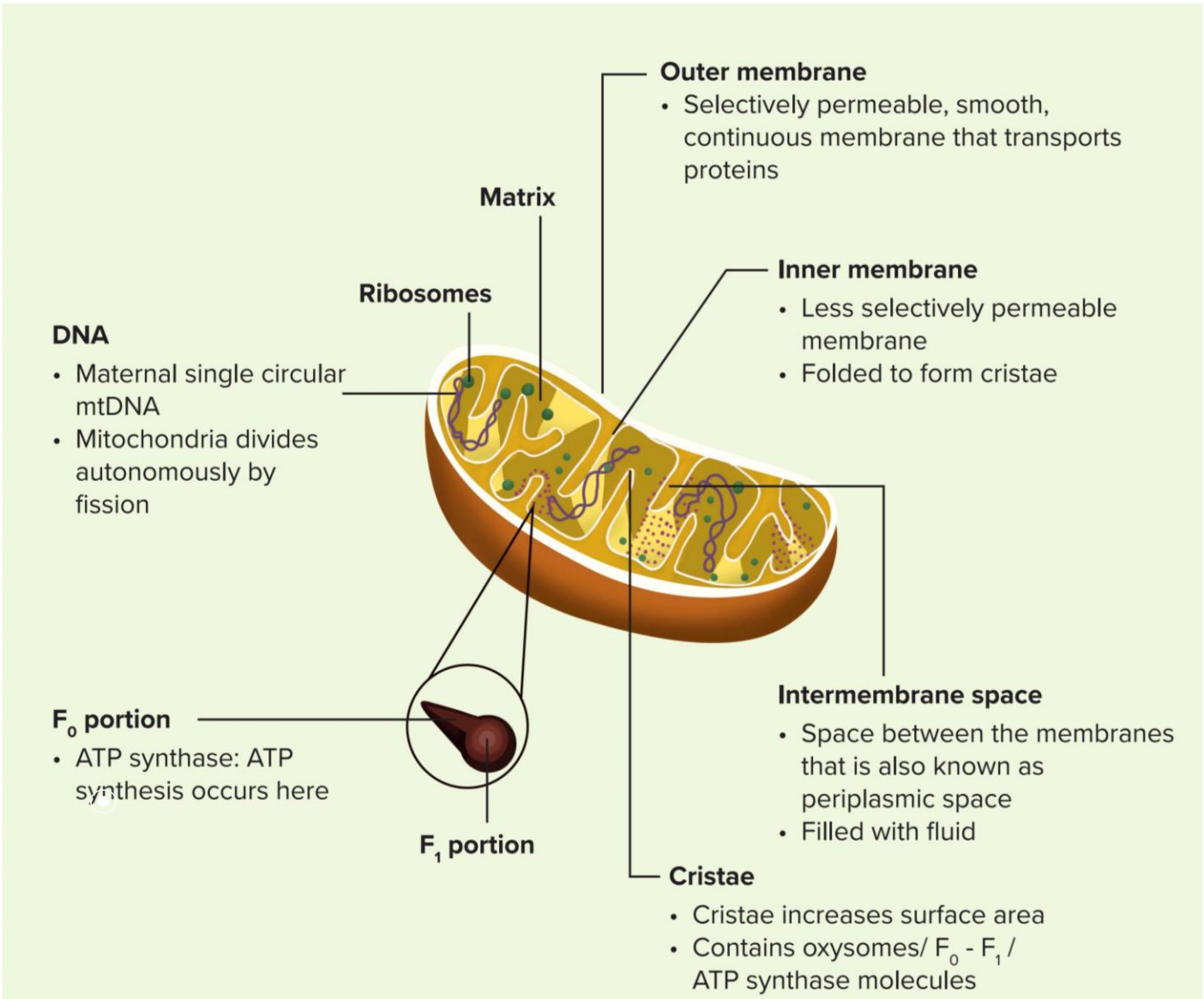
Summary Sheet

- **Nucleus** is a membrane bound organelle in eukaryotes. It contains DNA as the genetic material.

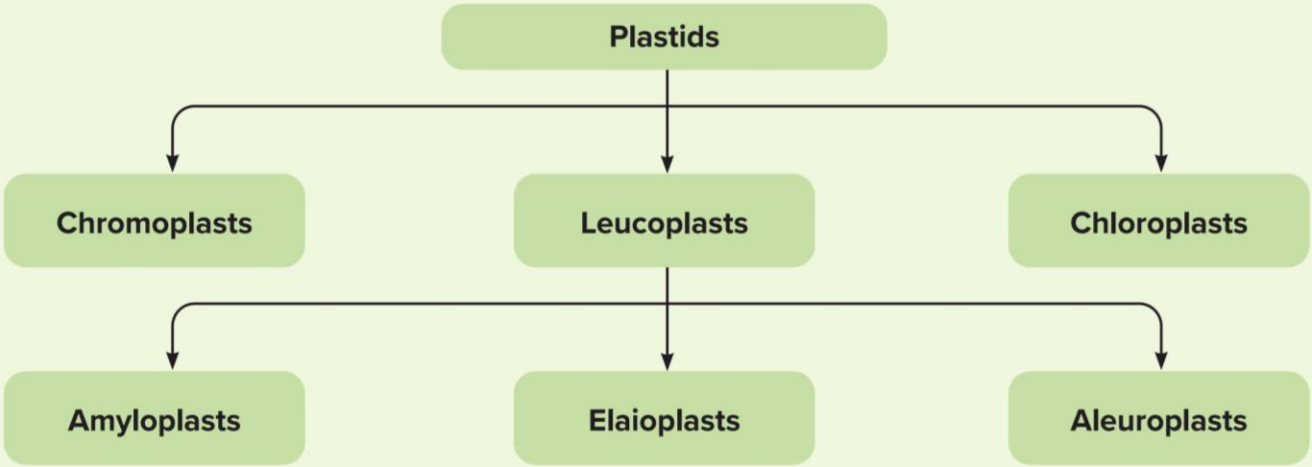


- **Mitochondria** is the powerhouse of the cell which stores and synthesises energy in the form of ATP.

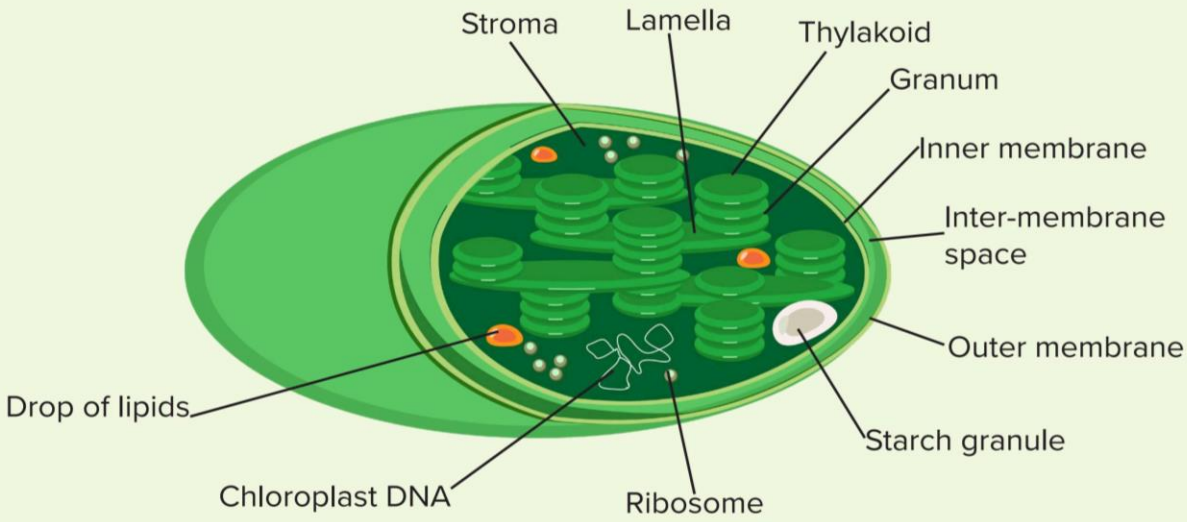


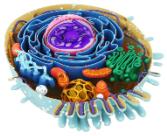


- **Plastids** are organelles that are present in photosynthetic organisms.



- **Structure of chloroplast**





BIOLOGY

CELL: THE UNIT OF LIFE

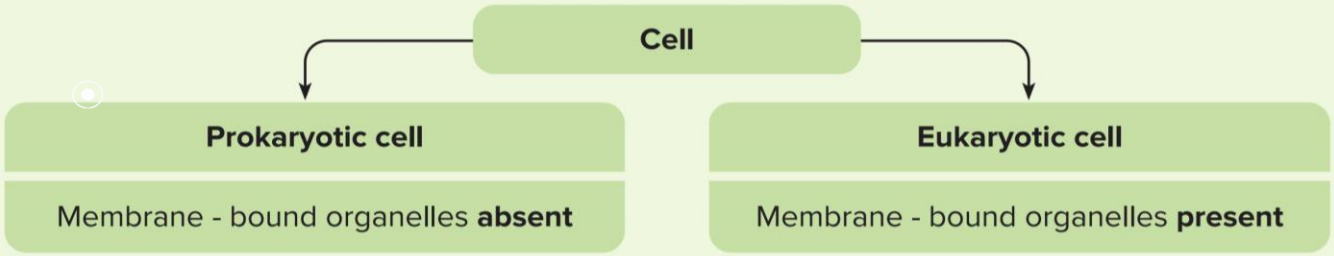
RIBOSOME, ENDOMEMBRANE SYSTEM AND MICROBODIES

Key Takeaways

- Ribosomes
- Endomembrane system
  - ➝ Endoplasmic reticulum ➝ Golgi apparatus ➝ Vacuole ➝ Lysosome
- Microbodies

Prerequisites

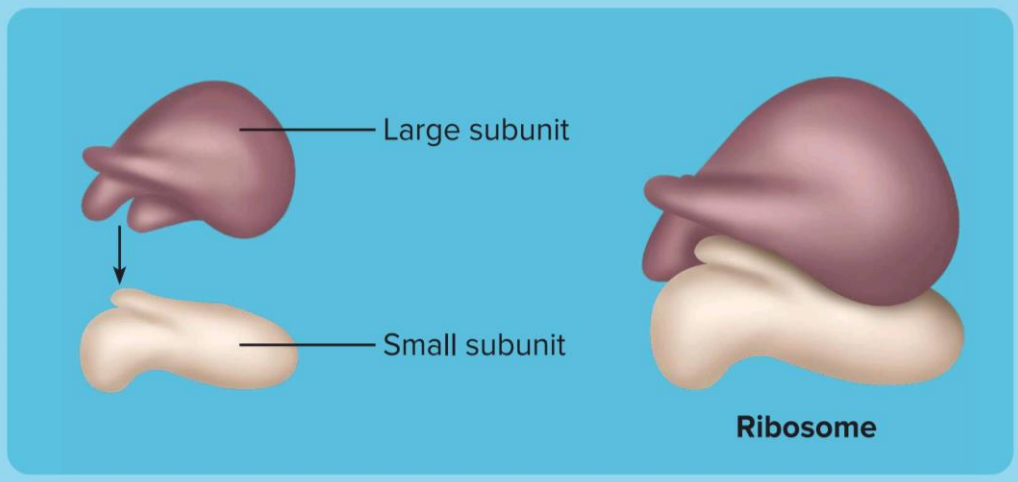
- **Cell** is the **structural** and **functional** unit of life.



- Organelles: Organelles are specialized structures within a cell that perform specific functions.

Ribosomes

- **George Palade** observed dense particles in cells under the electron microscope. He called them “Palade particles”.
- These particles were later renamed as **ribosomes**.
- It is made up of two parts:
  - ➝ RNA ➝ Proteins
- They are **not membrane-bound** organelles.
- They are solid and dense structures (not fluid-filled).
- All living cells have ribosomes except mammalian RBC.
- They are the smallest cell organelles, about 15 to 20 nm in size.
- Their main **function** is **protein synthesis.**
- They are made up of two units:
  - ➝ Large subunit ➝ Small subunit



Types of ribosomes

Prokaryotic (70S)

Synthesized in cytoplasm

Large subunit - 50S
Small subunit - 30S

Eukaryotic (80S)

Subunits are synthesized in nucleolus and are transported to cytoplasm via nuclear pore. The assembly of ribosomes occurs in the cytoplasm.

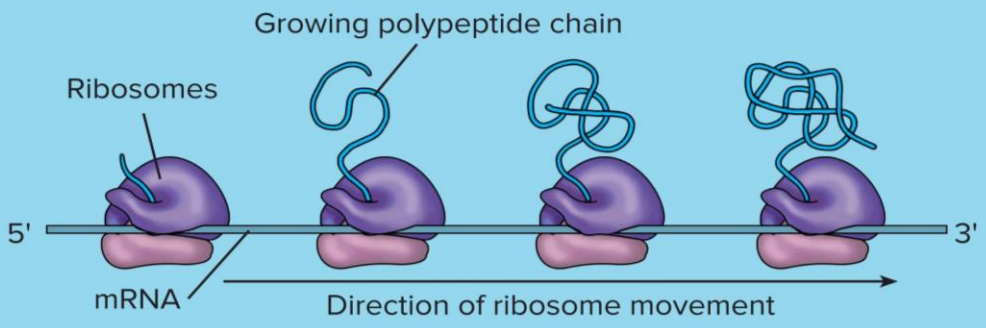
Large subunit - 60S
Small subunit - 40S

Free

Bound

- **S (Svedberg unit):**
  - → A unit for **sedimentation coefficient.**
  - → **Sedimentation coefficient** is a measure of how fast a particle settles when centrifuged in an ultracentrifuge.
    - Larger and denser the particle - the **greater** its 'S' value.
    - Smaller and lighter the particle - the **lesser** its 'S' value.
- **Organelle within an organelle:**
  - → Organelles like **mitochondria** and **chloroplast** synthesize their own ribosomes.
    - Mitochondria - 55S type of ribosome
    - Chloroplast - 70S type of ribosome

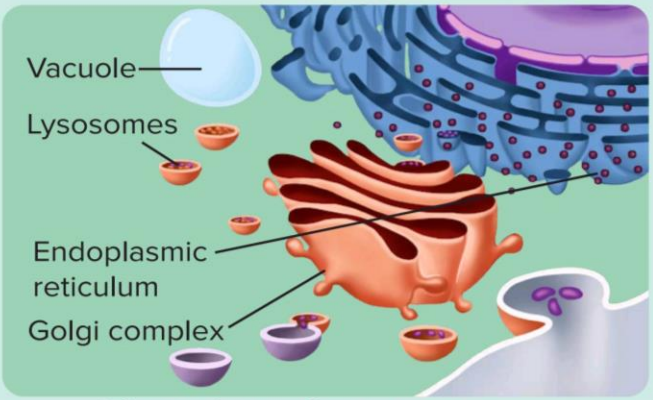
- **Functions of ribosomes:**
  - **Protein synthesis**
    - Ribosomes read the sequence of nucleotides on the mRNA and assemble the respective amino acids to make the proteins.
    - Sometimes the **same mRNA** strand has **multiple ribosomes** reading it at the same time. This condition is known as a **polysome.**



Role of ribosomes in protein synthesis

Endomembrane System

- The endomembrane system includes some membranous organelles present in the cytoplasm of the cell that **function in a coordinated manner.**
- It includes
  - Endoplasmic reticulum
  - Golgi apparatus
  - Lysosomes
  - Vacuoles



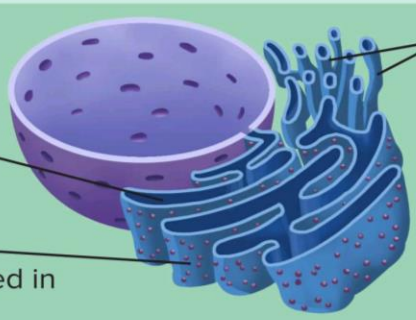
The endomembrane system

Endoplasmic reticulum (ER)

- It is a **single membrane-bound** organelle.
- **'Endo'** - inside, **'plasmic'** - cytoplasm, **'reticulum'** - network.
- It forms a **network** of **tiny tubular structures** in the cytoplasm.

Lumen
The cisternae and the tubules are hollow and this internal space is known as the **lumen.**

Cisternae
The long flattened units arranged in stacks are known as cisternae.

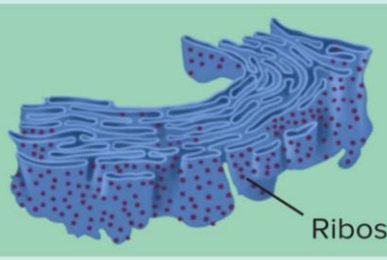
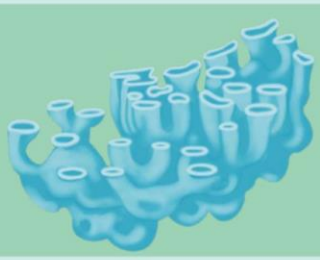


Tubules
The irregularly branched tubes which can be free or associated with cisternae are known as tubules.

The **ER** occupies a huge space of the cytoplasm, almost the whole of the cell.

- ER divides the intracellular space into two distinct compartments:
  - ➜ Luminal compartment - Space enclosed by the ER
  - ➜ Extraluminal compartment - Space that is not enclosed by the ER

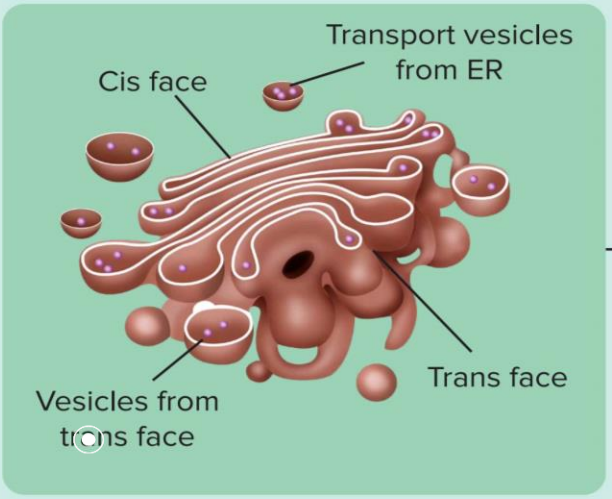
Endoplasmic reticulum

Rough ER (RER)	Smooth ER (SER)
	
• ER having **ribosomes** embedded in the membranes. • Appear **rough** due to the presence of ribosomes. • Composed mostly of **cisternae** (flattened sacs). • Ribosomes on RER are involved in **protein synthesis.** • Proteins, once synthesized, are transferred into the ER lumen. • Proteins destined to other parts of the cell or outside the cell are transported away from the RER in vesicles. • RER is more abundant in cells which are actively engaged in protein synthesis and secretion. Example: liver, pancreas, goblet cells, etc.	• ER that is **not associated** with **ribosomes**. • Appear **smooth** due to the absence of ribosomes. • RER transitions into the SER. They are present in continuity. • Composed mostly of **tubules.** • SER functions. ➜ Glycogen and lipid metabolism ➜ Synthesis of steroid hormones ➜ Detoxification of drugs and pollutants • SER is more abundant in cells of adipose tissue, glycogen-storing liver cells, cells of adrenal cortex, etc.

Golgi complex

- It was discovered by **Camillo Golgi** (1898). He observed **densely stained reticular structures** near the nucleus.
- The Golgi complex apparatus like a bunch of flattened sac-like structures.
- It is also known as **Golgi complex** and **Golgi bodies.**
- In **plants**, the Golgi apparatus is known as **dictyosome.**
- It lies close to the endoplasmic reticulum inside the cell.
- It is found in all eukaryotes except mature RBCs.

- **Structure:**
  - ➝ Consists of disc-like cisternae, vesicles and tubules.
  - ➝ Size: 0.5µm to 1.0µm in diameter
  - ➝ The cisternae are concentrically arranged parallel to one another.



Cis face

- Part of the Golgi apparatus facing the **towards** the **ER.**
- **Convex shape** - Cisternae **fold away** from the ER
- **Receiving face** - It receives proteins and lipids from the ER.

Packaging and transport

- As the proteins and lipids from the ER pass through the Golgi complex they are
  - ➝ Modified
  - ➝ Sorted and tagged

Trans face

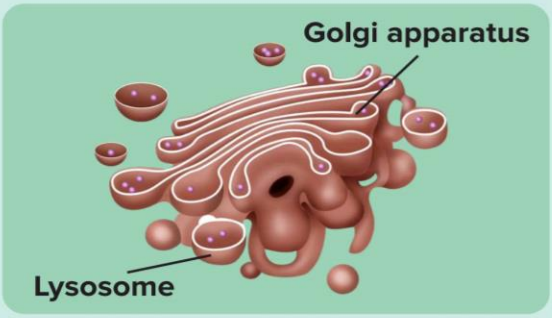
- Part of the Golgi apparatus facing **away** from the **ER** and **towards cytoplasm.**
- **Concave shape** - Cisternae **fold towards** the cytoplasm
- **Maturing face** - Modified materials are packed and released from this region

Vesicles

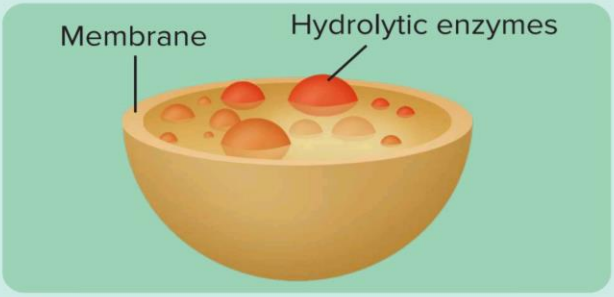
- Contain proteins or lipids that are to be delivered within the cell or secreted outside.
- When signalled by the cell, these vesicles fuse with the plasma membrane and release their contents into the extracellular space.
- Some vesicles also form **lysosomes.**

Lysosomes

- **Lyso** = digestive, **soma** = body
- Also known as **'Suicidal bags'** of the cell
- It was discovered by **Christian de Duve** (1955).
- Formed by the Golgi apparatus.
- Lysosomes are present in all animal cells except RBCs.



- **Structure**
  - ➜ Single membrane-bound - round, elliptical, or irregular
  - ➜ Filled with **hydrolytic enzymes* (hydrolases)**
    - ◆ Carbohydrases
    - ◆ Proteases
    - ◆ Lipases, etc.
  - ➜ Works in acidic pH



Cross section of the lysosome

* **Hydrolytic enzymes:** Enzymes that catalyze the **hydrolysis** of a chemical bond.

SUBSTANCES	HYDROLYTIC ENZYMES
Protein	Protease
Lipid	Lipase
Carbohydrates	Glycosidase
Nucleic acids	Nuclease
Phosphates	Acid phosphatase
Sulphates	Sulphatase

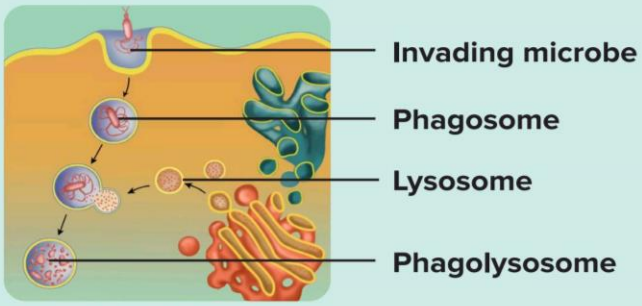
Function of lysosome

→ Intracellular digestion

Digestion that takes place **within** the cell.

(a) Desctruction of invading bacteria and viruses

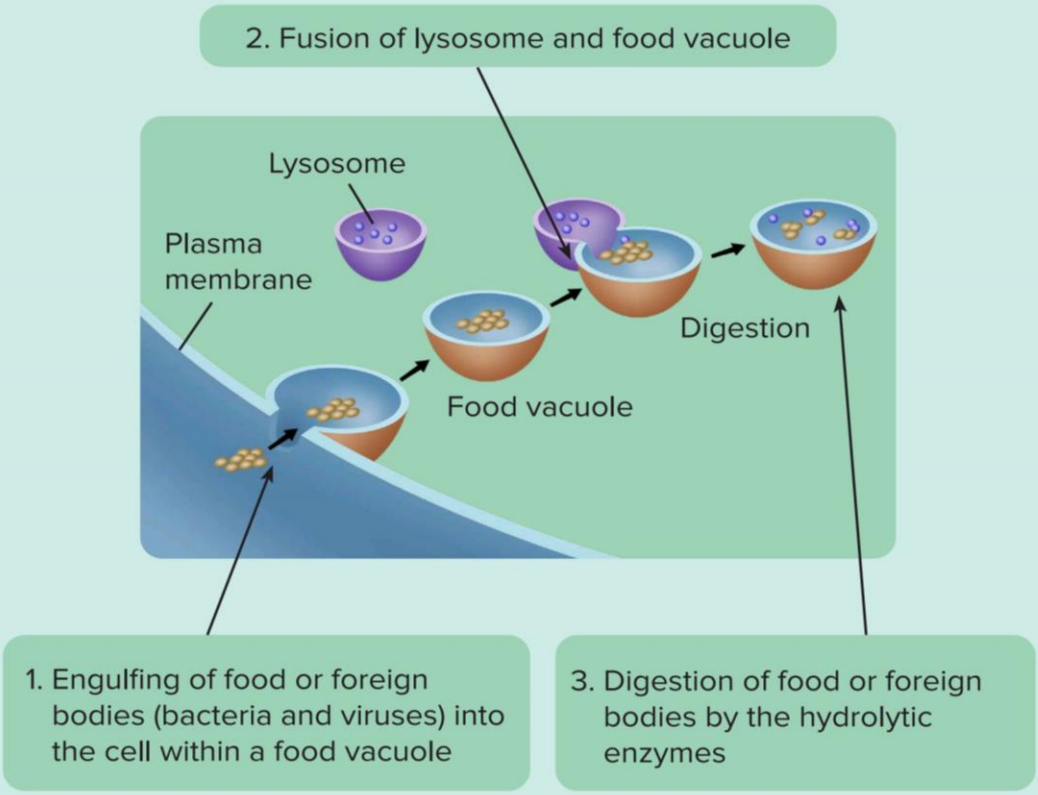
- The digestion of foreign materials received by cells is called **phagocytosis.**
- The vesicle in which the phagocytosed material is present is called the **phagosome.**



Heterophagy by lysosomes

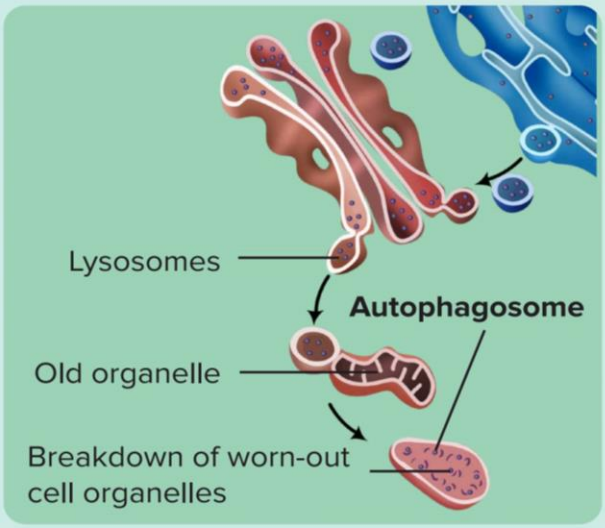
- The phagosome fuses with the lysosome to form the **phagolysosome.** This digestion of foreign materials (in the phagosome) through phagocytosis is known as - **heterophagy.**

(b) Digestion of food



(c) Breakdown of worn-out cell organelles

- Lysosomes that contain damaged cell organelles are called the **autophagosomes.**
- The process of digestion of old or dead cell organelles - **autophagy**



Breakdown of worn-out cell organelles

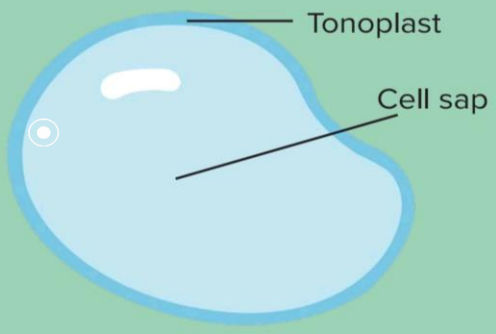
Extracellular digestion

- Digestion that takes place **outside the cell.**
- On certain occasions, lysosomes release enzymes outside the cell by **exocytosis** and carry out digestion.

Vacuoles

- Vacuole is a large **single membrane-bound** organelle found in plant cells.
- Also found in some cells of
  - → Fungi
  - → Protists
  - → Animals
  - → Bacteria
- It is more prominent in plant cells and can occupy around **70%** of the volume of the cell.

Vacuole structure



Tonoplast

- Single membrane enclosing the contents of the vacuole.
- Facilitates the transport of ions and other materials against concentration gradient into the vacuole.

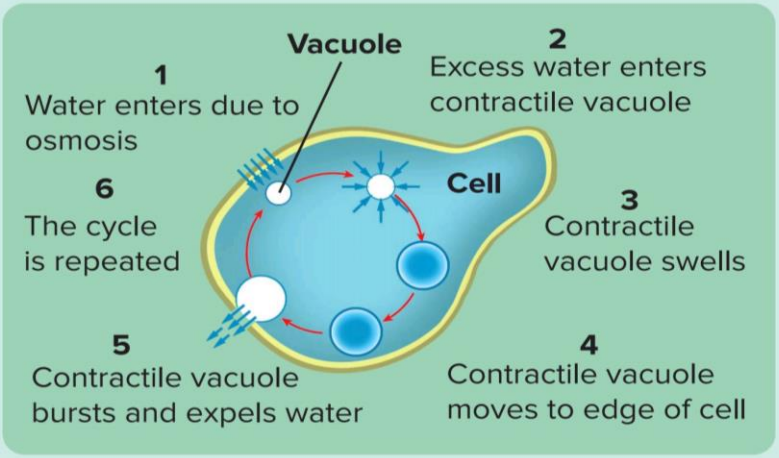
Sap

- Contains water with dissolved nutrients, and excretory products.
- Concentration of sap higher than that of cytoplasm. Hence, concentration of ions and minerals is significantly higher in vacuoles than in the cytoplasm.

Functions of vacuoles

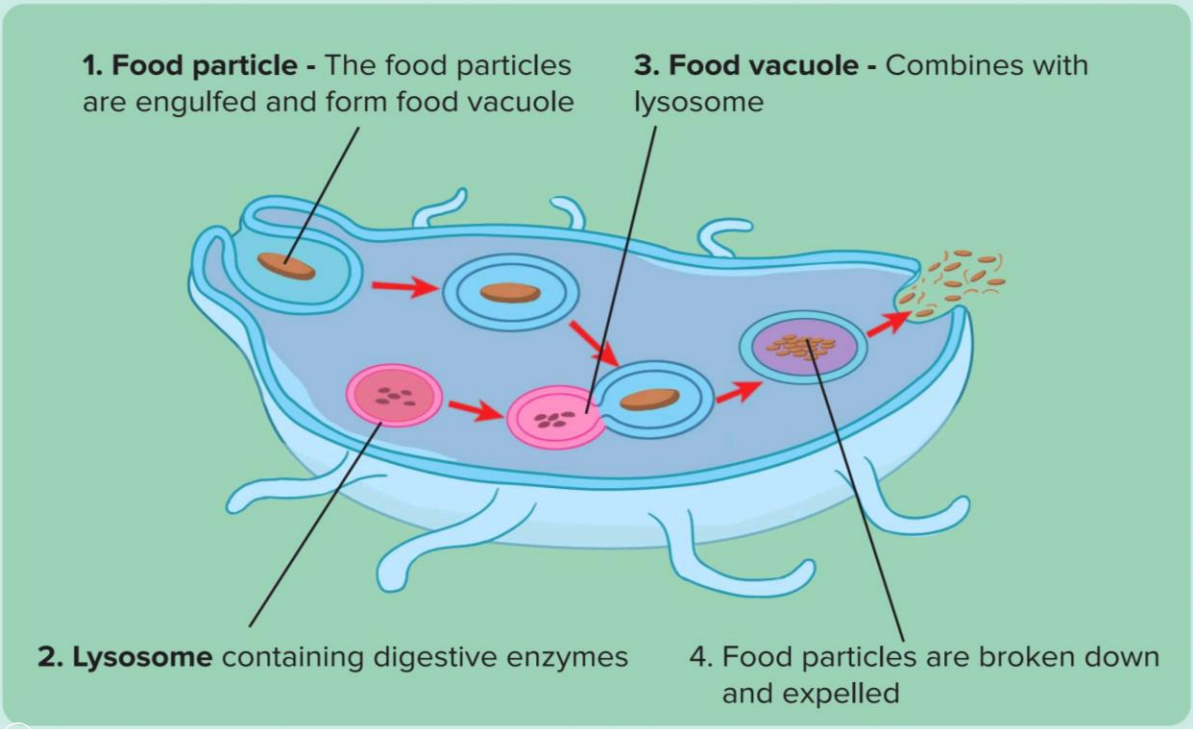
(a) Contractile vacuole

- Helps in **osmoregulation** and **excretion**.
- Osmoregulation - The maintenance of constant osmotic pressure in the fluids of an organism by the control of water and salt concentrations. It keeps the cell from bursting.



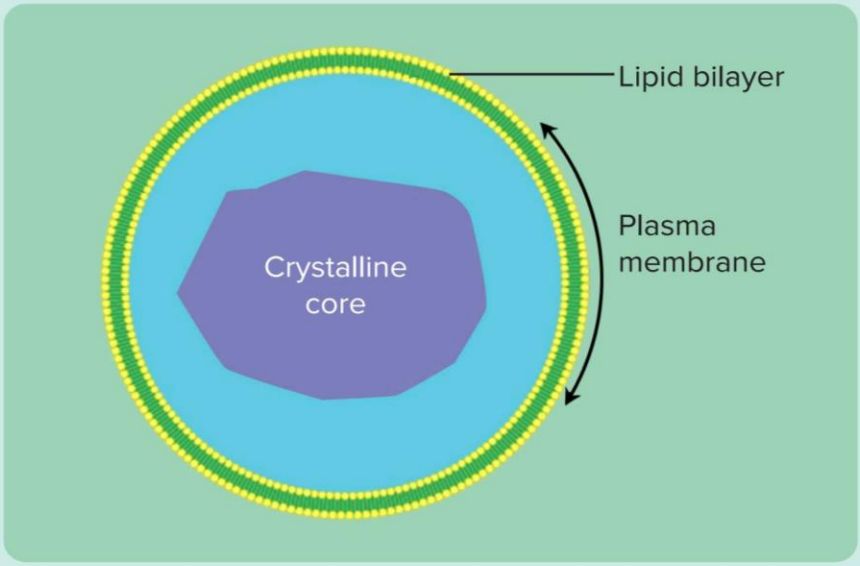
(b) Food vacuole

- In a few protists, **food vacuoles** are formed by engulfing the food particles.
- Food is stored and broken down when essential.



Microbodies

- These are **single membrane-bound vesicles** but they are not a part of the endomembrane system.
- Microbodies are found in both plants and animals.



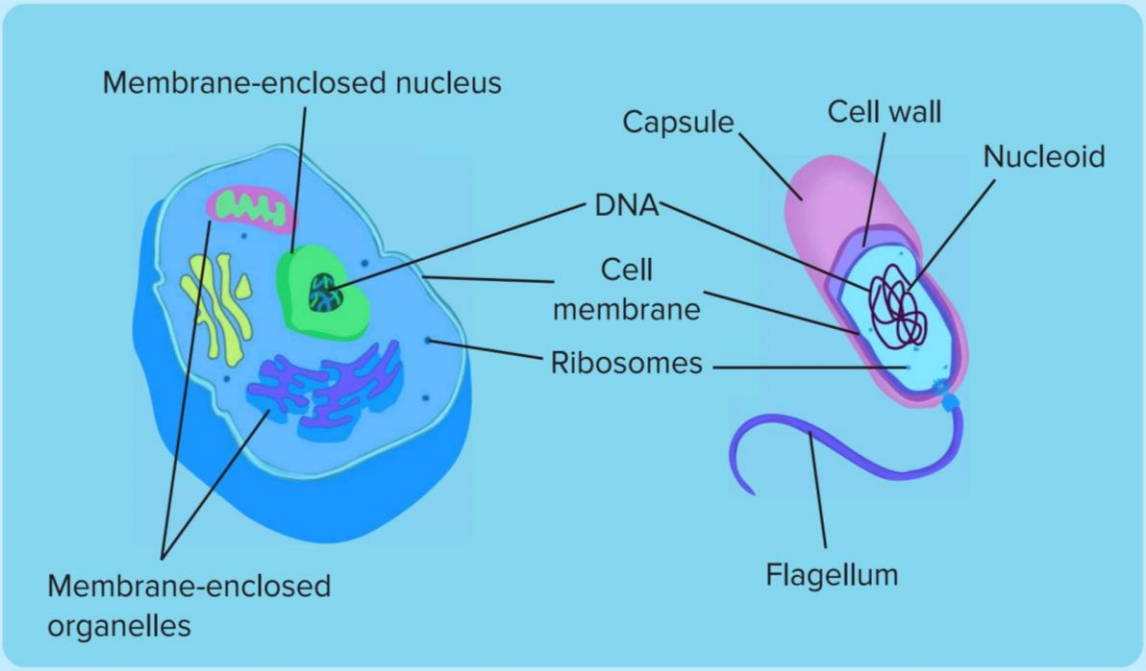
Microbodies

Types of microbodies

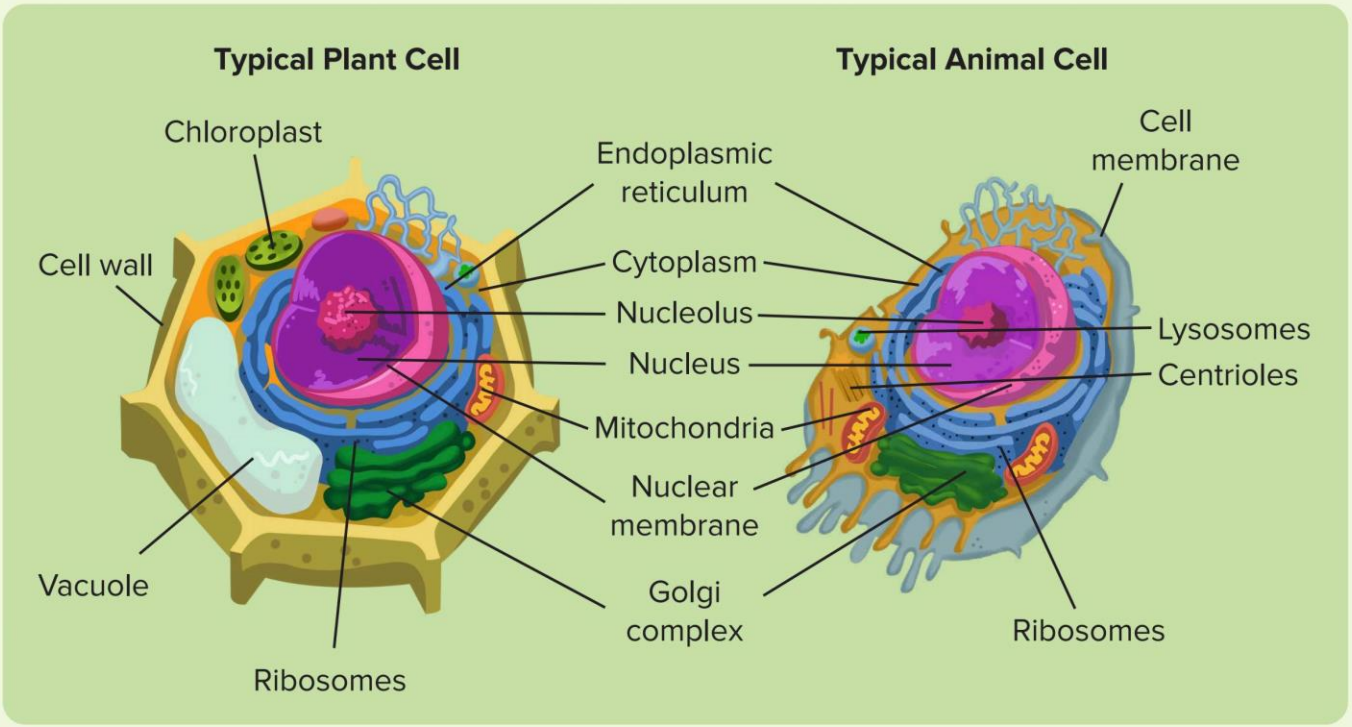
Peroxisomes	Sphaerosomes	Glyoxisomes
• Breakdown of very long chain fatty acids. • Involved in peroxide metabolism in animals. • Involved in photorespiration in plants.	• Synthesis and storage of lipids.	• Conversion of fats into carbohydrates.

Eukaryotic Cell vs. Prokaryotic Cell

- Eukaryotes and prokaryotes both have **ribosomes and cell membranes.**
- Eukaryotes **lack circular DNA.** They have **linear DNA.**
- Prokaryotes lack a **nucleus.** They have **nucleoid.**
- **Membrane-bound organelles** are present in **eukaryotic cells** which are absent in prokaryotes.



Plant Cell vs. Animal Cell



Plant cell only

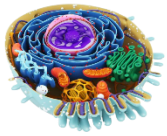
Plastids, Cell wall, Large central vacuole

Plant and animal cell

Nucleus, ER, Mitochondria, Golgi apparatus, Cell membrane, Cytoplasm, Cytoskeleton

Animal cell only

Centrosome, Small vacuole, Cilia, Flagella



Summary Sheet

Ribosomes
- RNA + proteins
- Not membrane-bound
- 2 subunits
- Prokaryotes - 70S
- Eukaryotes - 80S
- Synthesis of proteins

Microbodies
- Single membrane-bound organelle
- Contains enzymes

→ Peroxisome | Sphaerosome | Glyoxysome

Endomembrane System
- Single membrane-bound organelles
- Packaging and transport of materials

Endoplasmic Reticulum
- Tiny tubular structures
- Consists of cisternae and tubules

→ **RER**
- Mainly cistenae
- Protein synthesis

→ **SER**
- Mainly tubules
- Lipid metabolism

Golgi Apparatus
- Flattened sac-like structures
- Consists of cisternae, vesicles and tubules

→ **Cis Face**
- Receiving face

→ **Trans Face**
- Maturation face

Lysosome
- Suicide bags
- Contain hydrolytic enzymes (hydrolases)
- Intracellular and intercellular digestion

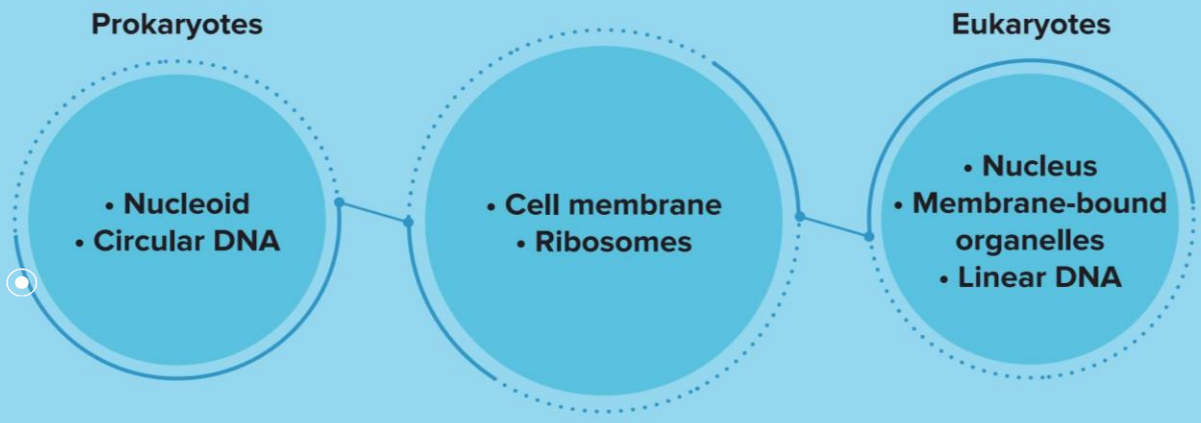
Vacuole
- Consists of tonoplast and sap
- Storage

Contractile Vacuole

Food Vacuole

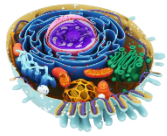
Eukaryotic vs Prokaryotic Cell

Common characteristics of eukaryotes and prokaryotes



Plant vs Animal Cell

- Plant cells have cell wall, plastids and large vacuoles.
- Animal cells have centrosome, small vacuole along with cilia or flagella.
- Both plant and animal cells have following:
  - Nucleus
  - ER
  - Mitochondria
  - Golgi apparatus
  - Cell membrane
  - Cytoplasm
  - Cytoskeleton



BIOLOGY

CELL: THE UNIT OF LIFE

CELL CYCLE AND CELL DIVISION

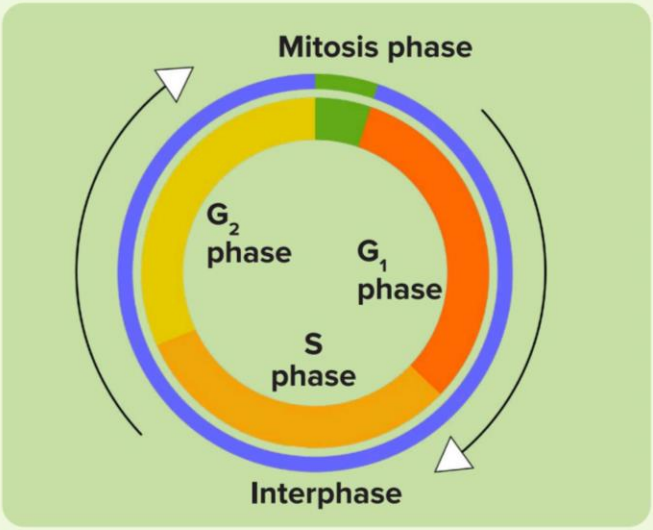
MITOSIS

Key Takeaways

- Mitosis
  - → Karyokinesis
    - Prophase
    - Metaphase
    - Anaphase
    - Telophase
  - → Cytokinesis
    - Cell furrow formation
    - Cell plate formation
- Significance of mitosis
- Cell cycle checkpoints
- Cancer

Prerequisites

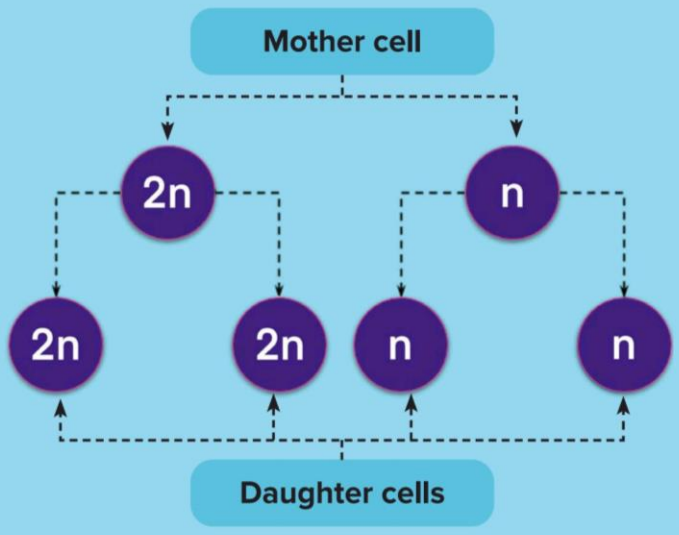
- **G_1 phase**
  - → The cell grows in size.
  - → Proteins and nutrients for the S phase are produced.
- **S phase**
  - → DNA replication takes place.
  - → Centrioles in the centrosome undergo duplication.
- **G_2 phase**
  - → It is the phase after DNA replication.
  - → Overall cell growth occurs and proteins required for M phase are produced.

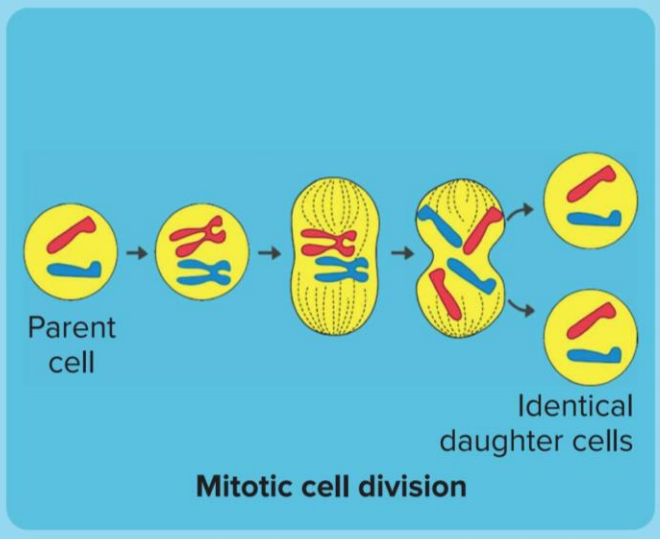


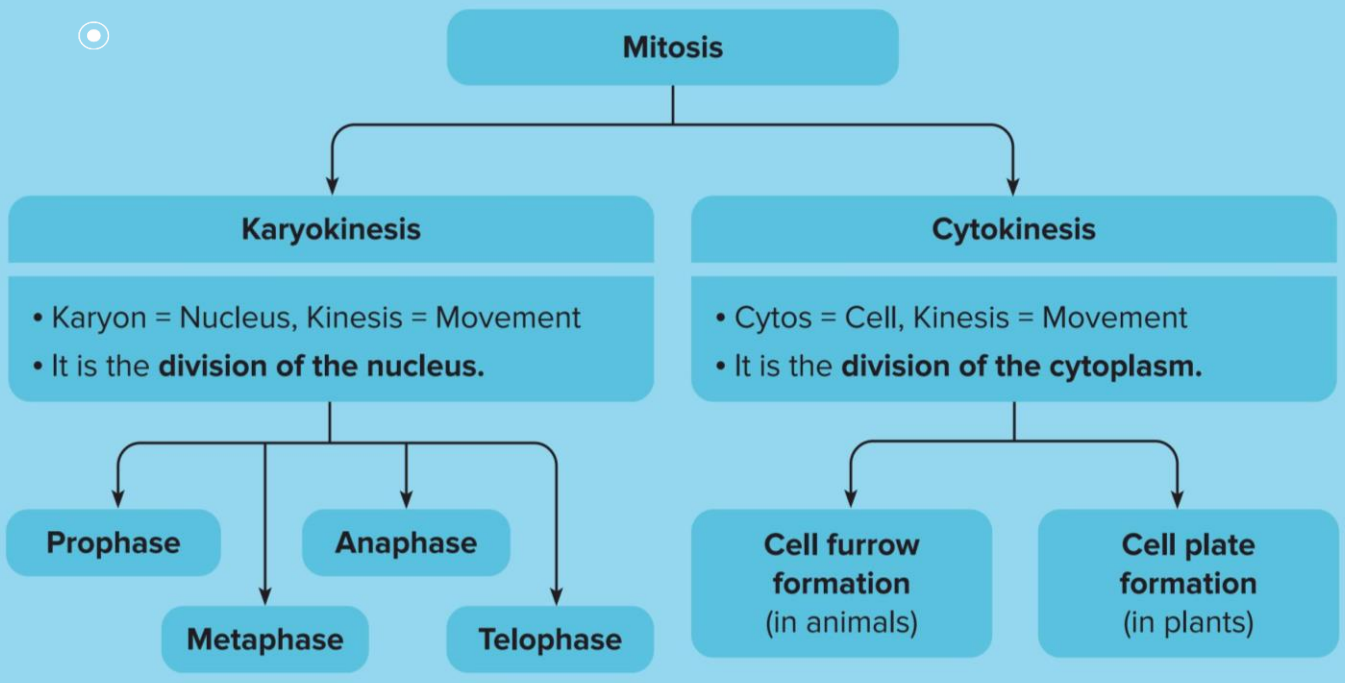
Cell cycle and its phases

Mitosis

- It is a type of **cell division** that produces two **similar daughter cells.**
  - ➜ The daughter cells have the **same number of chromosomes** as the parent cell.
  - ➜ The chromosome number remains **unaltered**, and it is **conserved** in parents and progeny.





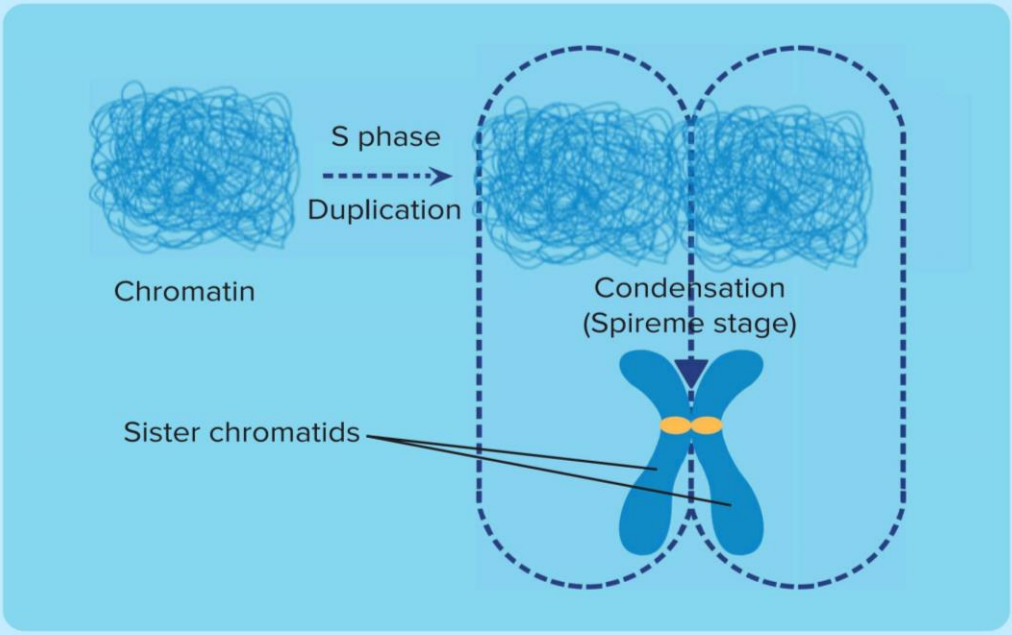


- Karyokinesis involves **four specific** and highly **coordinated** stages that occur **progressively**.
- **PMAT (Pass Me Another Tray)** is a mnemonic for stages of mitosis - Prophase, Metaphase, Anaphase, and Telophase.

Karyokinesis

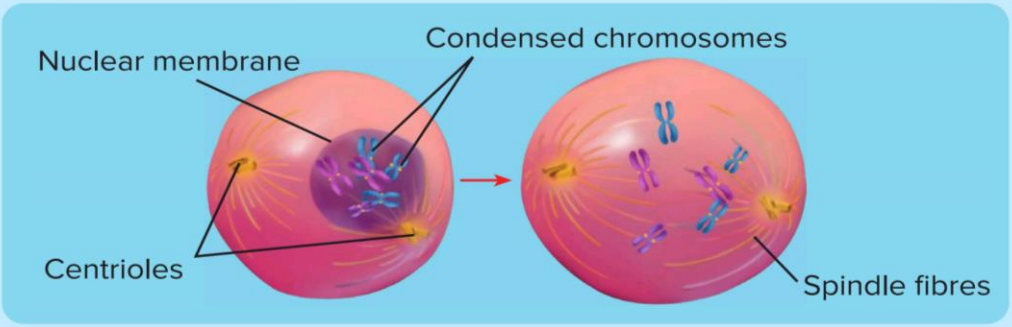
Prophase

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



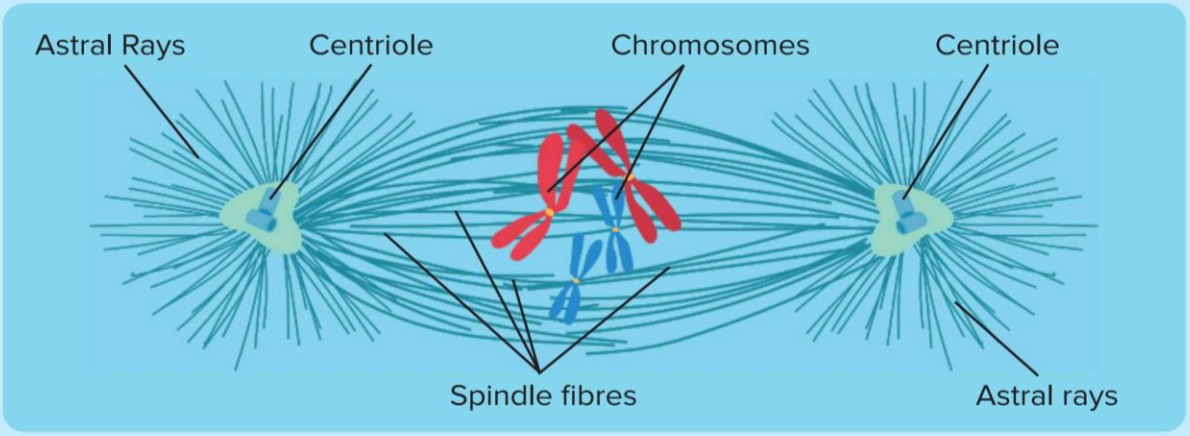
Chromatin fibres condense to form chromosomes

- Prophase also includes **nuclear membrane degeneration** and **disappearance of the nucleolus.**
- **Disintegration of endoplasmic reticulum** and **Golgi apparatus** 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.
- The centrioles form **spindle fibres**.



Centrioles on opposite sides and the disappearing nuclear membrane

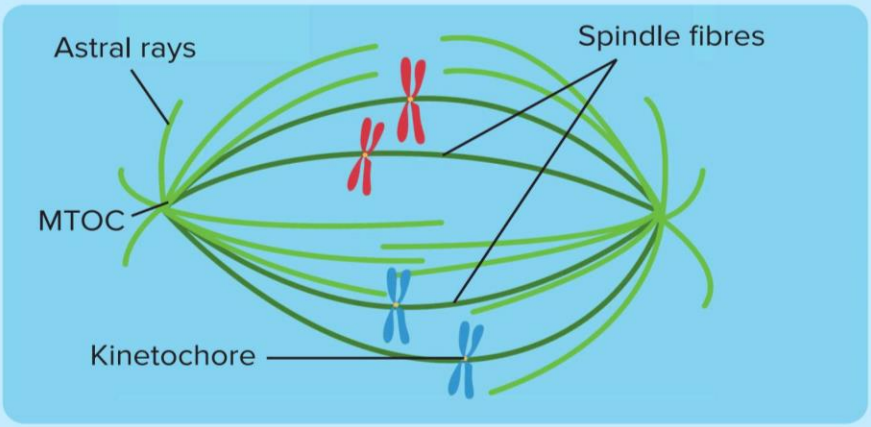
Aster rays	Spindle fibres
• The aster rays are made of microtubules and **radiate out in all directions** in a star-like fashion from the centrioles. • They are generally shorter when compared to spindle fibres. • They do not join with the chromosome.	• The spindle fibres are made of microtubules and **radiate from the centrioles towards the chromosomes.** • These fibres assume a spindle-shaped circular body with tapering ends. • They join with the kinetochores of the chromosomes.



Astral rays and spindle fibres attaching to centrioles and chromosomes

Microtubule-organising centre (MTOC)

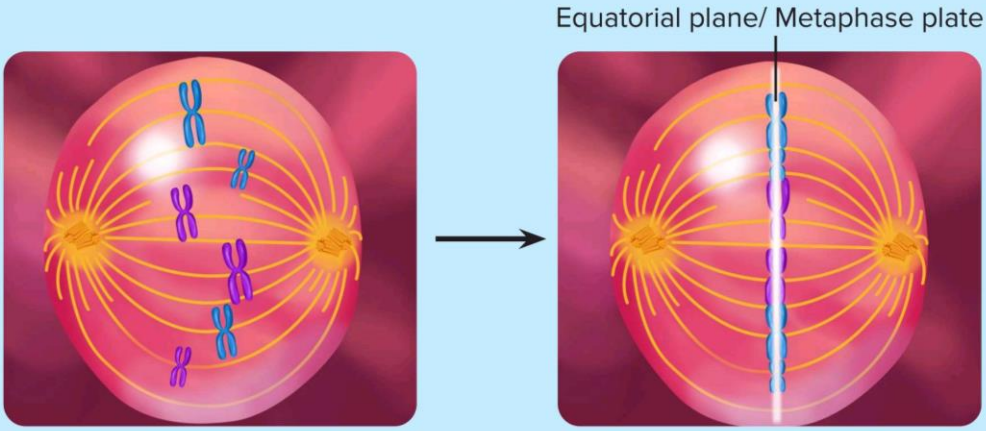
- The plant cells are devoid of centrioles.
- Aster formation is also not seen in plants.
- Plant cells have an area present just near the nuclear membrane is known as a **microtubule-organising centre (MTOC)**. It serves to **organise** and **assemble** the **microtubules** required for spindle fibre formation.
- Microtubules gather at opposite poles and begin to form the **spindle apparatus** at locations also known as **foci**.



MTOC

Metaphase

- The **complete degradation of the nuclear membrane** marks the start of metaphase.
- The chromosomes come to lie in the **equatorial plane** (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 spindle fibres attach to the kinetochore of the chromosomes.



Chromosomes align at the equatorial plane during metaphase

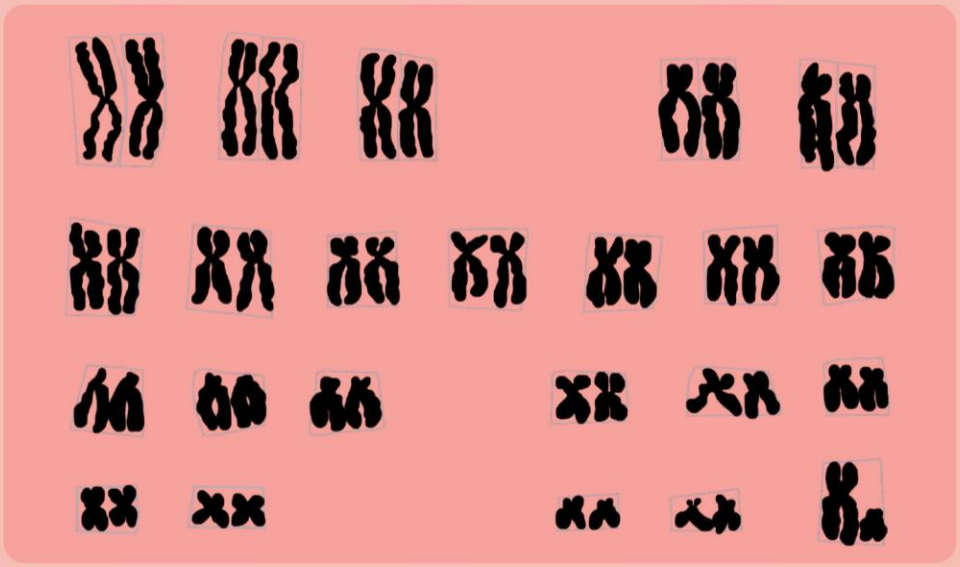
- Chromosomes are observed to be the thickest and the shortest at this stage.
- This is the best time to do the following:
  - ➔ Study the morphology of each chromosome
  - ➔ Count their numbers

Shapes of chromosomes

Metacentric	Submetacentric	Acrocentric	Telocentric
V-shaped	J-shaped	L-shaped	I-shaped

Karyogram

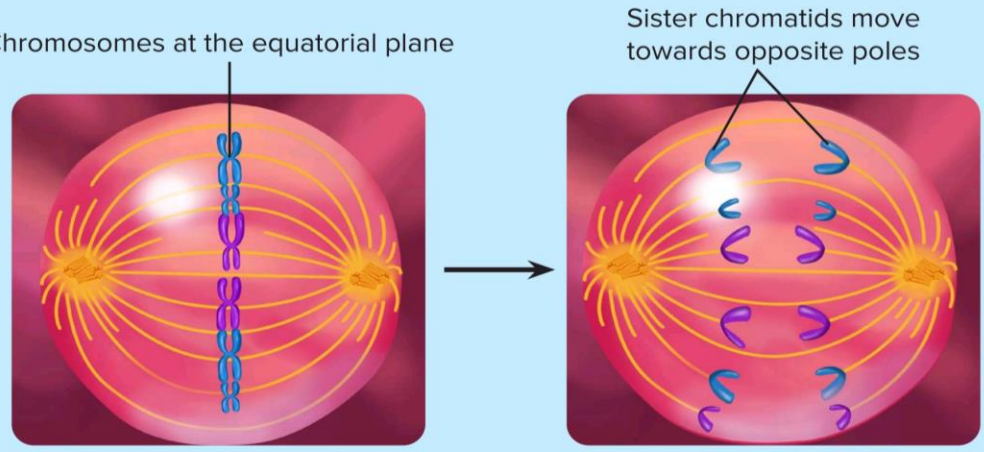
- It is the **arrangement of chromosomes** of an individual, usually in decreasing order of the size.
- The image of the chromosomes for karyogram are generally taken at the metaphase stage.



The image shows the karyogram of human male (23rd pair is XY). Characteristics such as arms (either long, short, or equi-length), centromere (its location, either the centre, the tip, or slightly above the centre), and structure of the chromosomes can be clearly seen here. This study also helps in detecting any abnormalities in the chromosomes such as duplication or deletion of the whole or a part of the chromosomes.

Anaphase

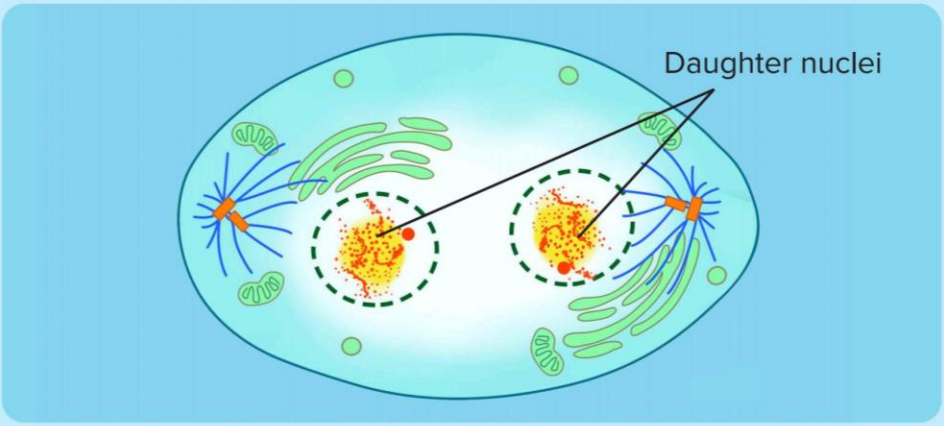
- The **centromere splits**.
- The **sister chromatids separate** into two identical and independent chromosomes.
- Each chromatid now has its **own centromere**.
- The spindle fibres pull the chromatids along with the centromere towards their respective poles.
- The **chromatids** move to **opposite 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.



Chromatids moving to opposite poles

Telophase

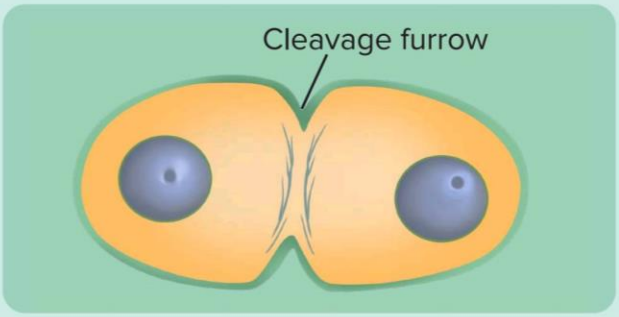
- **Chromosomes cluster** at opposite poles.
- They start **decondensing into chromatin fibres** and their individuality is lost as discrete elements.
- The nucleolus, ER, and Golgi apparatus reappear.
- The **nuclear envelope develops** around the chromatin at each pole, forming two daughter nuclei.



Formation of two daughter nuclei during telophase

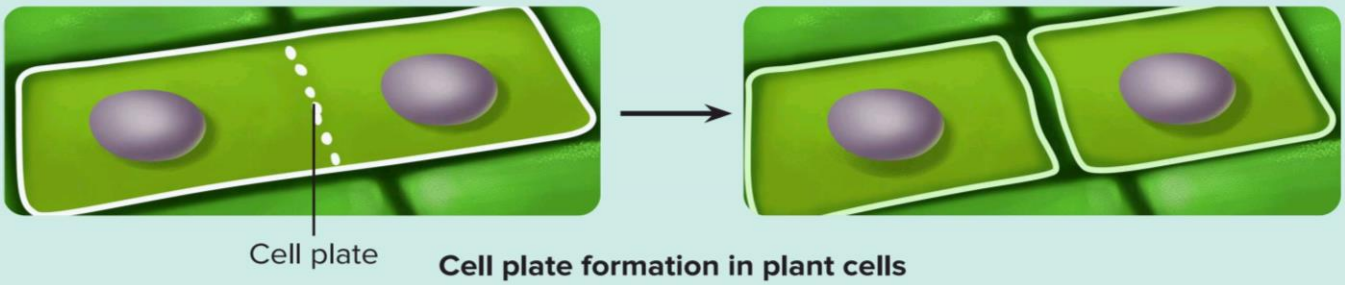
Cytokinesis

- **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**.



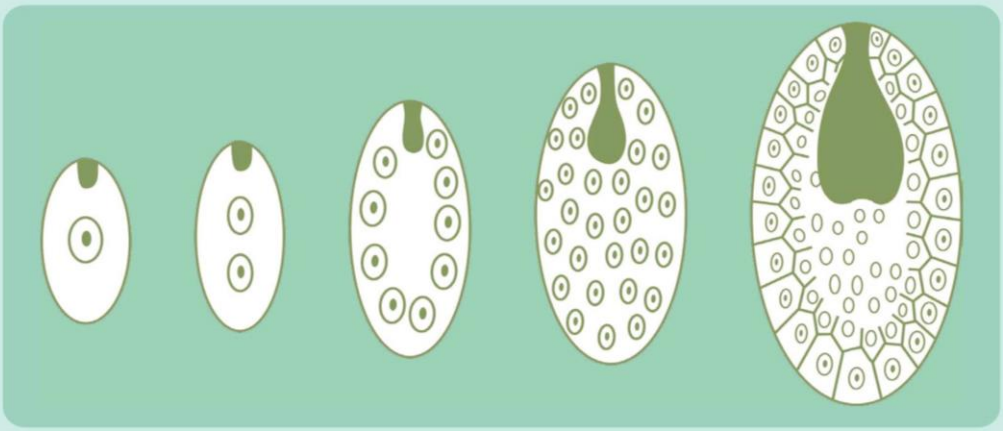
Cleavage furrow formation

- **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, 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.



Cell plate formation in plant cells

- **Syncytium:** It refers to a **multinucleate condition** resulting from **the absence of cytokinesis** after karyokinesis.
  - The **coconut water** that we drink is an example of syncytium.
  - It is the **liquid endosperm** that was formed due to free nuclear divisions without cell divisions.



Syncytium of coconut

Significance of Mitosis

(a) **Growth**: Mitosis causes growth and development in multicellular organisms.
- Plants can grow from a tiny zygote to huge lengths due to mitosis.

Growth of a plant from a zygote to a big tree

(b) **Surface area to volume ratio**: Maintenance of proper surface area to volume ratio of a cell.

(c) **Repair**: The old and worn-out cells are replaced by new cells.

(d) **Reproduction**: Unicellular organisms reproduce (multiply) through mitosis.
- In unicellular organisms, reproduction is synonymous with growth.

(e) **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.

Cell Cycle Checkpoints

- The process of cell division needs **unmatched accuracy.**
- This is achieved by **periodic checks** before proceeding to next phase.
- The decision of a cell to divide occurs in the G_1 phase.
- If a cell does not want to divide, then it will enter into the quiescent phase or G_0 phase.
- The cell checks for the conditions in each phase.
- The regulation of the cell cycle takes place by certain protein molecules known as **cyclins** and **kinases**.

Metaphase checkpoint

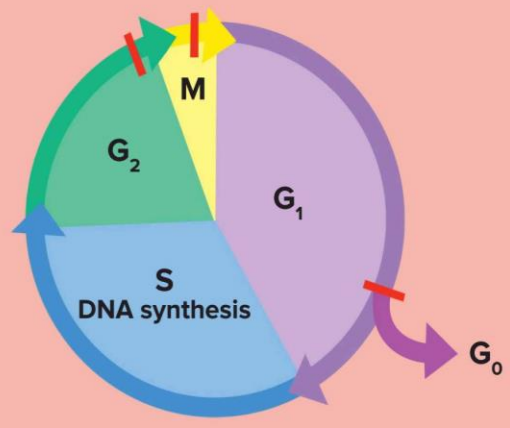
Check for
- Chromosome spindle attachment

G_1 checkpoint

Check for
- Nutrients
- Growth factors
- DNA damage

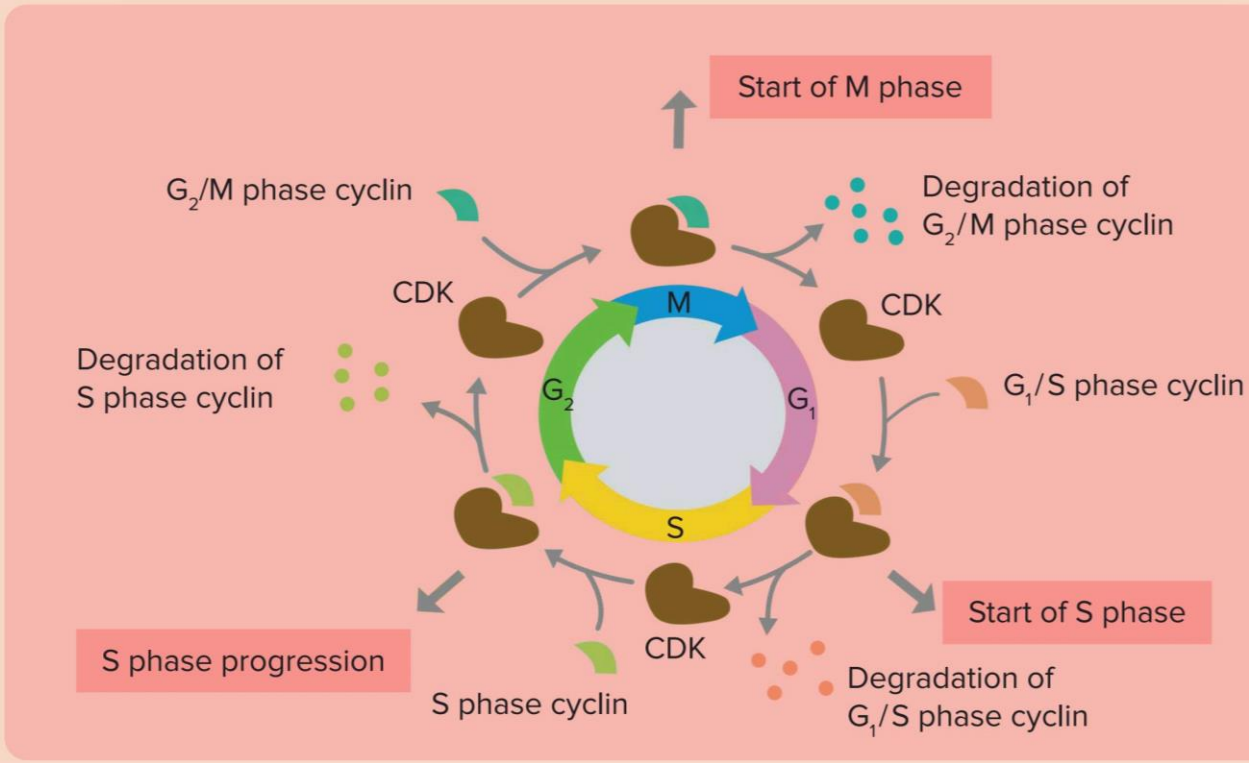
G_2 checkpoint

Check for
- Cell size
- DNA replication



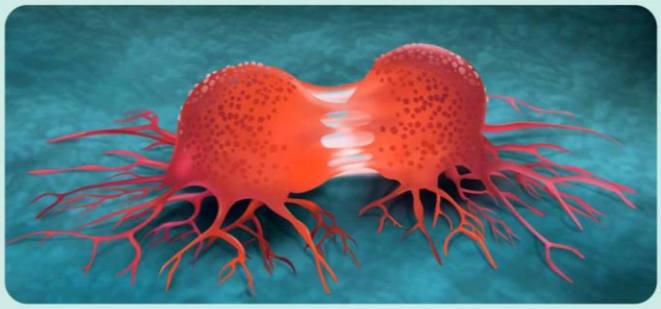
Cyclins and CDK

- **Cyclins** are proteins that bind to and activate the **cyclin-dependent kinases (CDKs).**
- **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.

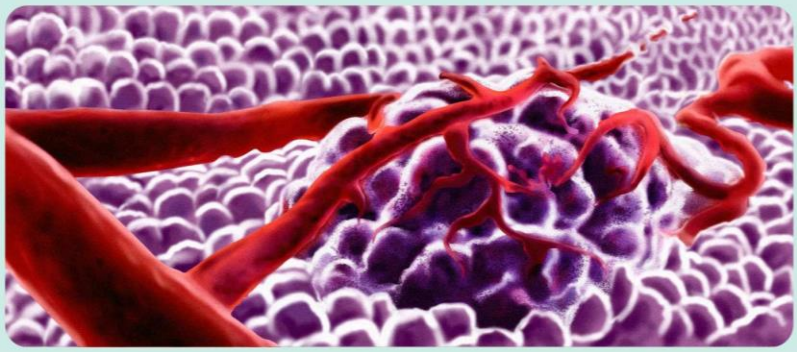


Cancer

- The **abnormal** and **uncontrolled division** of cells is known as **cancer**.
- The uncontrolled division gives rise to a mass of cells known as **tumors**.
- As the tumor grows, new blood vessels are formed around it to supply blood. This process is known as **angiogenesis**.
- Cancer cells compete with normal cells for food, oxygen, and space.
- They may replace cells of a vital organ and evade immune cells, produce chemicals that can kill normal cells, etc.

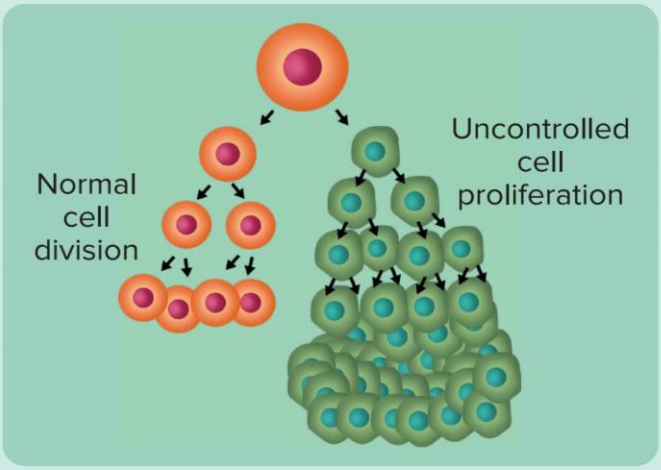


Division of cancer cells

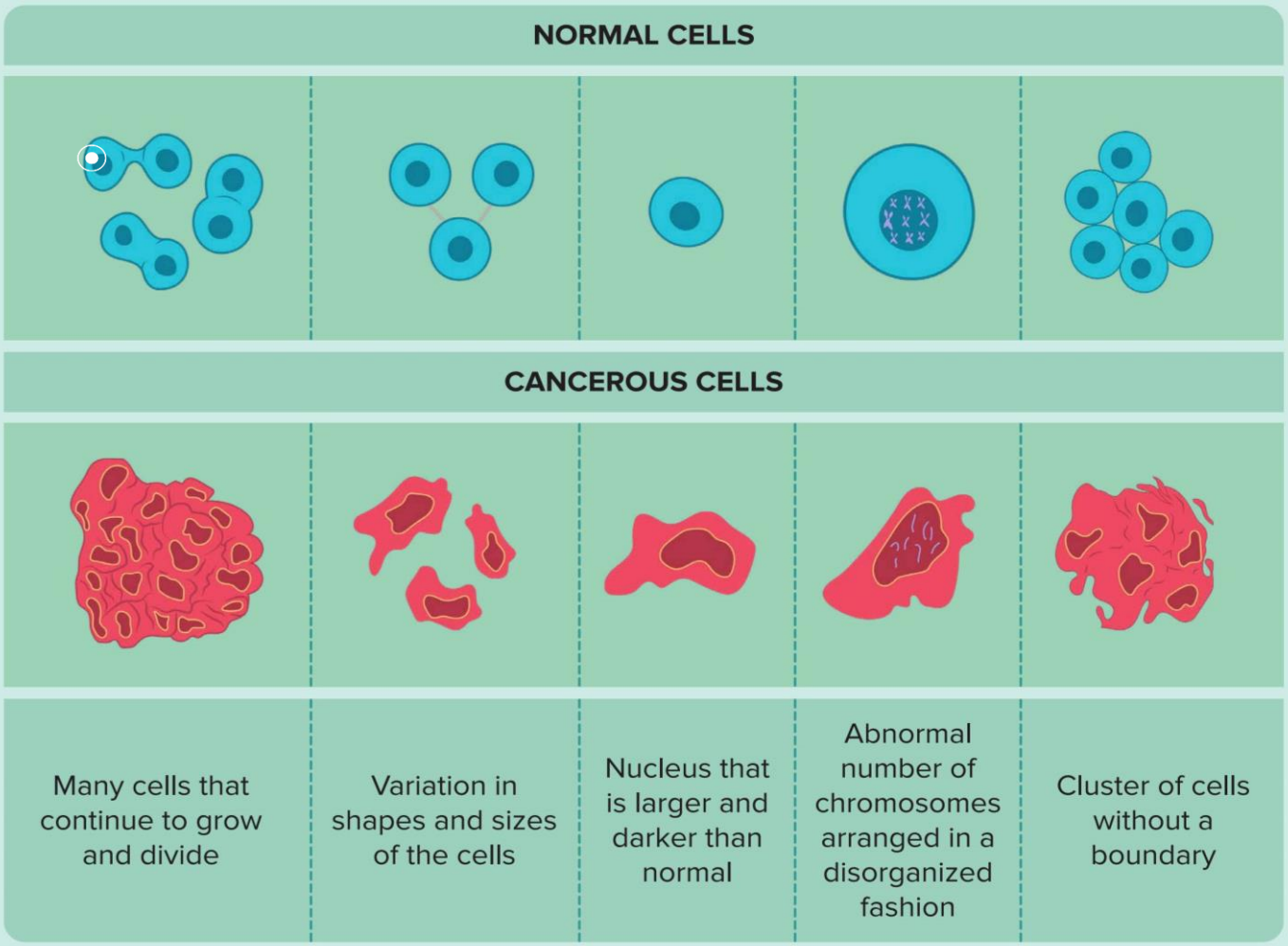


Angiogenesis

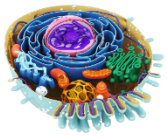
- **Genetic mutations** that may occur during the replication of DNA can cause cancer.
- These mutations cause **irreversible changes** in the sequence of nucleotides in DNA.
- These mutations can cause **malfunctioning of the regulatory processes** or **check points** resulting in the following:
  - ➜ 'Molecular switch' for mitosis being turned permanently on
  - ➜ Permitting uncontrolled multiplication of the cell
  - ➜ Leads to carcinogenesis or tumor development.



- Chemical, physical, and biological agents that cause cancer are known as **carcinogens**.
  - ➜ Examples: Radiation (ultraviolet), smoking, pesticides, viruses (for example, human papilloma virus), alcohol, and other chemicals such as soot, cadmium oxide, vinyl chloride, etc.
- Some cancer drugs control cell division by **inhibiting the spindle fibre formation.**



Normal cells vs cancerous cells



Summary Sheet

Metaphase checkpoint
G_1 checkpoint
G_2 checkpoint

Checkpoint

Cancer
- Uncontrolled cell division
- Chemical and physical agents known as carcinogens and mutations are for cancer

Significance
- Growth
- Maintenance of surface area to volume ratio
- Repair
- Reproduction
- Regeneration

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

BIOLOGY

CELL: THE UNIT OF LIFE

CELL CYCLE AND CELL DIVISION

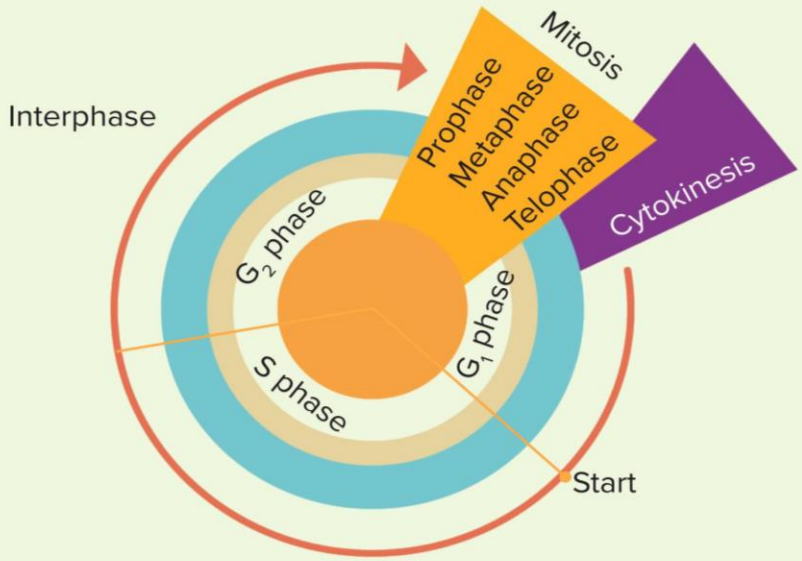
MEIOSIS

Key Takeaways

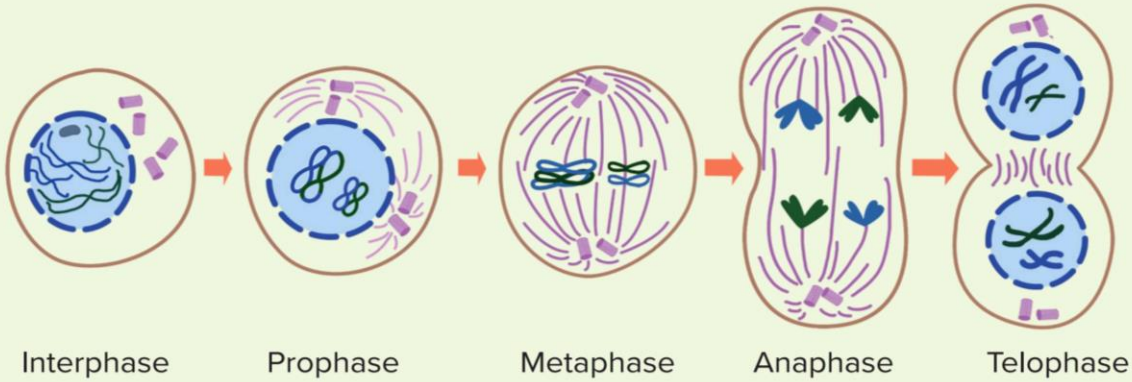
- Meiosis
  - → Meiosis I
  - → Meiosis II
  - → Significance of meiosis

Prerequisites

- Cell cycle

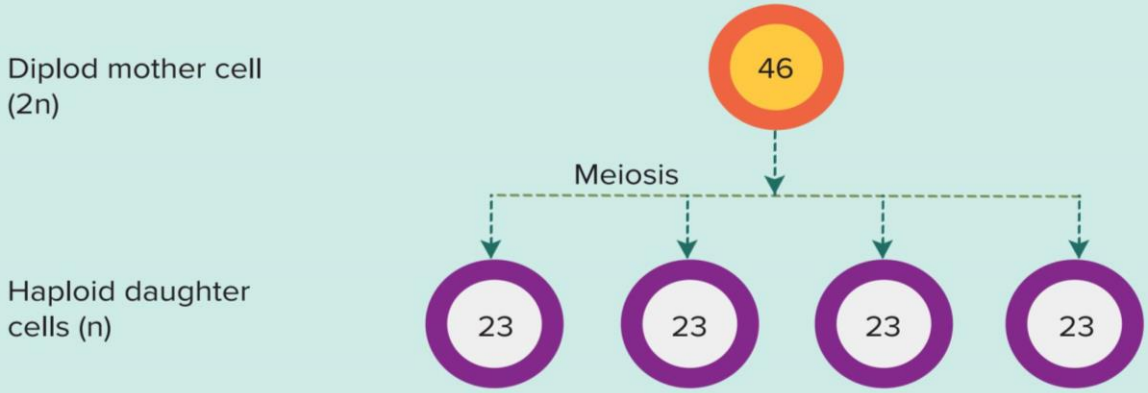


- Mitosis



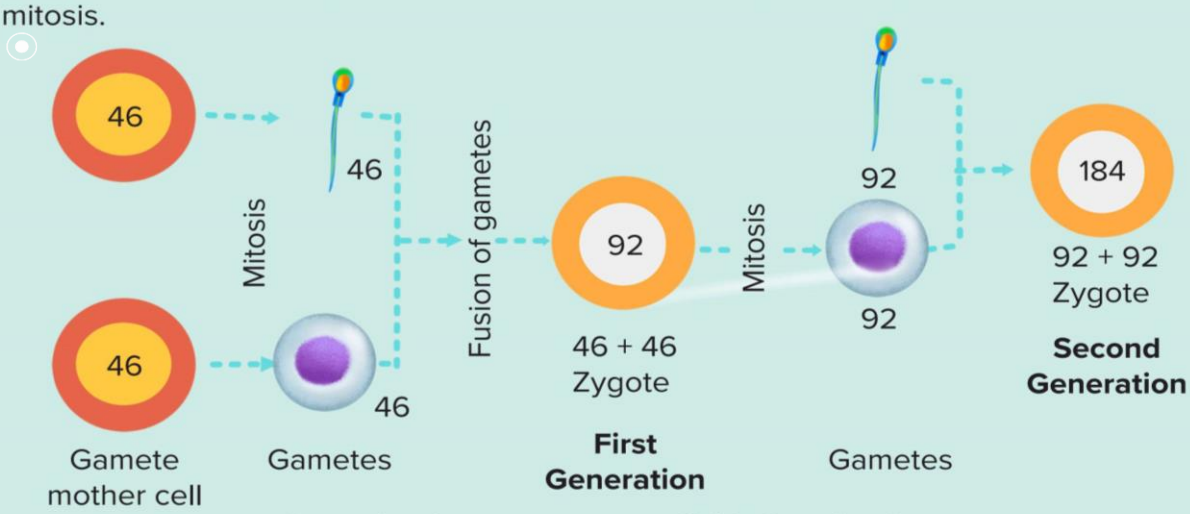
Meiosis

- **Meiosis definition:** It is the kind of cell division where the chromosome number is reduced to half in the daughter cells.
  - ➝ It is a **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.
  - ➝ Germ cells undergo meiosis to give rise to haploid gametes.
  - ➝ Male and female haploid gametes fuse to form a diploid zygote.



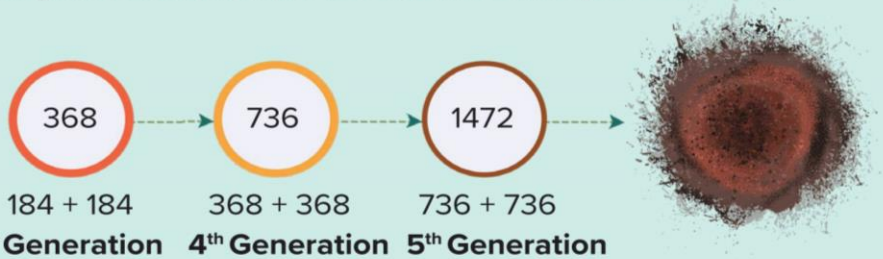
Why not mitosis for gamete formation?

- **Gametes** are formed from gamete mother cells. Assuming that the gamete mother cell divides by mitosis.

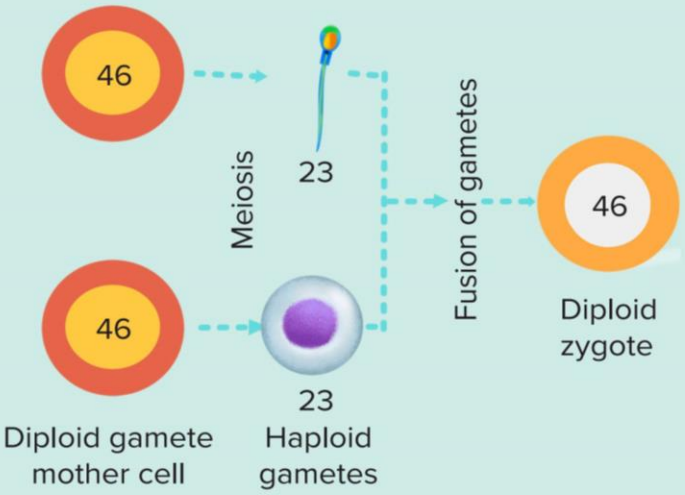


Assuming human gametes divide by mitosis

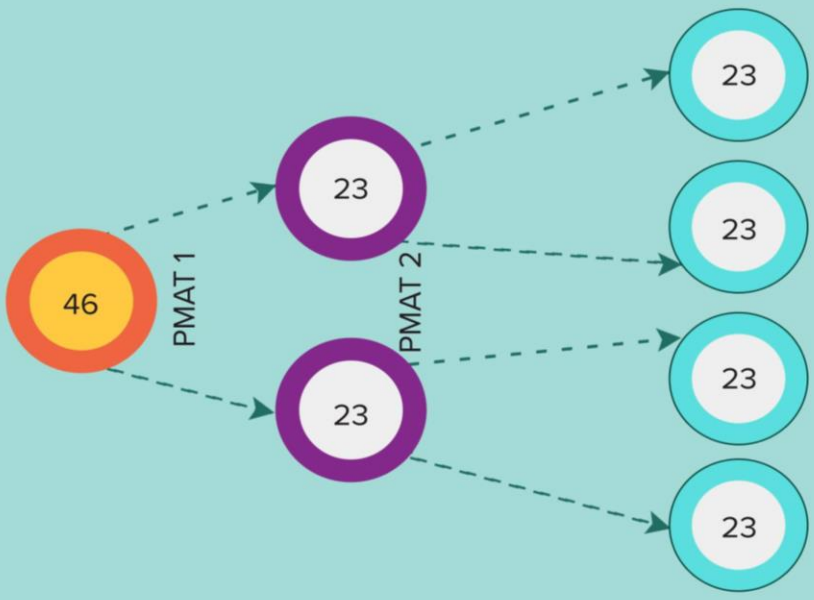
- The human gametes formed will also have 46 chromosomes.
- The gametes fuse and the formed zygote will have 92 chromosomes (46 + 46 = 92).
- Similarly, the next generation will have 184 chromosomes (92 + 92 = 184).



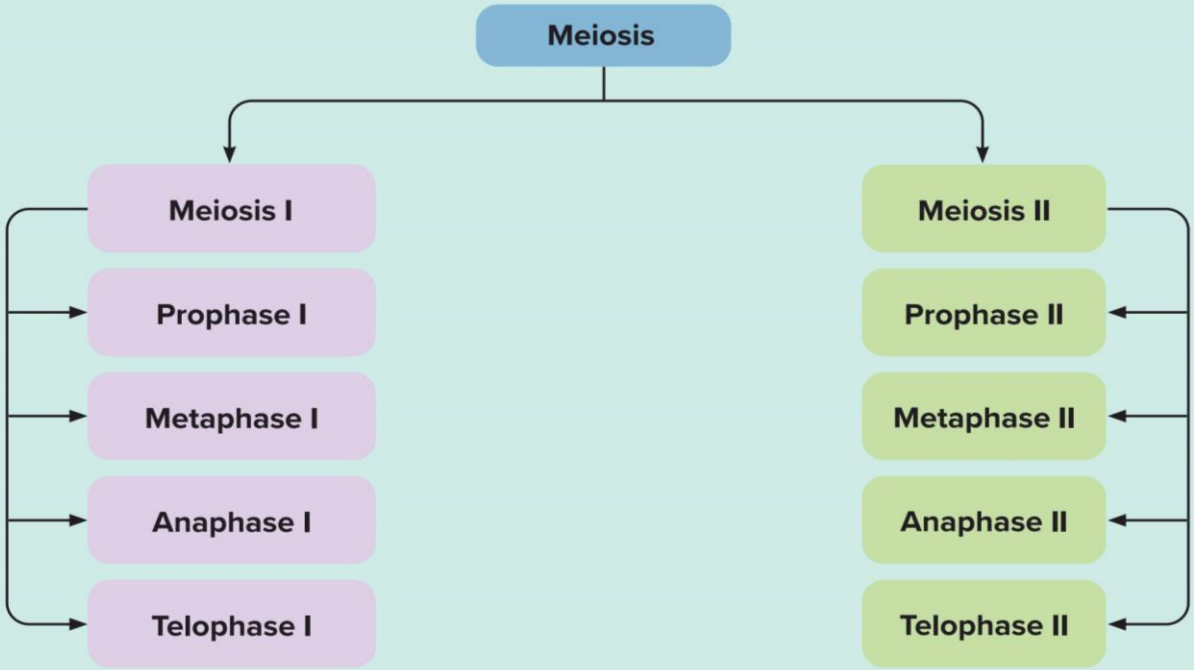
- If this process continues, the cell will burst eventually and will end up having huge amounts of chromosomes.
- **Hence, mitosis is not a good option for gamete formation.**
- Gamete formation **happens by meiosis instead of mitosis**.
- It ensures that gametes are haploid.
  - ➔ Mother cells in humans 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.



- Mitosis = PMAT
- **Meiosis** = **2 x PMAT** (**P**rophase, **M**etaphase, **A**naphase, and **T**elophase)

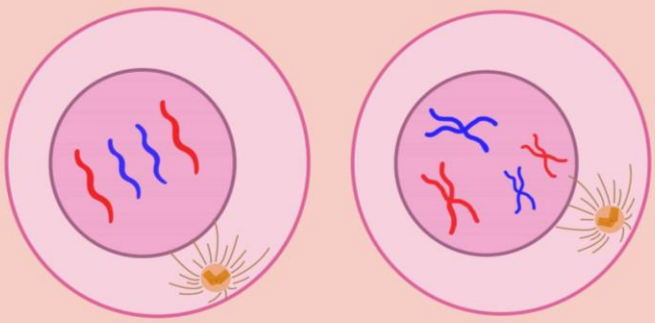


- Meiosis occurs in the following two steps:
  - → **Meiosis I**
  - → **Meiosis II**



Interphase

- A very short phase
- Also known as **synthesis phase** or **S phase**
- Here, the **DNA content gets doubled but chromosome number remains the same**, as the two copies of the DNA strands are still attached to each other.



Early interphase

Before S phase (G_1 phase)

Late interphase

After S phase

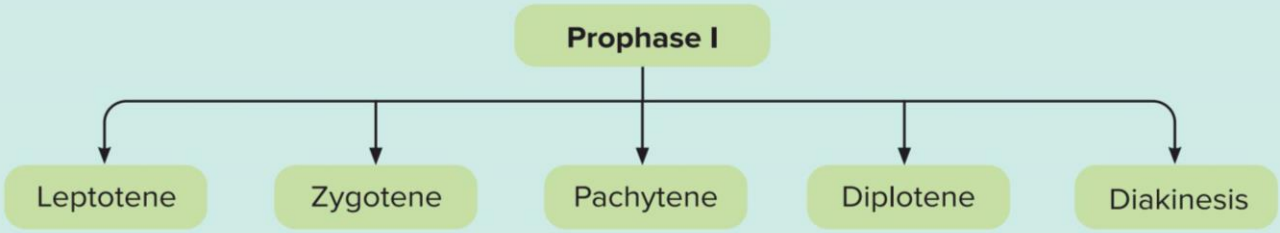
(c) ← DNA content → 2(c)

2n ← Chromosome number → 2n

Meiosis I

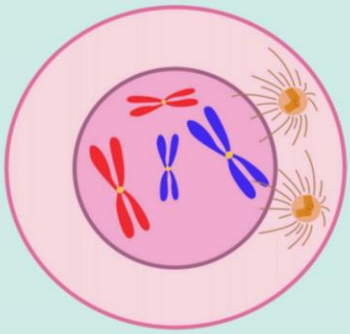
Prophase I

- This phase 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.



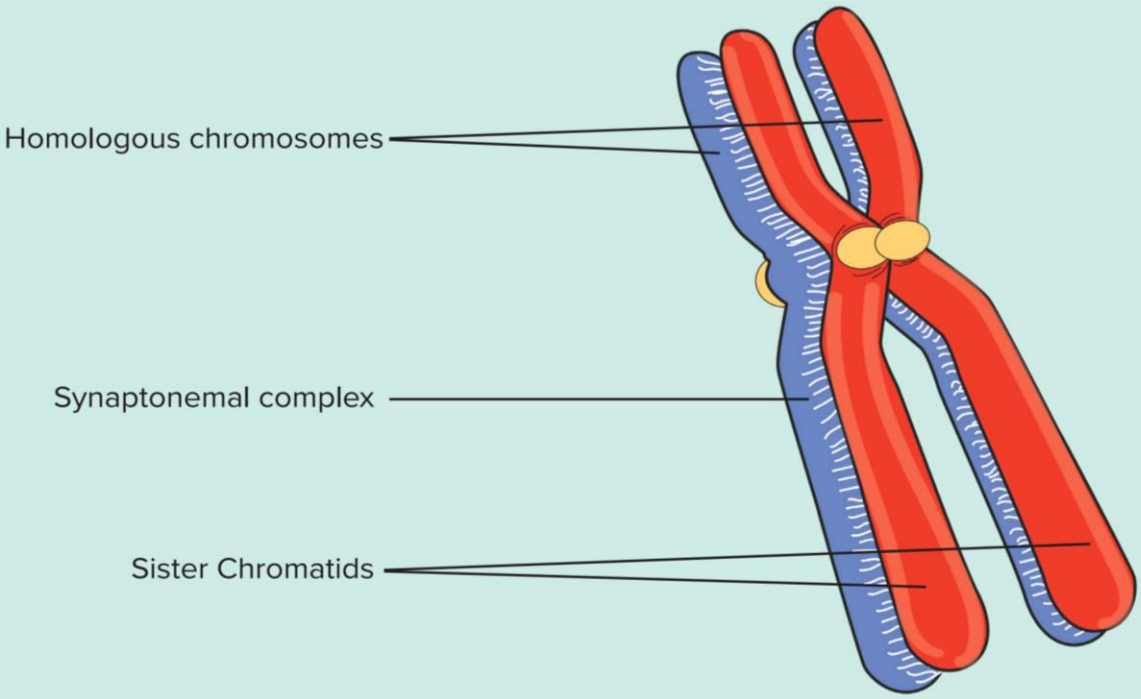
Leptotene

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



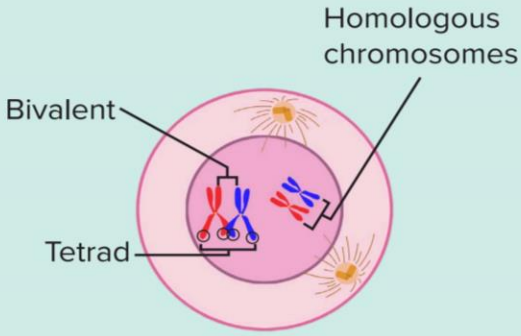
Zygotene

- Zygotene is the paired thread stage.
- Homologous pairs come together to form a **synaptonemal complex**.



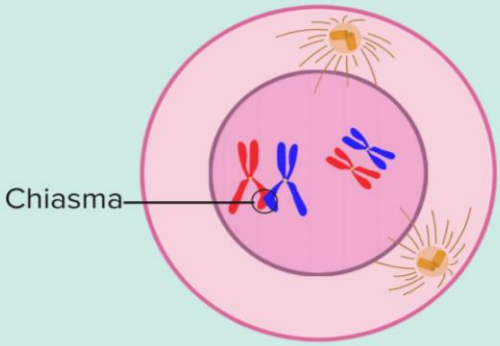
Synaptonemal complex

- **Synapsis** - Pairing together of homologous chromosomes
- The pair of synapsed chromosomes is known as the **bivalent or tetrad**.
- This stage lasts for a short time.

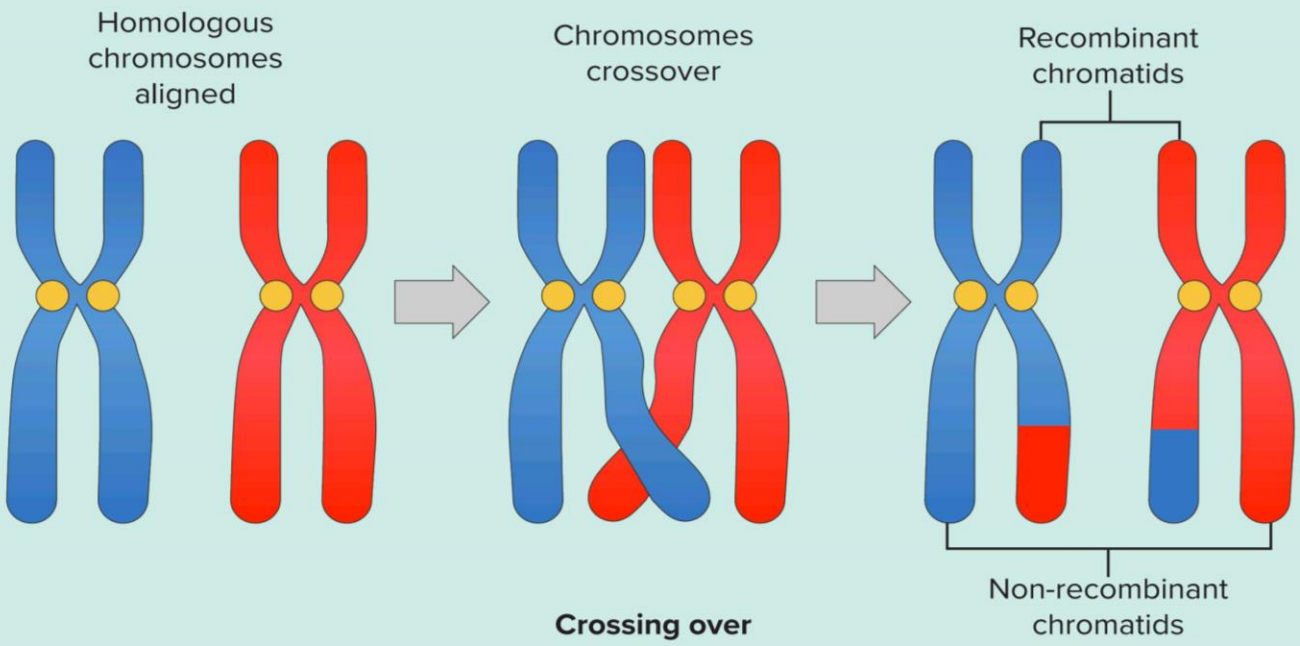


Pachytene

- Pachytene is the '**thick thread**' stage, as the synapse chromosomes appear thick.
- Bivalent chromosomes are clearly visible. They appear as tetrads.

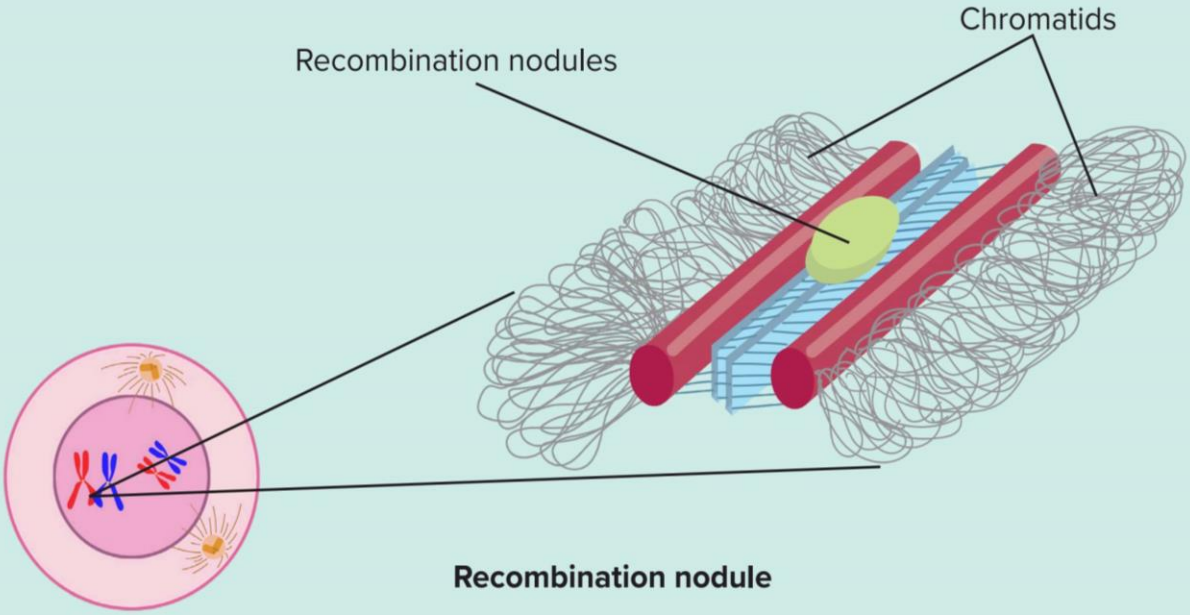


- It is the longest stage.
- **Chiasma** is the point where the chromosomes come together.



Crossing over

- **Recombination nodules** appear on the non-sister chromatids of homologous chromosomes.

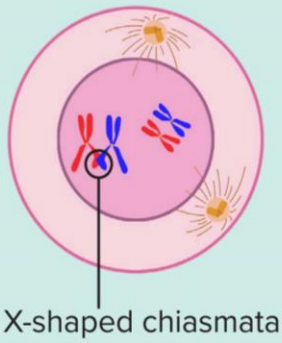


Recombination nodule

- 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**.

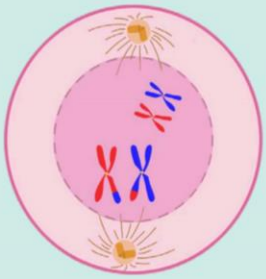
Diplotene

- Diplotene is the 'twin thread' stage.
- In this stage, **dissolution of the synaptonemal complex** occurs.
- Recombined homologous chromosomes separate from each other at all sites except at the site of crossover, as the synaptonemal complex dissolves.
- X-shaped chiasmata is observed.



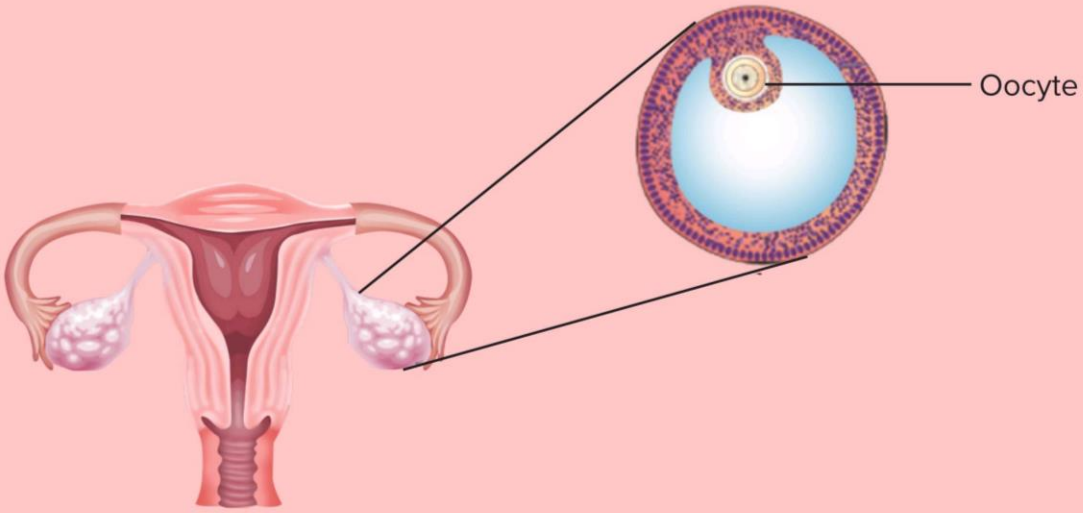
Diakinesis

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



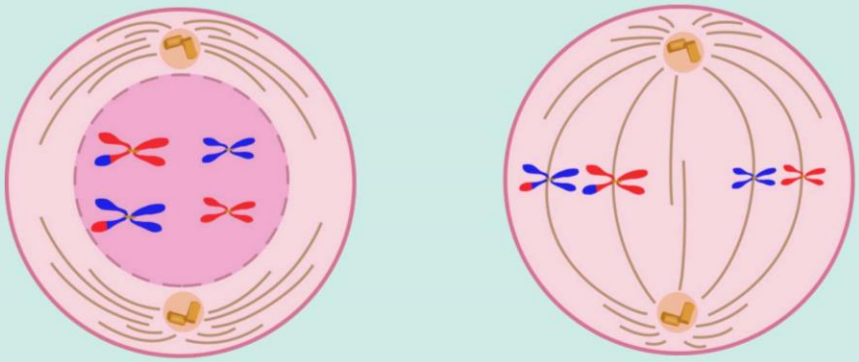
Did you know?

- After the baby is born, the oocyte or the gamete mother cell progresses with meiosis (prophase I).
- The oocytes of vertebrates remain **frozen** in the **diplotene stage before birth**.
- For years, it is frozen until the female reaches puberty.



Metaphase I

- In this phase, the recombined chromosomes, i.e., bivalents, **align on the equatorial plate**.

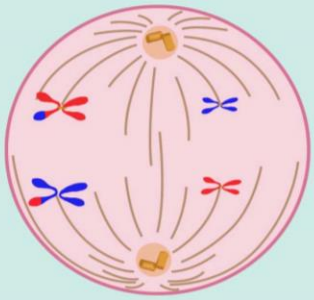


Early metaphase I **Late metaphase I**

- As the early metaphase I starts, the **microtubules arise** from the opposite **spindle poles** of the spindle apparatus.
- Microtubules from opposite poles attach to the homologous chromosomes.
- These microtubules attach to the **kinetochores** of the pair of homologous chromosomes.

Anaphase I

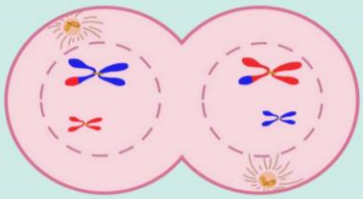
- In this phase, the **homologous chromosomes are separated**.
- The spindle microtubules pull the homologous chromosomes towards the opposite poles, respectively.
- The sister chromatids of the homologous chromosomes are associated with each other at the centromere.



Anaphase I

Telophase I

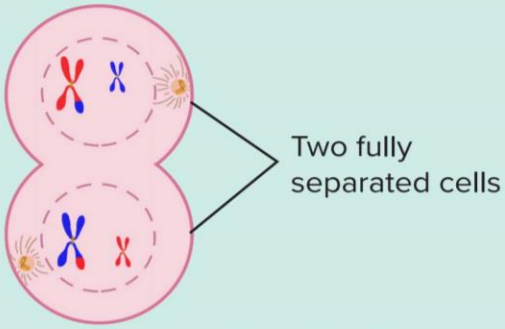
- In this stage, the **nuclear membrane** and the **nucleolus reappear** after the homologous chromosomes have separated and moved to the opposite poles.
- Nuclear membranes develop around each set of the chromosomes at opposite poles.



Telophase I

Cytokinesis

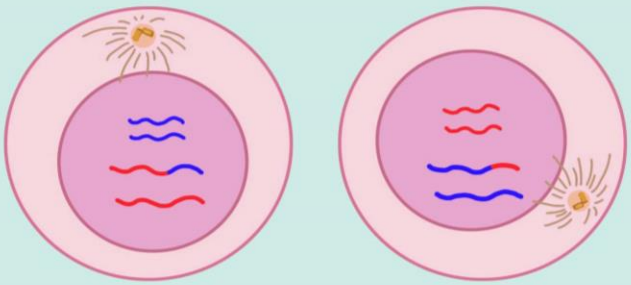
- Telophase I is followed by cytokinesis.
- Cytokinesis is the process where the cytoplasm is divided equally into daughter cells.
- The daughter cells formed at the end of meiosis have bivalent chromosomes, and this chromosome is also known as a **dyad** (one pair of chromosomes from the tetrad).



Cytokinesis

Interkinesis

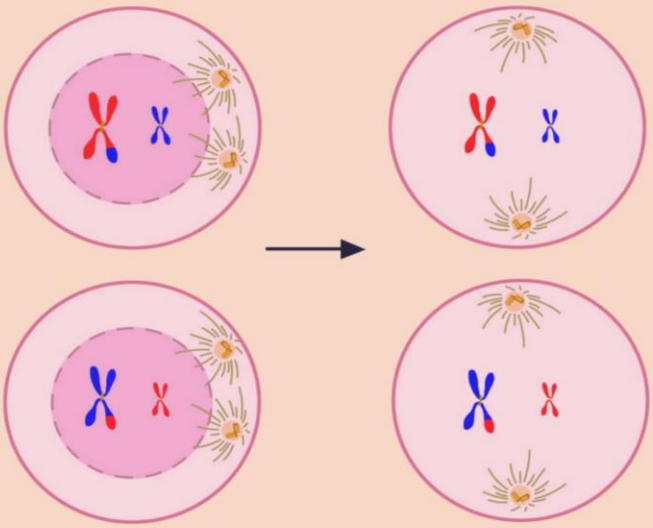
- It is a short-lived stage between meiosis I and meiosis II.
- This stage has no DNA replication.



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 disappear**.
- **Chromatin fibres** begin to **condense** to form chromosomes.



Early prophase II **Late prophase II**

- As the cell enters late prophase II, the nuclear membrane disappears and chromosomes become compact.
- The **centrioles** also move towards the **opposite ends**.

Metaphase II

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

Metaphase II

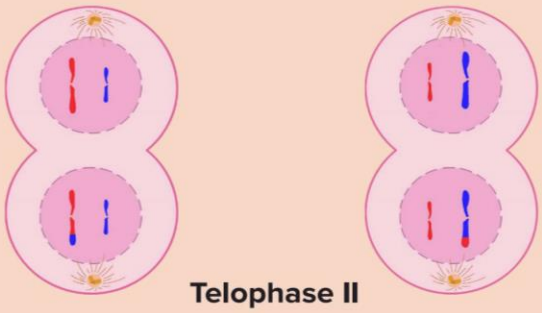
Anaphase II

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

Anaphase II

Telophase II

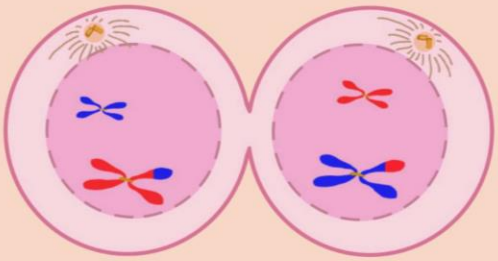
- It marks the end of meiosis II.
- The **nuclear membrane** and the **nucleolus reappear.**
- The **chromosomes decondense** into chromatin.



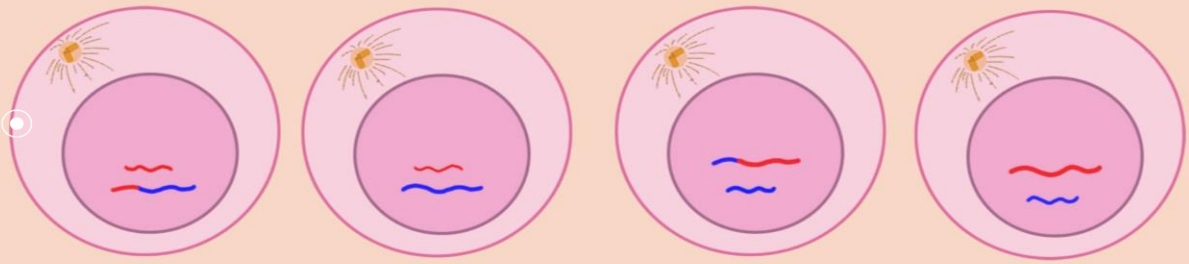
Telophase II

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.



Cytokinesis



Four haploid cells

Significance of Meiosis

- 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**.

Difference between Meiosis I and Meiosis II

Meiosis I	Meiosis II
DNA replication occurs in the interphase	No DNA replication occurs
Centromere is intact	Centromere splits
At the end, a dyad of cells is formed	At the end, a tetrad of cells is formed

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**
  - → In **meiosis II**, each cell has **one set of homologous chromosomes**.
  - → The **daughter cells,** after **mitosis**, are **diploid**, but those of meiosis II are haploid.

Summary Sheet